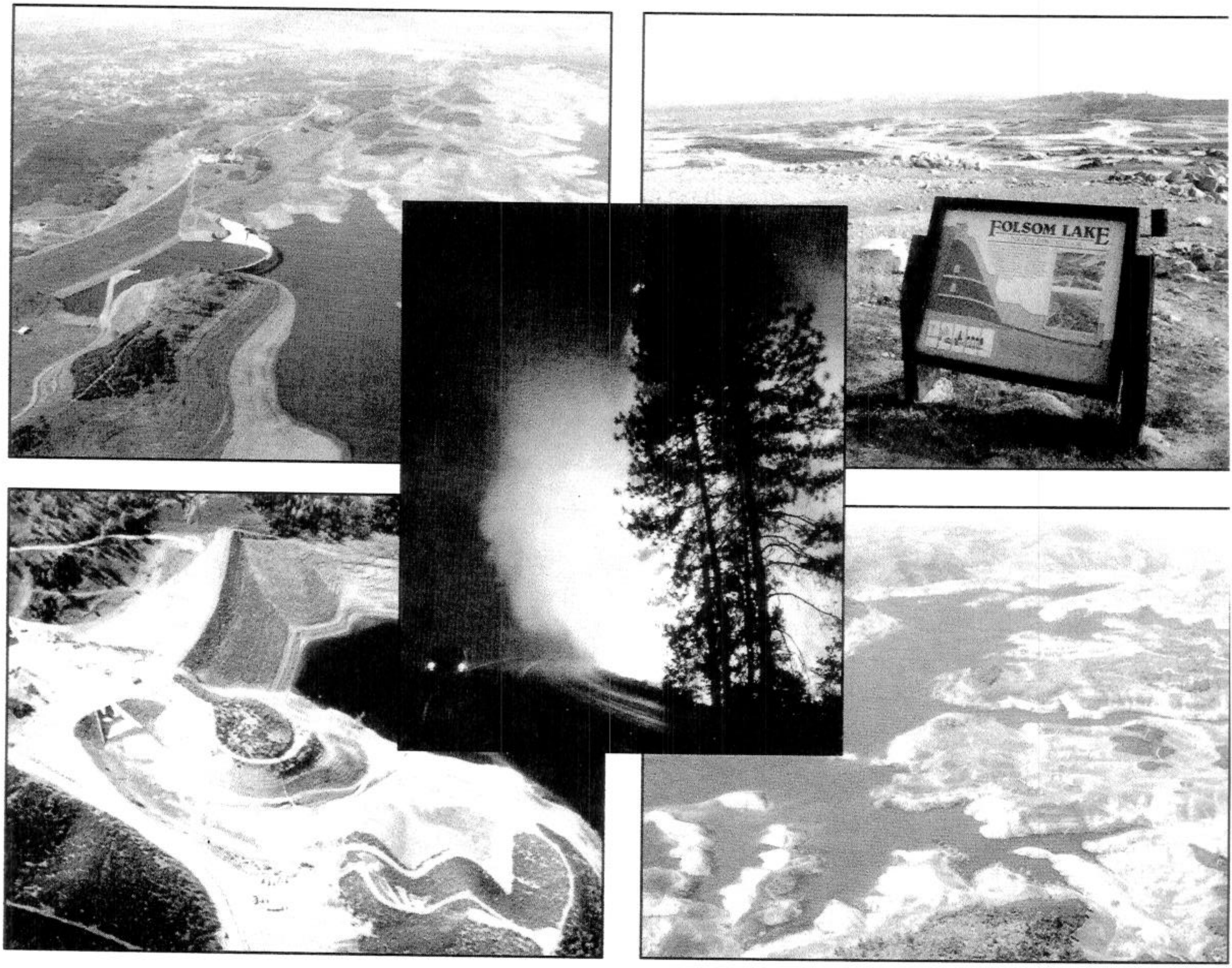
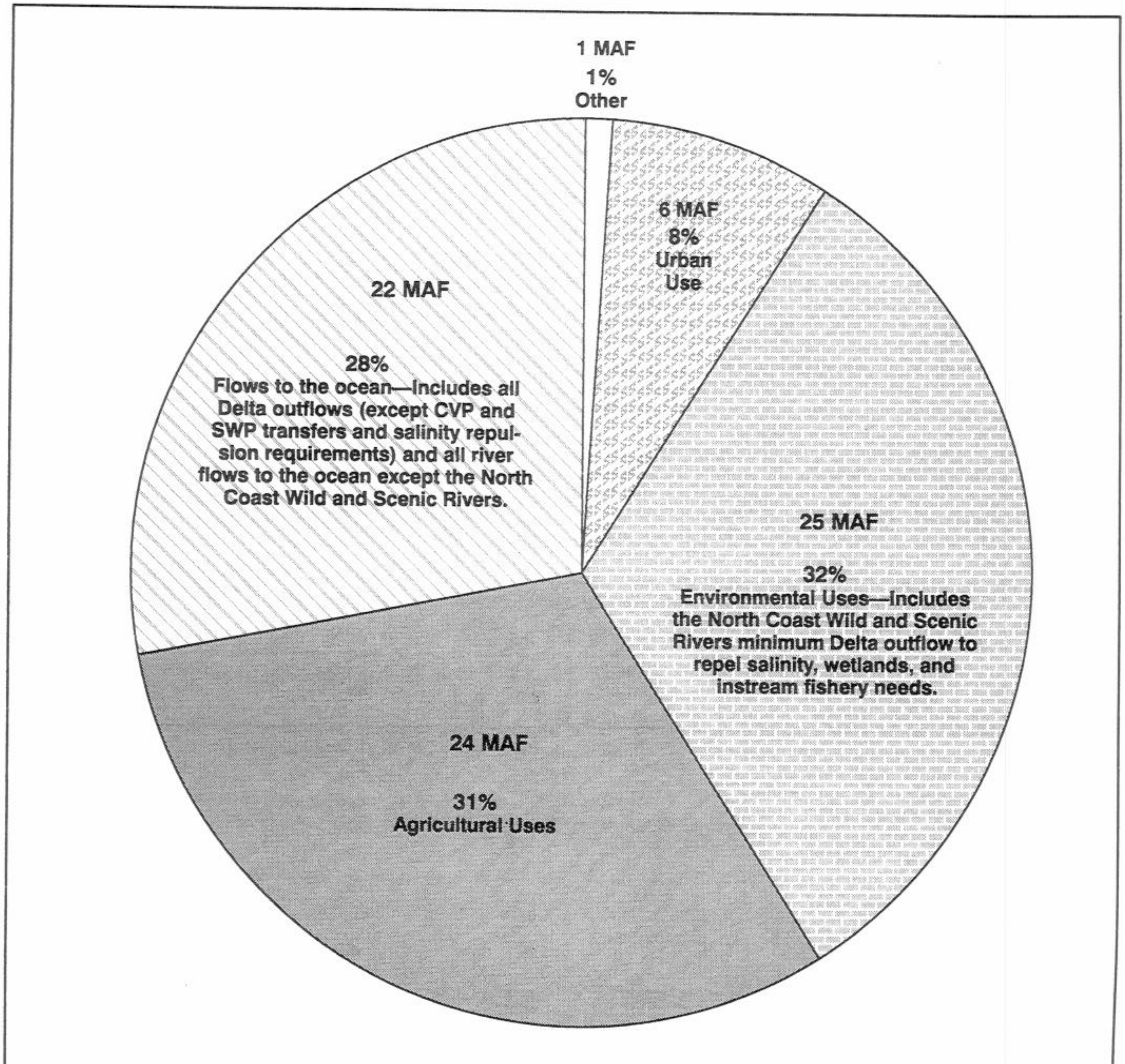


California's 1987–92 Drought

A summary of six years of drought

State of California
Department of Water Resources
July 1993

Disposition of California's Average Annual Surface Water Supply
78 million acre−feet



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Department of Water Resources
P.O. Box 942836
Sacramento, CA 94236−0001

Front cover: Drought intensified the Old Gulch forest fire (center) in 1992 and severely depleted water storage throughout the State. From upper left clockwise: New Hogan, with old reservoir exposed (February 1991), Folsom Lake (February 1991), Indian Valley Reservoir (February 1991), and New Melones Reservoir (April 1991).

California's 1987–92 Drought

A summary of six years of drought

State of California
Department of Water Resources
July 1993

Governor's Drought Action Team[1]

Appointed Members

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Director
Department of Water Resources

Douglas P. Wheeler
Secretary for Resources
The Resources Agency

Henry J. Voss,
Director
Department of Food and Agriculture

Richard Andrews
Director
Office of Emergency Services

Thomas W. Hayes
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Department of Finance

Boyd H. Gibbons
Director
Department of Fish and Game

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Molly J. Coye, M.D., M.P.H.
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Department of Health Services

Richard Sybert
Director
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Major General Tandy K. Bozeman
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State Water Resources Control Board

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State Conservationist
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Wayne S. White
Field Supervisor
U.S. Fish and Wildlife Service

Gerald R. Zimmerman
Executive Director
Colorado River Board of California

[1] *The Drought Action Team, with invited participating agencies, was established February 1, 1991, by Governor's Executive Order No. W–3–91. The Drought Action Team developed a plan to respond to the drought, and met during the course of the drought to coordinate inter–governmental actions and to advise the Governor.*

FOREWORD

This is a hydrologic summary of California's drought, from its inception in 1987 until Governor Pete Wilson's declaration that the drought was over on February 24, 1993. The report also contains summaries of the 1987–1992 operations of the State Water Project and the federal Central Valley Project, which are but two of the major water systems on which Californians relied for their daily water needs.

Most of California remained firmly in the grip of drought for six consecutive years, until 155 percent of normal precipitation occurred during the first five months of water year 1993, providing sufficient snowpack and reservoir storage to assure adequate water supplies for 1993.

All citizens were impacted to varying degrees by the six consecutive dry years, but the environment and agriculture suffered the most. While drought impacts were quite severe in some areas, they would have been much more severe had it not been for the reserves stored in the State's major water projects on which cities, farms, and to some extent the environment relied. Even as reserves were being depleted, water management tools to limit water use were being developed and implemented. Overall, the State's citizens did an excellent job of conserving water, generally exceeding established goals by significant amounts.

New and innovative urban and agricultural water management practices were developed and implemented, some by means of legislation. The State Emergency Drought Water Bank was established by Governor Wilson in 1991 to buy water from willing sellers to meet critical needs. In two years of operation, the Water Bank purchased and sold about 1 million acre–feet of water.

After enduring one of the longest dry periods in our history, we must again look at the reliability of existing water supplies, formulate plans, and take actions that will allow us to be prepared for the next drought, which will inevitably occur.

David N. Kennedy
Director

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The End Of The Drought

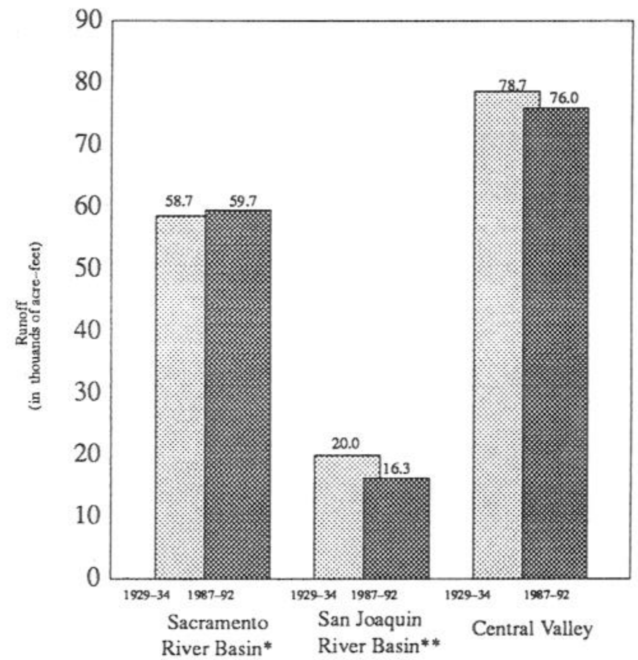
Gray, rainless skies hovered over California during November 1992 and seemed to herald what would be an historically rare seventh year of drought. Then the rains came and the snow. During December 1992 and the first two months of the new year, precipitation in California amounted to almost 200 percent of average. Some areas experienced severe flooding, particularly Southern California. In Northern California, snow depths reached record levels, closing roads and collapsing buildings.

These storms and those that followed brought an end to the most severe six years of drought in California's history, exceeding even the drought severity of 1929–34. On February 24, 1993, Governor Pete Wilson declared the 1987–92 drought officially over. The series of major Pacific storms which moved into California between December 1992 and February 1993 provided sufficient runoff to meet 1993 water demands and refill most reservoirs to near average levels. Even so, the governor urged Californians to continue their water conservation efforts as one way to offset future increases in water demands of an ever–growing population.

Five of the six years were designated critically dry (Table 1), and the severity of the 1987–92 drought set records throughout the State. In Table 1, 1977 information is included for comparison with the driest year of record. In the San Joaquin Valley, these were clearly the driest six years on record and average runoff in the Sacramento River Basin only exceeded the 1929–34 drought by roughly 1 percent (Figure 1).

No part of the State was spared, although drought impacts varied from region to region and year to year. April traditionally marks the beginning of unimpaired runoff measurements and preliminary measurements indicate that the winter storms assured a return to average runoff after six dry years. Drought severity is related to precipitation and runoff levels, shown in Figures 2 and 3.

Figure 1. Runoff Comparison Between 1929–34 and 1987–92 Droughts



*Based on Sacramento River Index
**Based on San Joaquin River Index

On May 1, storage in the State's 155 major reservoirs increased to about 27 million acre–feet from a low of 11.8 MAF at the end of November 1992. On May 1, statewide storage was 96 percent of average, 6.8 MAF above the same date in 1992. (See Table 2.) The water level in Lake Tahoe is a significant indictor of runoff in the high eastern Sierra Nevada. In November 1992, the lake level reached a record low of 2.8 feet below its natural rim. On May 1, 1993, the lake level was still almost 1 foot below the rim. Although most of the State's reservoirs will refill to near–average, some of the larger reservoirs such as New Melones, Clair Engle, and Berryessa were so low they will not refill during the 1993 runoff season.

Table 1. Summary of Statewide Water Year Data as of September 30
(in percent of average)

	1977	1986	1987	1988	1989	1990	1991	1992	*1993 Estimate*
Precipitation	45	128	61	82	86	69	76	72	145
Water year runoff	20	140	48	47	72	45	43	43	125
Reservoir storage	35	119	84	66	74	60	61	56	95
Sacramento River Index*	5.1	25.7	9.2	9.2	14.8	9.2	8.4	8.9	21.9
Snow water content**	22	105	20	20	40	10	65	25	150
Year type	Critical	Wet	Critical	Critical	Dry	Critical	Critical	Critical	Wet

**The Sacramento River Index is the sum of unimpaired water year runoff from the Sacramento River above Bend Bridge near Red Bluff, Feather River inflow to Oroville, Yuba River at Smartville, and American River inflow to Folsom. The 50–year average, 1941–1990, is 18.4 million acre–feet (MAF).*

***April 1 figures (beginning of runoff).*

Table 2. Summary of Storage in 155 Major Reservoirs
(in thousands of acre–feet)

Region	No. of Reser-voirs	Total Capacity	Historical Average	Sep. 30 1977	Sep. 30 1989	Sep. 30 1990	Sep. 30 1991	Sep. 30 1992	May 1 1993
North Coast	7	3,148	2,112	294	1,684	1,479	1,004	1,187	1,906
SF Bay	18	696	397	285	342	310	333	355	624
Central Coast	6	947	551	228	121	94	164	288	683
South Coast	29	1,983	1,117	838	1,141	1,202	1,342	1,322	1,899
Sacramento	43	15,997	10,305	4,219	8,877	6,647	6,664	6,210	13,484
San Joaquin	33	11,358	6,454	1,525	3,895	3,350	3,660	2,798	6,939
Tulare Lake	6	2,045	699	200	243	170	291	198	1,009
North Lahontan	5	1,072	585	36	221	107	98	90	179
South Lahontan	8	402	298	153	200	206	228	224	232
Colorado Desert*									
Total	**155**	**37,648**	**22,518**	**7,778**	**16,724**	**13,565**	**13,784**	**12,672**	**26,955**
% of Average				35	74	60	61	56	96

* No In–State reservoirs in this region.

Note: The 1989 through 1991 storage amounts include New Melones, Spicer Meadows, and Warm Springs reservoirs, which began operation after 1976.

Figure 2. Water Year Runoff in Percent of Average

By Hydrologic Regions

1987–93

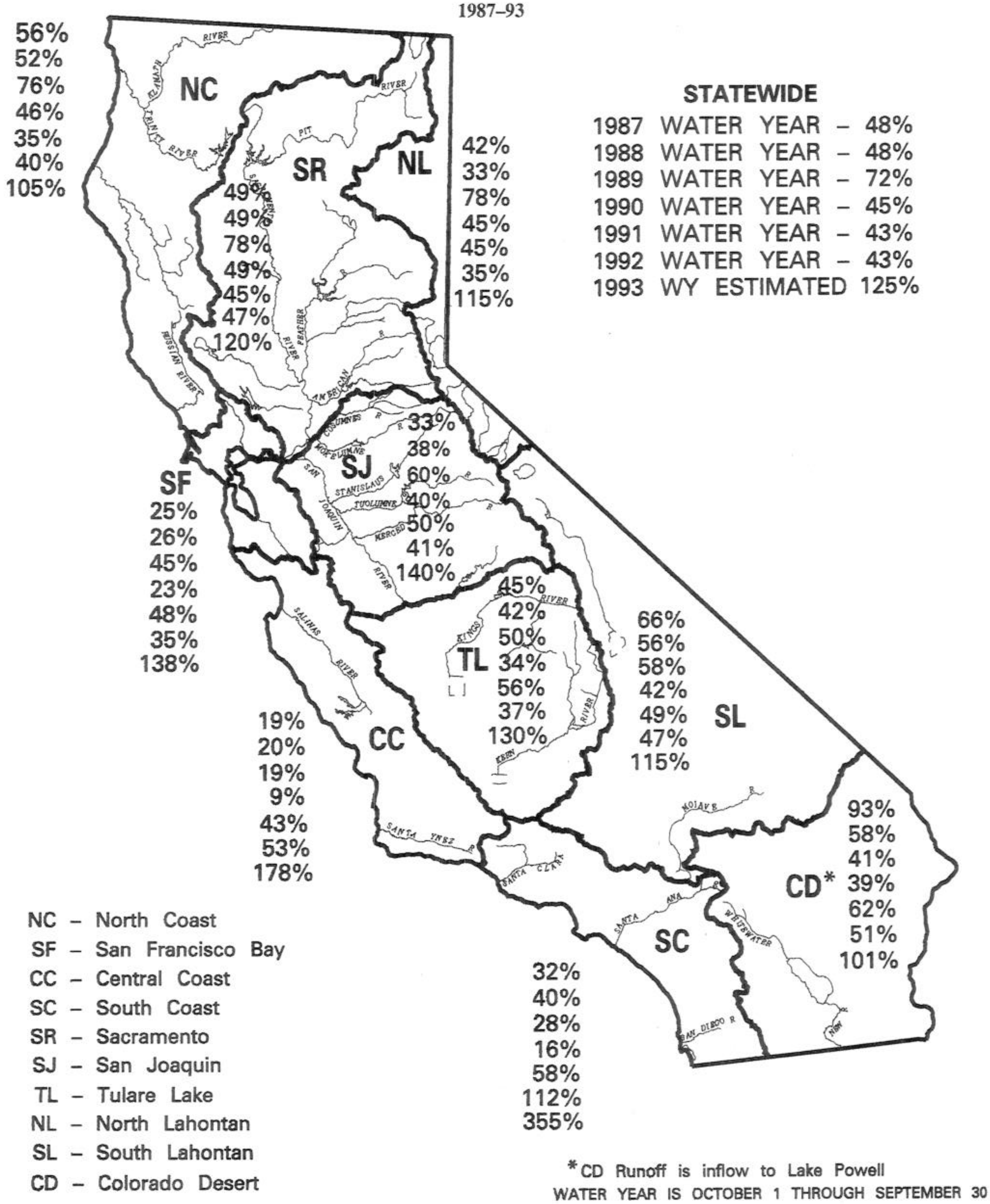
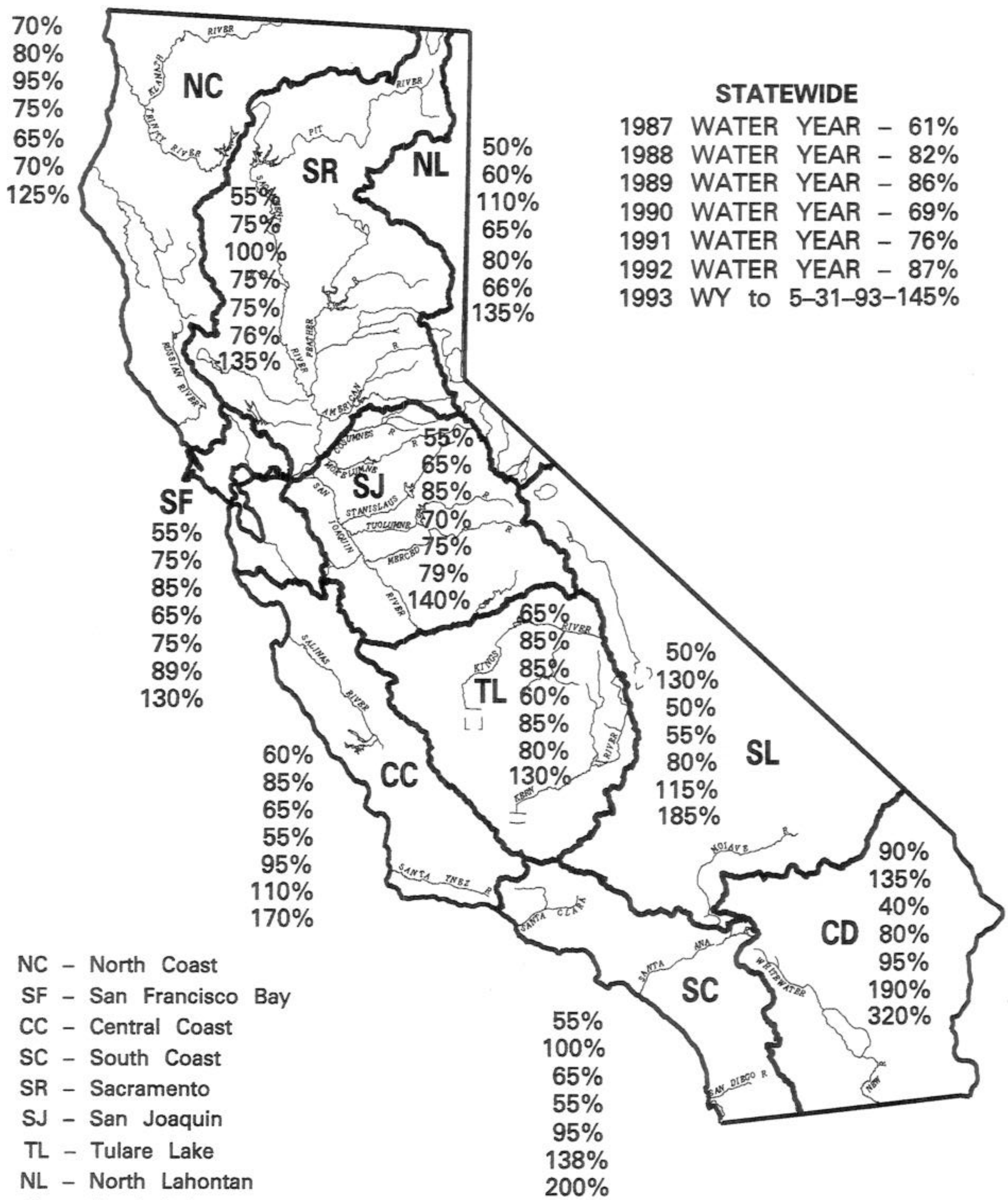


Figure 3. Water Year Precipitation in Percent of Average
By Hydrologic Regions
1987–93



WATER YEAR IS OCTOBER 1 THROUGH SEPTEMBER 30

Ground water levels also will rise as a result of recharge from the wet 1992–93 winter. Recharge will result from natural runoff, irrigation with surface water, and intentional recharge.

Climate Factors

The many causes related to large–scale droughts and their links to worldwide weather patterns are not fully understood. The following is a brief look at some of the climatic factors which may have contributed to the extended drought.

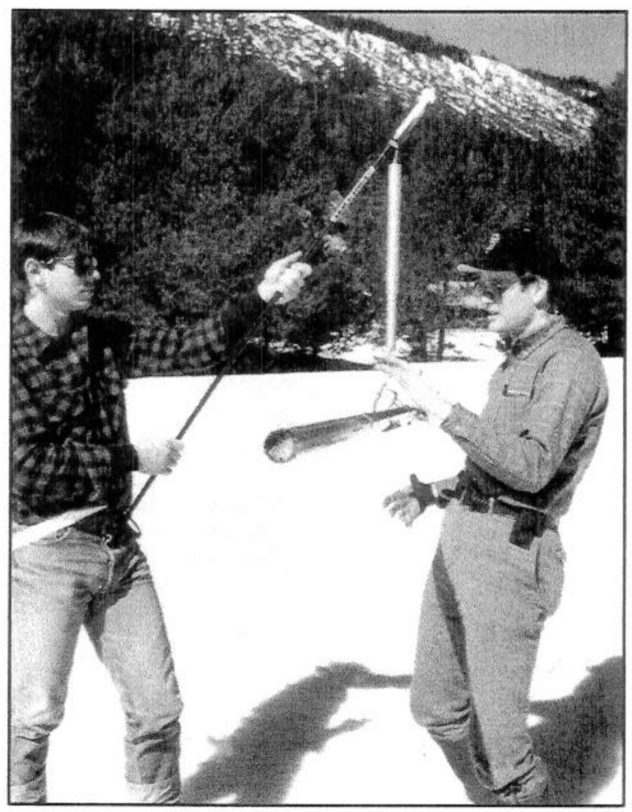
California's global location is near a region where a continuing series of west–to–east cyclonic storms produce periodic rainfall. To the south is a zone of semi–permanent high pressure with descending warm dry air, known as the Pacific High, which shifts with the season. Much of the year California is in the high pressure belt, which accounts for fair weather and lack of precipitation during the summer. During the winter, however, the storm belt usually shifts southward, occasionally placing the State under the influence of Pacific storms that bring vitally needed rain and snow.

Most of California's moisture originates in the Pacific Ocean and falls in Northern California watersheds. Storms which move over the more southerly warm Pacific waters generally produce heavy precipitation, sometimes leading to floods. As moisture–laden air is blown over mountain barriers, such as the Sierra Nevada, the air is lifted and drops even heavier rain or snow in the high country. The mountain–induced precipitation is called orographic precipitation and is very important to California's water supply. For example, the one–mile high Blue Canyon weather station northeast of Sacramento averages 63 inches of precipitation a year, about 3–1/2 times the 18 inches expected at Sacramento on the Central Valley floor, which is near sea level.

The direction of orographic wind flow also is important because the greatest amount of precipitation results when wind flow is at right angles to the mountain barrier or from the southwest into the Sierra Nevada. Wind flowing from a more southerly direction, such as occurred frequently during water year 1992, produces little precipitation.

Normally during the wet season, five to seven major winter storms occur, each of which would drop 1 to 2 inches of rain in the Sacramento Valley and three to four times as much rain and snow in the Sierra. A shortage of only a couple of major storms causes a dry year; conversely a couple of extra storms can produce a wet 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.

A multitude of factors can influence Northern California weather, and some are not very well understood. One such is El Niño, which influences weather around the world. El Niño is ocean warming in the eastern tropical Pacific, which in turn produces wetter conditions in Arizona, New Mexico, and Southern California. Under El Niño, the Pacific Northwest has a tendency to be warm and dry. Conditions during water year 1991–92 generally followed a pattern expected during an El Niño event. In Northern California, some El Niño years are wet, others are dry.



DWR snow surveyors weighing a sample of snow in tube to determine the snow water content.

Water year 1986–87, the first year of the six drought years, was an El Niño year.

The weather patterns shown in Figures 4 and 5 represent the flow of air at 500 millibars, or about 18,000 feet. Figure 4 represents a typical drought pattern which occurred frequently during the first five winters of the drought. A pattern of this nature could create three to four weeks of mid–winter dryness. The Figure 5 weather pattern represents the late winter and early spring of the sixth drought year. This was an El Niño instigated weather regime which produced heavy rain in Southern California during the spring of 1992, but did not produce heavy precipitation in the Northern Sierra.

Past Droughts

Extremely dry periods frequently last more than one year. But based on historical record, long droughts exceeding three years seem to be rare in Northern California. Records reaching back to 1850 indicate that the only exception prior to this drought was the 1929–34 drought. A comparison of California's two six–year droughts is shown in Figure 1.

In the absence of historical records, data from indirect runoff indicators, such as tree rings, are needed in order to get an idea of what the longer record looks like. With certain species of trees at sensitive locations, the thickness of annual growth rings indicates the wetness of the season. Tree ring widths are not a perfect match year by year. Although they produced a good match with the 1929–34 drought, the Sacramento River Basin group of trees didn't show the severity of 1976–77 drought. Nonetheless, they are useful in investigating historical runoff or precipitation.

A 420–year reconstruction of Sacramento River Basin runoff from tree ring studies was made for DWR in 1986 by the Laboratory for Tree–Ring Research at the University of Arizona. This reconstruction, beginning in 1560, showed that the 1929–34 drought was the worst in the reconstructed period. It is apparent that few droughts prior to 1900 exceeded three years, and none lasted over six years, although there was an eight–year period of less than average runoff from 1839 through 1846.

Table 3 provides a listing of multiyear droughts—three years or more—from the tree ring study.

Table 3. Sacramento River Multiyear Droughts (reconstructed from tree rings prior to 1900)

Period	Length (in years)	Average Runoff (MAF)
1579–82	4	12.4
1593–95	3	9.3
1618–20	3	13.2
1651–55	5	12.3
1719–24	6	12.6
1735–37	3	12.2
1755–61	6	13.3
1776–78	3	12.1
1793–95	3	10.7
1839–41	3	12.9
1843–46	4	12.3
1918–20 (actual)	3	12.0
1929–34 (actual)	6	9.8
1959–62 (actual)	4	13.0
1987–92 (actual)	6	10.0

The Final Year

Most of California continued firmly in the grip of drought during water year 1992. Although 1992 was classified as critically dry, a series of storms dropped rain on the dry Central Coast and across Southern California alleviating most drought impacts in those areas. The normally wet areas of the Sierra Nevada and the North Coast experienced the largest shortages in precipitation. By February 1, 1992, seasonal precipitation was about 60 percent of average and another critically dry year was forecast. February produced 160 percent of average; but hopes for a better water year were dashed in March as storm production again declined. Water content in the Sierra snowpack was about 60 percent of average and melted quickly. Most was gone by the middle of May and snowmelt runoff was only about 40 percent of average. Monthly precipitation totals during the last three years for eight northern Sierra stations are shown in Figure 6. Spring 1992 was one of the driest in history, and as a result, statewide runoff was the lowest of the six drought years.

Figure 4. Typical Drought Pattern Weather Map

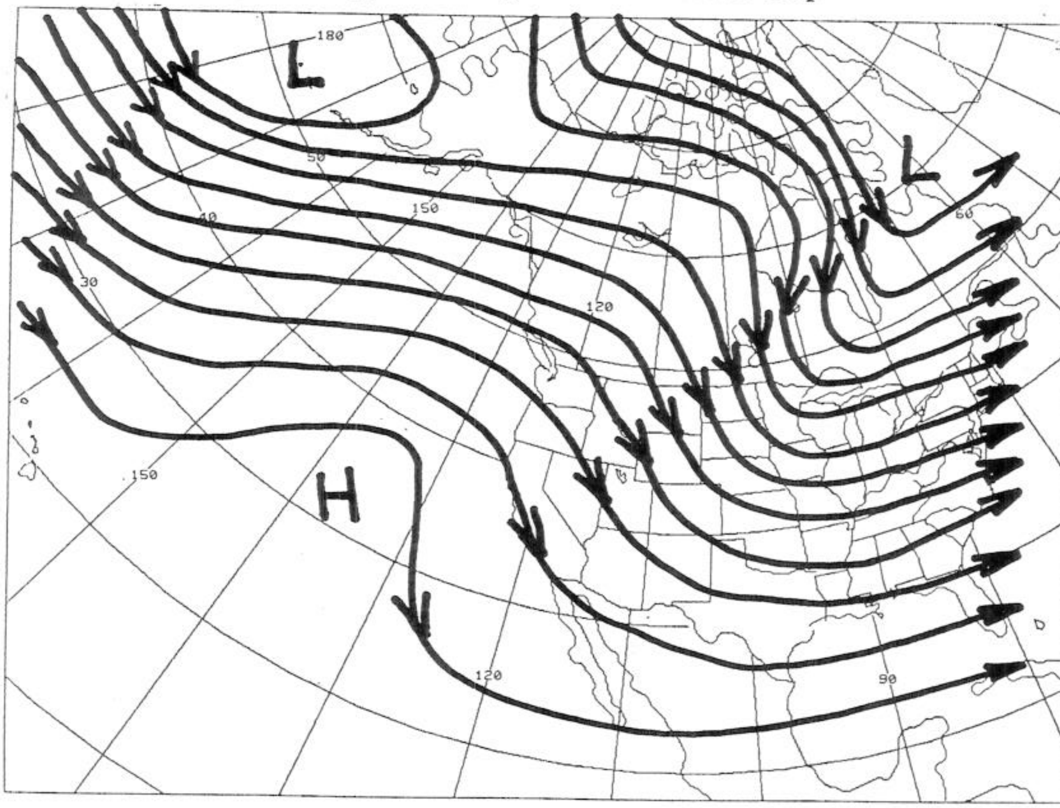


Figure 5. 1992 El Nino Weather Map

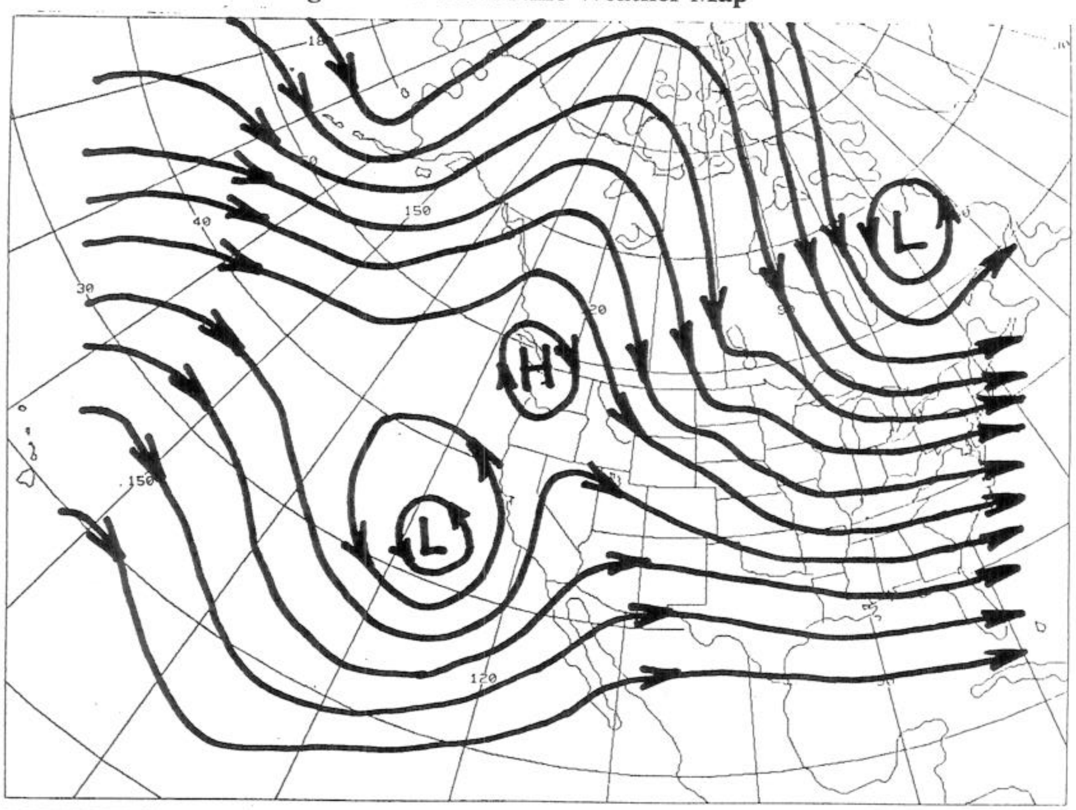
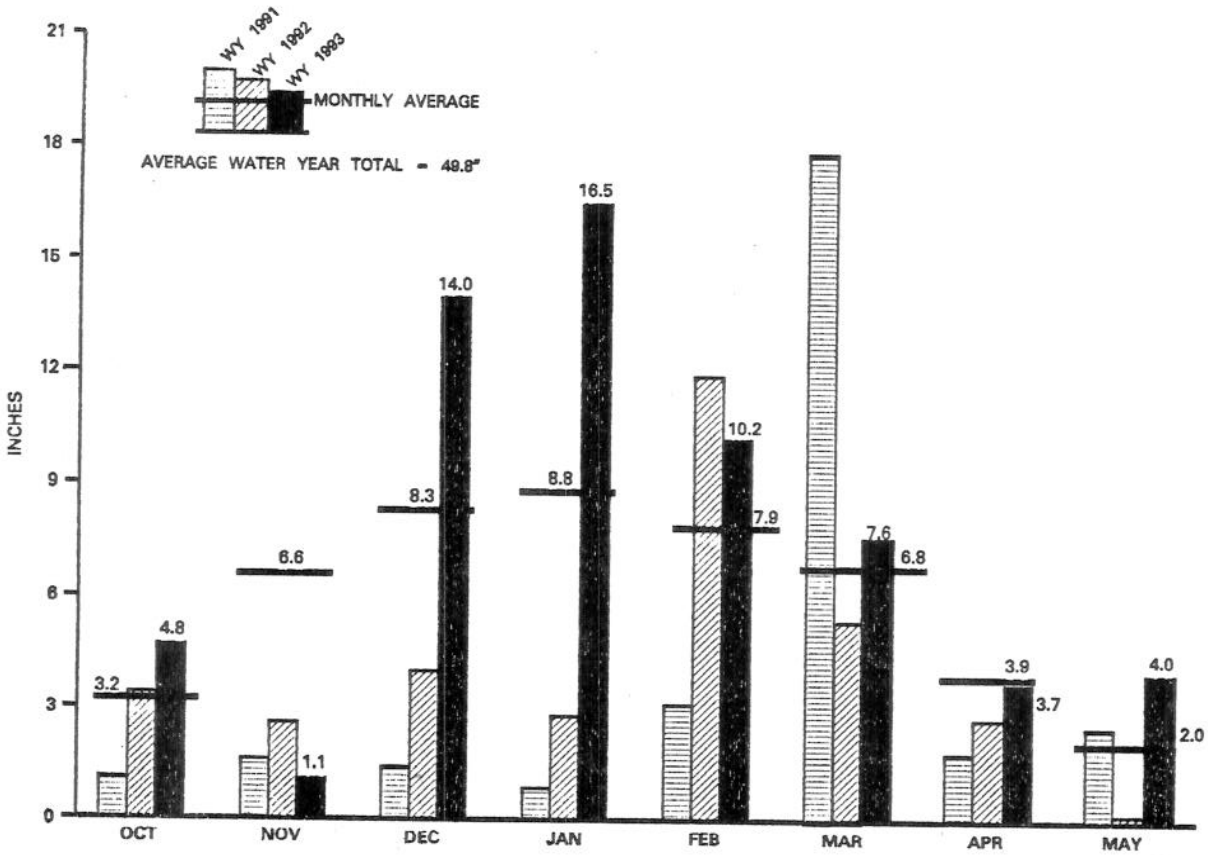
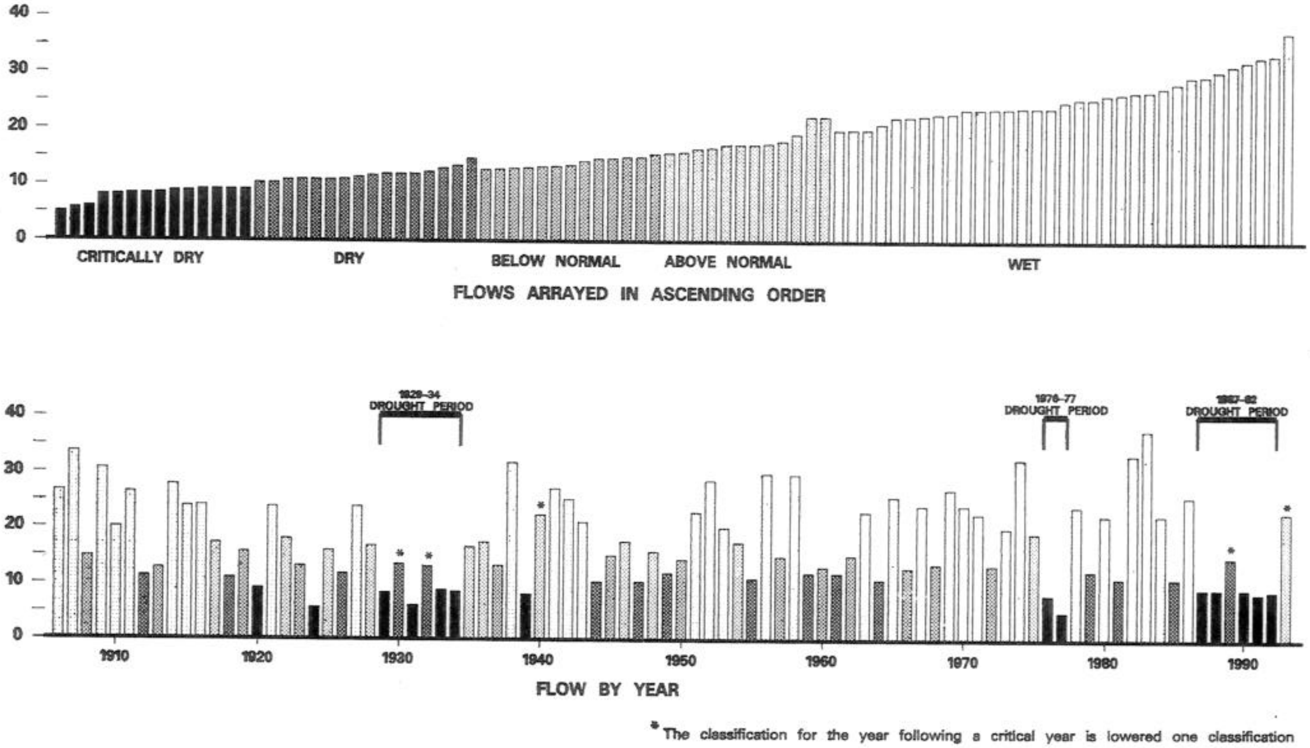


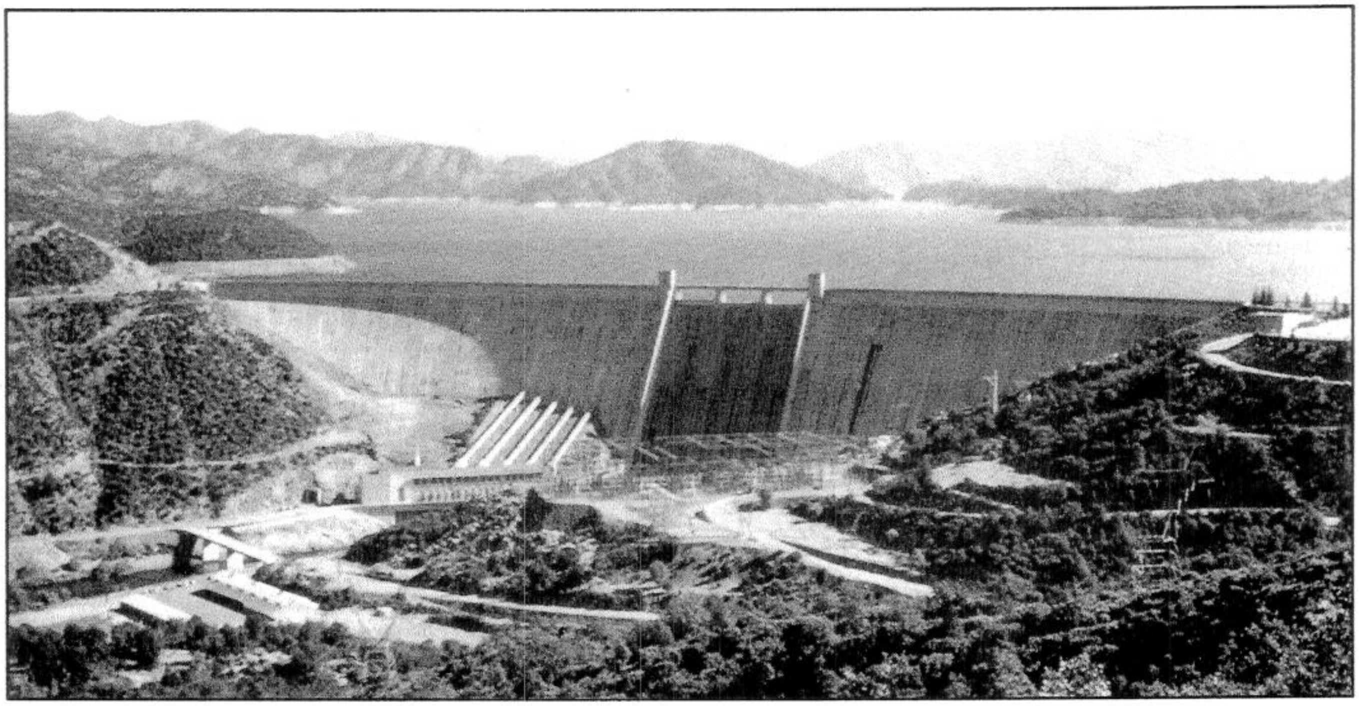
Figure 6. Northern Sierra Basin Precipitation
Eight–Station Average



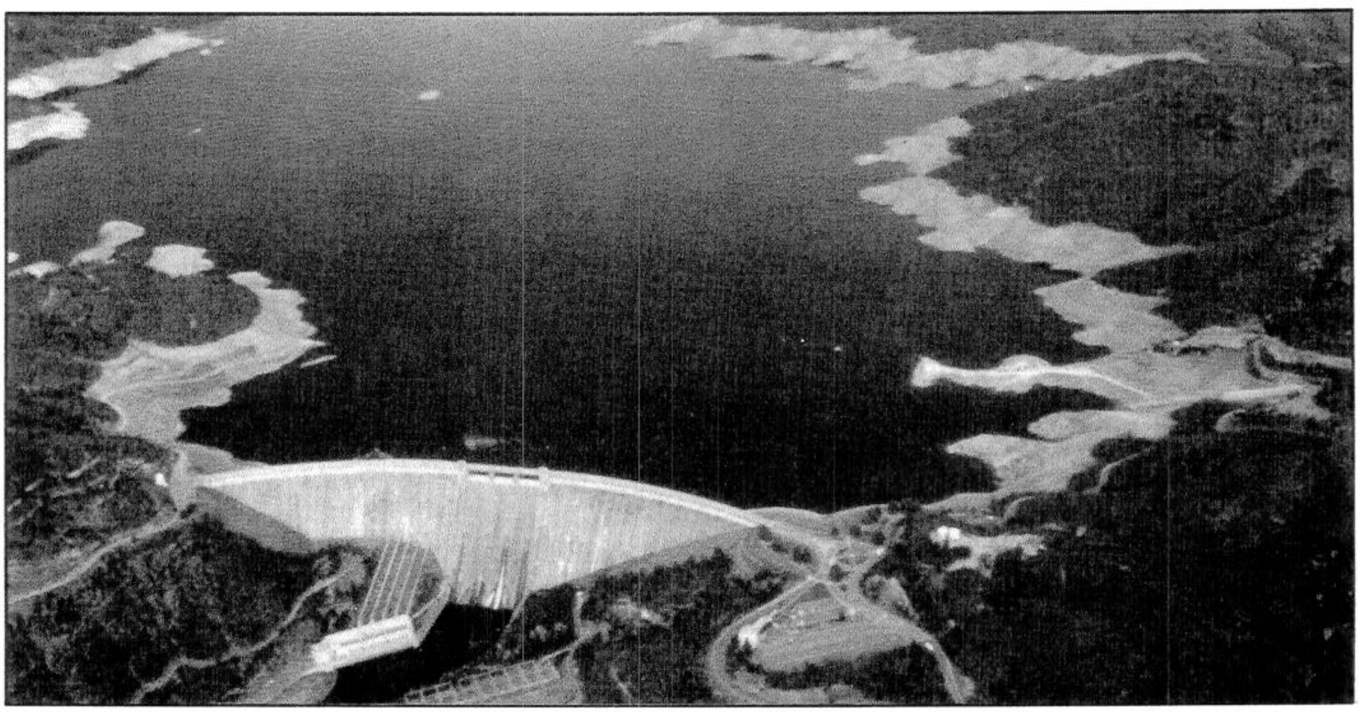
Sacramento River Basin runoff was slightly more than the previous water year, but was still about half the average 18.4 MAF. In 1992, the Sacramento River Index was 8.9 MAF, compared to 8.4 MAF during 1991. Figure 7 shows the Sacramento River Basin Index flows. More significant was the slight runoff in the central and southern Sierra, 4.2 MAF in 1992 compared to 5.4 MAF in 1991.

Figure 7. Sacramento River Basin Flows
(in millions of acre–feet per year)





Shasta Reservoir with storage about 100 percent of capacity.



Shasta Reservoir with storage about 33 percent of capacity in February 1991.

Summary of Statewide Water Data

Every drought is different, and during the 1987–92 drought, each of the six years had its own characteristic. Water year 1987 followed a wet water year (1986) and the impacts were minimal throughout most of the State. Water year 1988 was the second consecutive critically dry year and confirmed the existence of drought conditions throughout California. Water year 1989 was marginally better, with 86 percent of average statewide precipitation, and the only noncritical year of the drought (it was classified as dry). Water year 1990 was critically dry and concerns about water supply were rising even as reservoir levels were dropping. The water supply outlook was very bleak through February of 1991. Then came the "March Miracle," a month of storms exceeding 300 percent of average which took the edge off the crisis but was not enough to lift the water year out of the critically dry classification, the fourth critically dry year in the preceding five.

Precipitation

Statewide precipitation for each water year was below average during the 1987–1992 period. Statewide and Northern Sierra percentages are listed in Table 4. Water year 1992 (which extended from October 1, 1991, through September 20, 1992) produced 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 5) was about three–quarters of average, northern basins were near normal and the southern portion of the State was dry. Water year 1977, which was the driest year of record, is also shown on Tables 4 and 5.

Oroville Reservoir with storage at about 26 percent of capacity in February 1991.

Table 4. 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

Table 5. Percentage of Average Runoff

	Water Year						
	1977	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**
Statewide	20	48	48	72	45	43	43
Northern Sierra	28	50	50	80	50	46	48
Sacramento River Index (MAF)	5.1	9.2	9.2	14.8	9.2	8.4	8.9

Runoff

The 1987–1992 drought for the Sacramento River basin is unique in that runoff, as measured by the Sacramento River Index, in five of the years has been very similar, about half of average. Only in 1989 was there a substantial change.

Precipitation during 1987–92 was about three–quarters of average. The deficit in precipitation was magnified in runoff which was about half of average over the six 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.

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.

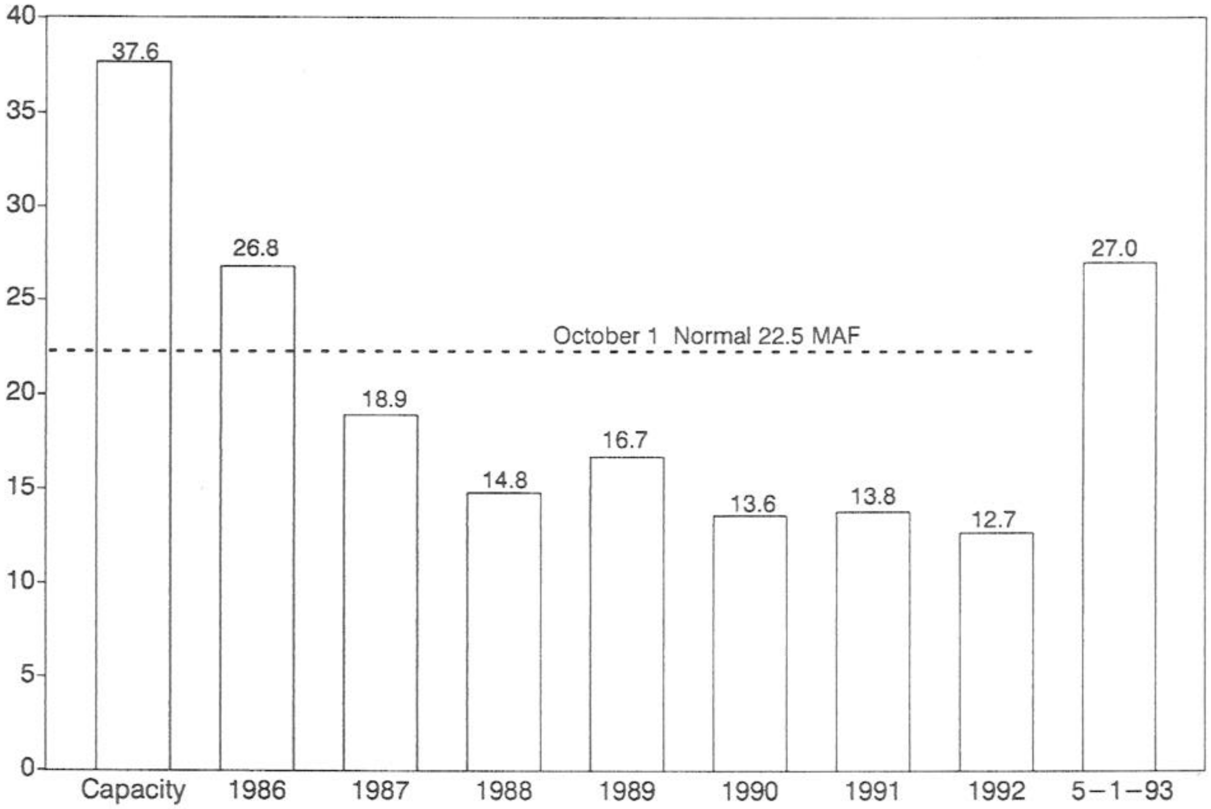
In water year 1987 storage in the 155 major reservoirs of California was 26.8 MAF. This gradually decreased until it reached the lowest cumulative total storage of 11.8 MAF at the end of November 1992. Storage began to increase in December 1992 and by the first of May 1993 had reached 27 MAF. The 50-year average May 1 storage is 28 MAF. (See Figure 8.)

Snow Water Content

The Sierra snowpack's depth and water content increased significantly. On December 1, 1992, water content of the snowpack was about 30 percent of average. By the end of that month, snowpack water content increased to about 120 percent of average. At the end of February 1993, water content reached 180 percent of average.

Figure 8. Statewide Storage in 155 Major Reservoirs at End Of Water Year on September 30, 1986 through 1992 and on May 1, 1993

(in millions of acre–feet)



Year	Storage*	Percent of Normal	Difference from Previous Year*	Accumulated Loss*
1986	26.8	119	– –	– –
1987	18.9	84	−7.9	−7.9
1988	14.8	66	−4.1	−12.0
1989	16.7	74	+1.9	−10.1
1990	13.6	60	−3.1	−13.2
1991	13.8	61	+0.2	−13.0
1992	12.7	56	−1.1	−14.1
12/1/92	11.8	55	−0.9	−15.0
5/1/93	27.0	120	+15.2	+0.2

** in millions of acre–feet*

Regional Water Systems

California is divided into 10 hydrologic regions and each typifies climate and hydrologic conditions for that area. In average years, many areas have abundant surface supplies from rivers and reservoirs along with the necessary canals and pipelines to convey the water for agricultural or municipal and industrial use. Other areas depend more on ground water and have little or no means to transport supplemental water supplies.

Drought impacts varied in intensity throughout California, partly due to the differing capability of local water systems to meet local needs. A comparison of May 31 water storage in 81 reservoirs shows how the system reservoirs were used as the drought intensified, and how water levels improved leading to the end of the drought. The reservoirs listed in Table 6 comprise almost 90 percent of the capacity of major reservoirs in California.

Colorado River Supply

The Colorado River is an important water source for the State. During the early 1980s the Colorado River Basin experienced abundant amounts of precipitation and runoff. This has mitigated the recent decline in storage experienced during the 1987–92 drought on the lower Colorado River, as shown in Table 7. Additional water can, and is, made available when the Secretary of the Interior determines a surplus condition exists or when the other lower basin states, Arizona and Nevada, are not fully using their apportioned water. Since 1985, neither Arizona nor Nevada has fully used its basic apportionment and the Secretary has allowed California to divert and consumptively use more than 5 MAF per year. California's basic annual entitlement to Colorado River water is 4.4 MAF.

Drought impacts in Southern California were significantly lessened because The Metropolitan Water District of Southern California was able to divert at the full capacity of its Colorado River Aqueduct (an estimated 1.25 MAF) during most of the drought. MWD is again expected to divert at aqueduct capacity in 1993.

If the total Colorado River mainstream consumptive use by the three Lower Division States exceeds 7.5 MAF, California will be required to compensate for the overuse by 1996. Adjustments to California's consumptive use apportionment would be the compensation, unless other alternatives are agreed to between the Secretary of the Interior and the governors of the seven Colorado River Basin states.

Table 6. Comparison of May 31 Water Storage by System and Reservoir

(in thousands of acre–feet)

System	Reservoir	Cap.	Avg.	1976	1977	1987	1988	1989	1990	1991	1992	1993
Humboldt MWD	Ruth	51.8	49.7	51.4	27.2	46.5	48.0	47.6	51.6	47.6	46.9	51.0
Russian	Warm Springs	381.0	192.5	0.0	0.0	181.1	183.6	188.7	167.9	200.9	239.8	246.0
Marin MWD	Nicasio	22.4	19.2	2.6	0.3	20.9	16.9	15.7	11.0	14.6	21.1	22.4
	Kent	32.9	16.3	10.7	0.5	16.4	15.1	26.3	17.1	20.4	26.0	31.8
	Alpine	8.9	6.6	6.5	6.5	7.3	7.1	8.9	7.6	8.9	8.8	8.9
	Soulajule	10.6	9.8	n/a	n/a	9.6	8.8	9.1	6.0	4.3	9.6	10.1
	Subtotal	74.8	51.9	19.8	7.3	54.2	47.9	60.0	41.7	48.2	65.5	73.2
East Bay MUD	San Pablo	38.6	30.7	22.6	24.7	27.8	31.8	33.3	32.3	34.6	29.8	33.7
	U San Leandro	41.4	32.8	17.4	18.6	31.3	35.4	34.1	34.0	35.3	32.9	27.0
	Chabot	10.4	9.6	9.8	9.7	9.8	9.3	9.0	8.4	8.0	8.1	9.7
	Briones	60.5	54.1	59.5	58.5	56.5	59.9	57.6	55.1	55.6	53.1	55.2
	Pardee	210.0	188.3	155.8	60.9	190.6	167.4	204.8	191.3	175.6	198.2	191.2
	Camanche	430.9	292.6	257.1	119.4	208.3	76.3	134.3	187.0	115.5	116.2	349.3
	Subtotal	791.8	608.1	522.2	291.8	524.3	380.1	473.1	508.1	424.6	438.3	666.1
San Francisco	San Antonio	50.5	33.0	24.0	19.0	14.1	16.5	28.1	27.0	40.1	46.2	50.0
	Calaveras	96.9	72.9	40.8	29.8	55.8	55.2	57.1	31.7	14.7	34.5	97.2
	San Andreas	19.0	15.7	11.2	16.9	11.8	15.2	10.3	17.5	16.2	16.7	15.7
	Crystal Springs	58.4	49.8	29.2	45.6	30.8	44.9	52.1	37.8	39.0	59.1	55.5
	Hetch Hetchy	360.4	261.9	210.0	93.9	288.7	297.4	344.0	236.2	191.5	251.2	268.2
	Cherry Lake	268.0	189.9	160.2	123.6	234.3	203.4	213.0	163.0	151.2	125.5	229.6
	Eleanor	26.1	20.1	4.8	3.0	26.6	14.1	20.8	14.9	6.7	4.6	25.6
	Subtotal	879.3	643.3	480.2	331.8	662.1	646.7	725.4	528.1	459.4	537.8	741.8
Salinas	Salinas	23.0	19.9	14.6	9.8	13.8	7.8	5.5	2.4	13.2	22.5	23.3
	San Antonio	330.0	252.0	268.0	161.9	245.1	201.7	116.3	20.6	45.9	51.9	148.0
	Nacimiento	340.0	213.6	163.2	42.4	229.6	131.2	26.9	26.3	125.3	103.8	271.7
	Subtotal	693.0	485.5	445.8	214.1	488.5	340.7	148.7	49.3	184.4	178.2	443.0
Santa Ynez	Gibraltar	8.2	9.7	8.0	6.0	5.3	7.0	2.2	0.0	9.0	9.0	8.7
	Cachuma	204.9	171.7	165.9	129.8	152.5	122.8	82.6	52.1	74.9	178.6	191.1
	Subtotal	213.1	181.4	173.9	135.8	157.8	129.8	84.8	52.1	83.9	187.6	199.8
Nevada ID	Jackson Mdws	69.2	56.9	38.3	3.0	42.9	34.2	69.3	59.4	49.9	53.5	65.7
	Bowman Lake	68.5	59.2	44.3	36.4	57.3	39.3	65.7	54.9	61.1	39.6	54.2
	French Lake	13.8	11.4	7.8	2.2	6.0	9.1	13.9	11.9	13.8	13.4	13.2
	Scotts Flat	48.5	37.4	38.5	16.7	42.3	36.3	48.0	46.1	47.6	42.5	48.3
	Rollins	66.0	60.9	35.7	10.1	63.2	60.4	66.0	65.9	65.2	48.9	66.0
	Subtotal	266.0	225.8	164.6	68.4	211.7	179.3	262.9	237.9	237.6	197.9	247.4

Table 6. Comparison of May 31 Water Storage by System and Reservoir (continued)
(in thousands of acre–feet)

System and Reservoir		Cap.	Avg.	1976	1977	1987	1988	1989	1990	1991	1992	1993
So. Sutter WD	Camp Far West	104.0	92.4	72.9	11.4	73.5	52.6	103.7	84.2	97.1	78.5	103.8
SMUD	Loon Lake	76.5	58.7	52.2	29.1	66.6	32.4	70.3	70.9	62.7	58.4	62.0
	Union Valley	277.3	215.0	138.6	53.9	137.3	84.4	254.5	259.5	173.0	151.6	262.5
	Ice House	46.0	36.7	26.7	13.3	34.3	20.5	43.9	43.0	43.3	30.8	36.2
	Slab Creek	16.6	14.1	12.8	15.8	14.6	15.6	14.9	16.1	15.3	16.1	16.0
	Subtotal	416.4	324.5	230.3	112.1	252.8	152.9	383.6	389.5	294.3	256.9	376.7
Sly Park	Jenkinson L.	41.0	37.7	24.7	9.4	25.2	18.6	40.7	38.6	40.6	39.4	41.2
Orland Project	East Park	50.9	44.0	2.1	0.3	42.9	48.3	50.3	34.9	48.2	49.7	50.8
	Stoney Gorge	50.0	42.9	6.6	4.6	38.0	47.2	41.0	44.9	47.7	45.7	49.3
	Subtotal	100.9	86.9	8.7	4.9	80.9	95.5	91.3	79.8	95.9	95.4	100.1
Yolo County	Indian Valley	301.0	188.1	55.0	0.0	196.5	110.3	61.4	36.9	47.5	10.8	142.7
Calaveras	New Hogan	317.1	178.7	116.4	41.6	120.5	48.3	37.5	40.5	54.5	62.2	202.5
Tri Dam	Donnells	64.3	58.5	44.9	5.0	59.8	53.9	63.2	59.6	43.3	61.6	64.0
	Beardsley	97.8	79.9	20.6	4.4	44.6	34.2	97.4	68.5	52.6	50.7	96.6
	Tulloch	67.0	59.7	66.8	44.2	64.2	66.0	66.0	64.1	63.8	65.3	65.2
	Subtotal	229.1	198.1	132.3	53.6	168.6	154.1	226.6	192.2	159.7	177.6	225.8
Stanislaus	New Melones	2420.0	1815.3	41.9	4.6	1709.8	1278.8	909.0	633.9	423.2	289.5	684.4
Tuolumne	Don Pedro	2030.0	1314.5	1115.4	525.4	1349.7	963.5	1224.5	1250.2	1122.0	1100.6	1774.0
Merced	Exchequer	1024.6	735.5	564.7	209.5	666.4	389.8	350.8	258.0	313.0	347.1	838.0
Kern	Isabella	568.0	269.6	169.7	72.1	273.1	155.7	184.8	94.4	138.5	153.6	369.2
Truckee	Stampede	226.5	137.8	103.7	34.0	103.8	85.7	100.7	97.6	87.7	79.9	167.0
	Prosser Creek	29.8	17.4	12.7	4.6	14.6	9.9	22.8	17.2	9.7	9.8	21.0
	Boca	41.1	33.7	30.5	33.4	39.7	14.0	40.1	27.2	18.3	6.1	38.6
	Lake Tahoe	732.0	503.5	472.8	132.0	523.6	200.4	190.7	95.9	0.0	0.0	17.0
	Subtotal	1029.4	692.4	619.7	204.0	681.7	310.0	354.3	237.9	115.7	95.8	243.6
Walker	Bridgeport	42.6	28.9	27.0	10.7	34.8	13.1	13.0	10.2	4.5	7.0	14.8
LA DWP	Grant Lake	47.6	24.8	20.8	7.6	16.0	15.5	17.0	16.9	14.3	26.6	22.9
	Lake Crowley	183.2	125.0	119.4	60.4	165.4	115.6	105.9	91.7	107.0	120.9	111.3
	Tinemaha	16.3	4.9	4.0	2.8	3.9	2.8	7.3	7.2	3.1	2.9	2.2
	Haiwee	41.2	39.8	40.3	38.1	38.8	34.9	16.1	14.1	19.5	13.9	22.4
	Subtotal	288.3	194.5	184.5	108.9	224.1	168.8	146.3	129.9	143.9	164.3	158.8
Feather	Almanor	1143.0	909.9	605.6	663.3	962.3	841.8	942.9	868.5	836.7	866.3	1021.9
	Oroville	3537.6	3088.1	2632.7	1353.4	2928.4	2478.9	3278.9	1727.6	1684.7	1879.4	3516.0
	Subtotal	4680.6	3998.0	3238.3	2016.7	3890.7	3320.7	4221.8	2596.1	2521.4	2745.7	4537.9

Table 6. Comparison of May 31 Water Storage by System and Reservoir (continued)

(in thousands of acre–feet)

System and Reservoir		Cap.	Avg.	1976	1977	1987	1988	1989	1990	1991	1992	1993
CVP North	Clair Engle	2447.7	2232.0	2112.1	925.9	2328.2	2013.0	1891.4	1598.0	1200.5	1143.8	1838.6
	Shasta	4552.0	4042.4	2568.1	1127.1	3673.6	2965.1	3453.5	2476.6	2087.0	2586.4	4470.9
	Whiskeytown	241.1	236.6	236.9	237.4	237.5	238.5	238.3	232.7	233.4	238.6	239.9
	Folsom	974.5	866.7	633.8	303.9	736.0	485.3	944.3	566.8	742.6	656.6	953.0
	Subtotal	8215.3	7377.7	5550.9	2594.3	6975.3	5701.9	6527.5	4874.1	4263.5	4625.4	7502.4
Yuba Co. WA	Bullards Bar	966.1	777.5	417.7	311.4	811.2	753.1	930.6	848.7	863.3	681.1	924.8
PG & E	Spaulding Sys	144.6	128.6	97.6	69.4	117.7	112.0	139.8	126.1	118.4	112.2	129.9
Placer Co. WA	French Mdws	136.4	113.2	58.2	53.3	106.7	102.4	132.7	110.0	88.1	74.9	124.1
	Hell Hole	207.6	170.5	128.0	99.8	161.2	153.2	202.3	166.5	129.4	99.8	175.3
	Subtotal	344.0	283.7	186.2	153.1	267.9	255.6	335.0	276.5	217.5	174.7	299.4
Solano	Berryessa	1600.0	1393.9	1224.2	914.1	1321.1	1157.0	976.7	772.7	720.6	584.2	914.2
Friant	Millerton	520.0	375.6	365.5	213.1	322.4	351.7	381.2	350.2	398.2	435.7	443.0
Upper San Joaquin	Florence L	64.6	29.7	13.3	20.4	30.8	33.6	32.1	26.6	19.9	41.9	26.9
	Edison	125.0	57.0	30.1	8.3	66.7	11.9	40.4	24.0	28.9	40.4	56.7
	Huntington L	89.8	68.2	72.8	86.4	86.2	68.0	78.1	80.4	65.7	77.1	80.1
	Shaver Lake	135.4	76.1	50.1	32.9	54.0	33.9	54.9	35.7	51.0	77.0	97.0
	Mammoth Pool	122.7	102.4	86.4	91.8	88.9	93.5	103.1	65.0	80.1	87.8	123.0
	Redinger	35.0	34.6	25.2	19.7	24.2	24.5	24.8	25.0	24.7	24.5	25.5
	Bass Lake	45.4	41.1	32.3	23.2	39.0	38.6	29.2	42.6	44.5	43.8	44.5
	Subtotal	617.9	409.1	310.2	282.7	389.8	304.0	362.6	299.3	314.8	392.5	453.7
Kings	Courtright	123.2	67.5	50.5	1.1	103.5	121.4	116.8	70.4	100.2	108.6	80.0
	Wishon	128.3	90.7	60.3	110.6	104.2	87.9	104.8	56.2	47.9	47.9	90.3
	Pine Flat	1000.0	687.9	577.4	390.1	784.8	411.2	382.6	306.0	362.2	357.0	822.9
	Subtotal	1251.5	846.1	688.2	501.8	992.5	620.5	604.2	432.6	510.3	513.5	993.2
Kaweah	Terminus	143.0	103.4	73.5	49.7	105.9	101.9	129.1	88.5	141.6	88.9	138.0
Tule	Success	82.3	54.8	31.8	13.4	34.2	22.4	42.0	22.0	44.2	26.3	53.3
San Luis	San Luis	2039.0	1727.0	1684.6	1169.2	1583.7	1686.0	1276.3	1672.2	1372.6	1571.7	1668.1
Ventura	Casitas	254.0	189.4	213.5	194.2	229.1	213.5	184.3	151.8	155.6	201.1	253.9
Total	81	33,121.5	26,260.1	19,304.3	10,927.7	25,225.3	20,468.4	22,229.8	17,623.7	16,352.0	16,923.7	26,255.7

Table 7. Comparison of March 1 Lower Colorado River Water Storage
(in thousands of acre–feet)

Reservoir (Capacity)	Capacity	1976	1977	1987	1988	1989	1990	1991	1992	1993
Lake Powell	25,002	19,837	17,984	21,571	22,174	21,131	18,197	15,242	13,745	12,994
Lake Mead	26,159	20,527	21,843	24,485	24,655	23,279	21,741	20,149	20,065	21,515
Lake Mojave	1,810	1,681	1,671	1,711	1,762	1,694	1,658	1,704	1,654	1,709
Lake Havasu	619	560	554	547	544	537	540	552	550	599
Totals	**53,590**	**42,605**	**42,052**	**48,314**	**49,135**	**46,641**	**42,136**	**37,647**	**36,014**	**36,817**

Lake Tahoe

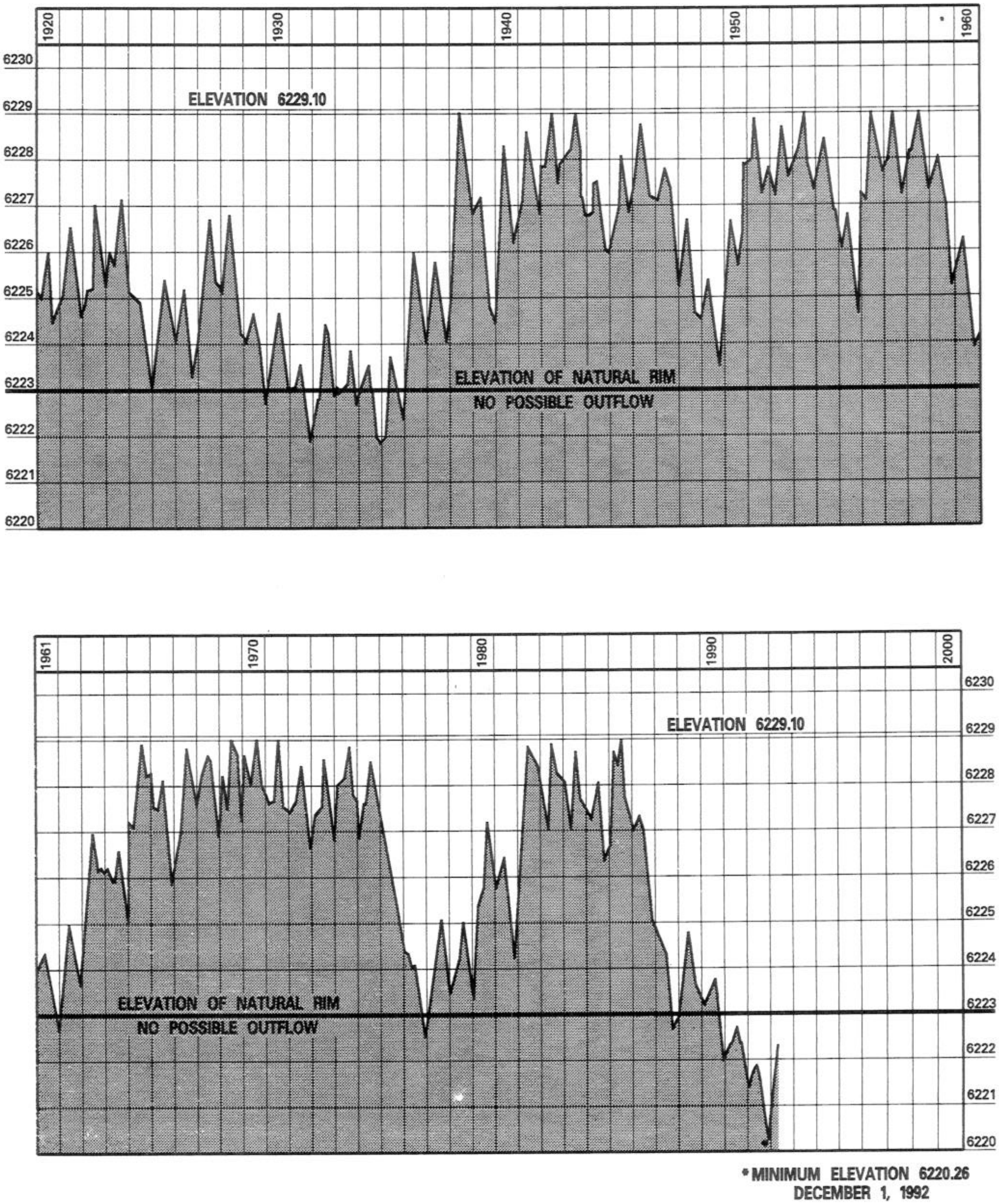
Without a doubt, Lake Tahoe is the best known body of water in the Sierra Nevada. It is renown for its beauty and water clarity. The lake occupies about 190 square miles (122,000 acres) of a total drainage area of 506 square miles. A small buttress dam at the outlet regulates outflow and controls the upper 6.1 feet of the lake, providing usable storage of 732,000 AF according to the USBR. However, Lake Tahoe is deep, up to 1,650 feet, with an average depth of 990 feet. The total volume of the lake below the natural rim is estimated to be 122 MAF, enough if spread evenly to cover the entire State to a depth of 1.2 feet.

The historical elevation of Lake Tahoe is shown in Figure 9. The recorded minimum elevation was 6,220.26 feet on November 30, 1992, some 2.74 feet below the natural rim. Although the lake dipped below the rim in late 1988, it was below the rim continuously from September 15, 1990 to may 26, 1993. This length far exceeds previous historical episodes of which the worst was in 1931 and 1934. The period below the rim in the earlier events was less than a year. The lowest previous stage was 6,221.79 feet in December 1934, about 1.5 feet higher than in 1992. Approximately 0.3 feet of the 1934 drawdown was estimated to be due to pumping from the lake into the Truckee River to maintain some streamflow and water supply during that drought. There was no pumping during the recent drought.

Average outflow of Lake Tahoe since 1900 has been about 180,000 AF per year. Estimated average lake evaporation is 375,000 AF per year, over twice the outflow. Average precipitation in the entire watershed is about 35 inches. During the 1987–92 drought, average Tahoe basin precipitation seems to have been 70 percent of average or around 25 inches. Total lake outflow during the six water years was about 350,000 AF, not quite 60,000 AF per year. However, the lake was relatively high at the end of water year 1986 with a decrease in storage by September 30, 1992 of nearly 850,000 AF. The total evaporation over the six years exceeded inflow by about 500,000 AF or an average deficit of 83,000 AF per year. What these facts show is that climate conditions roughly 20 to 25 percent drier are enough to stop outflow from Lake Tahoe.

There are a number of places where submerged tree stumps, and even submerged trees, can be seen around the edge of Lake Tahoe. Some of these have been dated to be 5,000 to 6,000 years old. One explanation is that a sustained period of aridity caused the lake level to drop for along enough time for the trees to grow. It is also possible that sediments blocked the sill at the outlet or tectonic movement changed the level of the outlet relative to the main body of the lake. Since submerged trees have been reported from other lakes in the eastern Sierra, the sustained drought hypothesis is more likely to be the reason. Additional research has been proposed to delve into the stump phenomenon.

Figure 9. Historical Elevation of Lake Tahoe



Ground Water

Ground water is one of the State's most valuable natural resources, and was a critical water source during the six-year drought. During an average year, ground water provides nearly 37 percent of the State's applied water. During the drought, ground water provided as much as 60 percent of the statewide total applied water. The actual amount of ground water used during the drought varied in different hydrologic regions and ranged from 18 percent in some areas to as much as 90 percent in others.

Supply and Storage Impacts

Water levels in wells indicate the amount of ground water that remains in a basin, and ground water levels are usually quite different from basin to basin and can vary in different parts of the same basin. Water levels are affected by many factors, including recharge in previous years, the ratio of use between surface water and ground water, the number and location of extraction wells, the amount of ground water that flows out of the basin, the site-specific hydrogeology, and the amount of water extracted from the basin.

While most surface water reservoirs can refill in a single year if precipitation is above average, it can take several years of above average precipitation before ground water basins can return to previous high levels. This is because in years with higher runoff, more surface water is available and less ground water is extracted, thereby allowing the ground water levels to recover. Conversely, in lower runoff years, as with the recent drought, there is less surface water available and more ground water is extracted. Little or no recharge of ground water aquifers occurs during low runoff years.

When the amount of water extracted from a ground water basin exceeds the amount of water recharging the basin over a long period of time, the basin is said to be in "overdraft." During the recent drought, several ground water basins were considered to be in overdraft. The most severely affected region was the San Joaquin Valley, where ground water levels decreased considerably because of the low recharge and the large amount of ground water extracted between spring 1987 and spring 1992. In Stanislaus, Merced, Madera, and Kings counties, more ground water was extracted during 1987–92 than during the more extreme but shorter drought of 1976–1977. In those counties, this resulted in less ground water remaining in storage in 1992 than in 1978.

In Tulare County (Figure 10) the amount of ground water extracted during 1987–92 was almost twice as much as was extracted during the 1976 and 1977 drought. The total remaining ground water in storage, however, is about the same. In Fresno and Kern counties (Figures 11 and 12), more ground water was extracted during 1987–92 than during 1976 and 1977; however, slightly more ground water remained in storage in both counties in 1992 than in 1978.

Because of the drought, most ground water specialists expected ground water extraction in all San Joaquin Valley counties to be higher than normal through spring 1992. But calculations based on ground water level measurements indicate that between spring 1991 and spring 1992 significantly less ground water was extracted than during previous years in Stanislaus, Merced, Madera, Fresno, Tulare, and Kings counties (Figures 10–17). Only Kern County showed an increase in ground water extraction. The reasons for the decrease in ground water extractions are unknown, but may be caused by several factors such as rainfall variations, fallowed land, crop changes, and the unexpected heavy precipitation in March 1991.

Although other ground water basins suffered a decline in storage, for the most part these areas fared better than the San Joaquin Valley. In the Sacramento Valley (Figure 17), ground water in storage did not decline significantly during the drought in Glenn or Colusa counties. In Butte and Tehama counties, however, the amount of ground water in storage declined, but not as much as during the 1976–77 drought.

Figure 10. Cumulative Storage Change of Unconfined Ground Water in Tulare County

(in thousands of acre–feet)

Figure 11. Cumulative Storage Change of Unconfined Ground Water in Fresno County

(in thousands of acre–feet)

Figure 12. Cumulative Storage Change of Unconfined Ground Water in Kern County

(in millions of acre–feet)

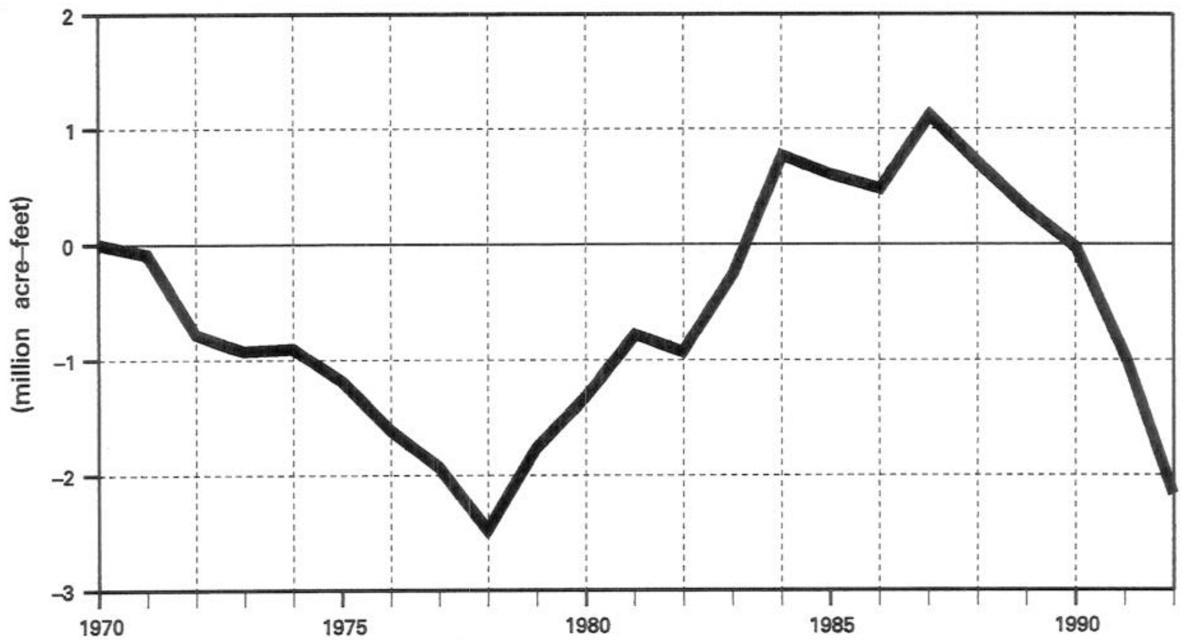


Figure 13. Cumulative Storage Change of Unconfined Ground Water in Merced County

(in thousands of acre–feet)

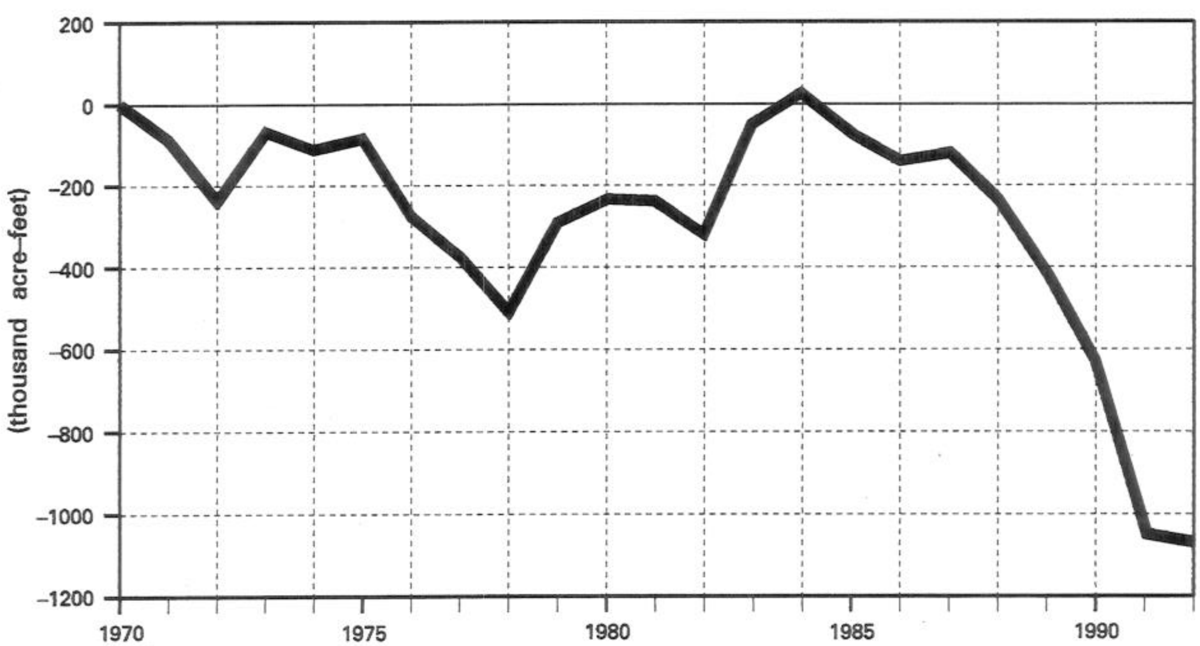


Figure 14. Cumulative Storage Change of Unconfined Ground Water in Madera County
(in thousands of acre–feet)

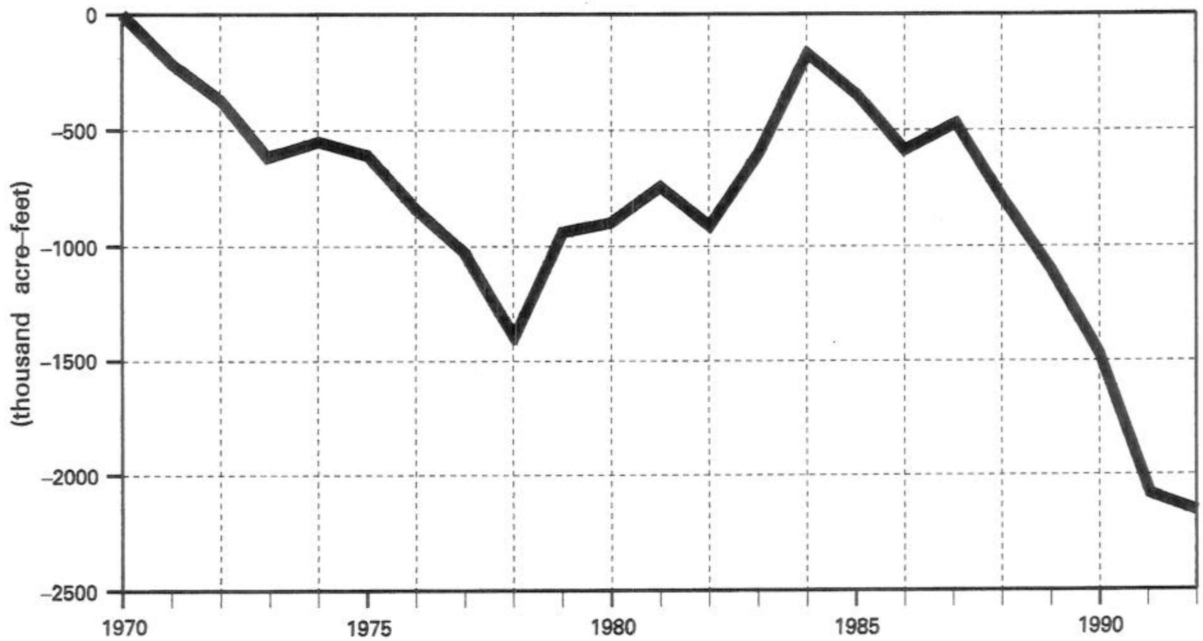


Figure 15. Cumulative Storage Change of Unconfined Ground Water in Stanislaus County
(in thousands of acre–feet)

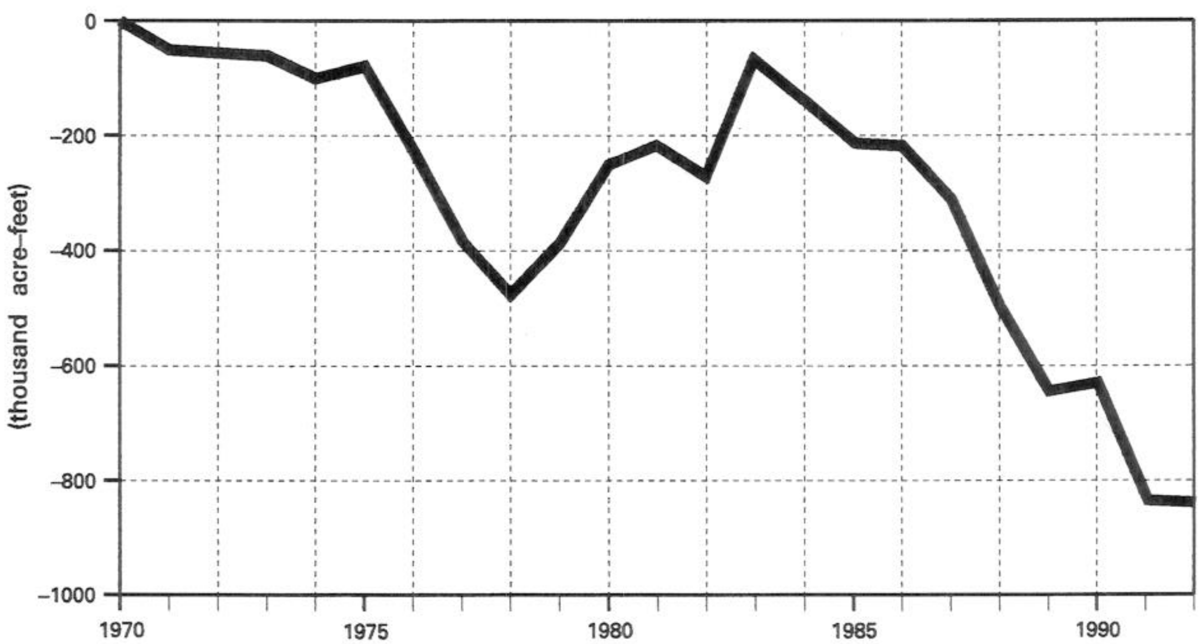
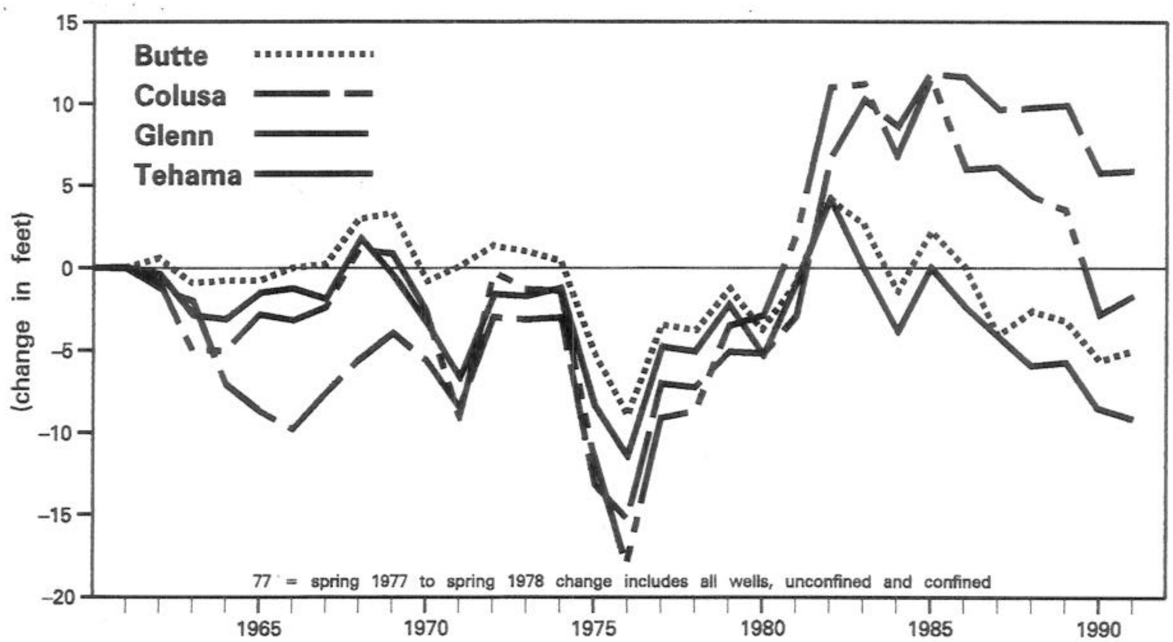
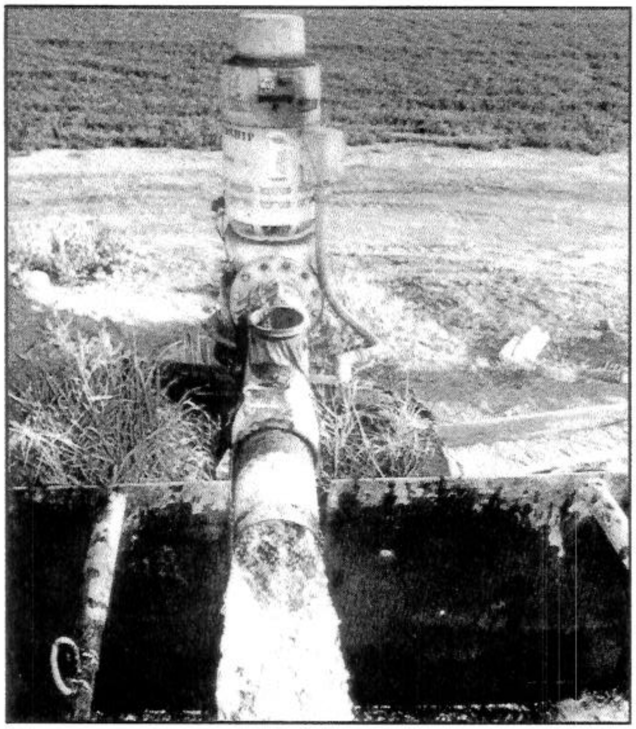


Figure 16. Cumulative Storage Change of Unconfined Ground Water in Kings County
(in thousands of acre–feet)

Figure 17. Change in Ground Water Levels in Butte, Colusa, Glenn, and Tehama Counties
(in feet)





Discharge of ground water from irrigation well. Ground water supplies an estimated 60 percent of the water used in California during droughts and 37 percent during normal years.

In coastal areas, where the total storage capacity of the ground water basins is small and basin supplies were seriously depleted, ground water levels rose rapidly because of the high rainfall in March 1991 and the wet 1992–93 winter.

Ground water levels in the adjudicated and managed basins in Southern California vary. In the Main San Gabriel Basin and the coastal plain of Orange County, water levels are about at the middle of their operating range.

The net amount of ground water extracted during the summer of 1992 will not be known until after 1993 water level measurements are collected and evaluated. The spring measurements of any year reflect the net effect of the ground water extracted and recharged during the previous spring and summer. For example, spring 1992 measurements reflect the spring 1991 recharge, the summer 1991 extraction, and the fall and winter 1991 recharge.

Subsidence

In parts of California, ground water extraction can result in land surface subsidence. Accurate prediction of subsidence normally is not possible, given the present level of knowledge about the properties of soils in subsidence areas. Subsidence usually begins when ground water levels decline below a certain level. Records from extensometers near the aqueduct in Fresno County indicate that the land surface there has subsided between .2 feet to more than 2.5 feet between 1987 and 1993. Also, subsidence of 2 feet has been recently noted in the Tulare Lake Region. Subsidence of up to 6 feet between Zamora and Knights Landing in the Sacramento Valley may have happened prior to the drought, although some of it may be drought-related.

Ground Water Quality

The drought-related increase in ground water extractions can adversely affect the ground water quality. Lower ground water levels can create gradients that cause lower quality water to flow more quickly toward water-producing wells. This is happening in at least three areas in the San Joaquin Valley near Fresno, Mendota, and a portion of Kern County, as well as in other areas of the State.

Sea Water Intrusion

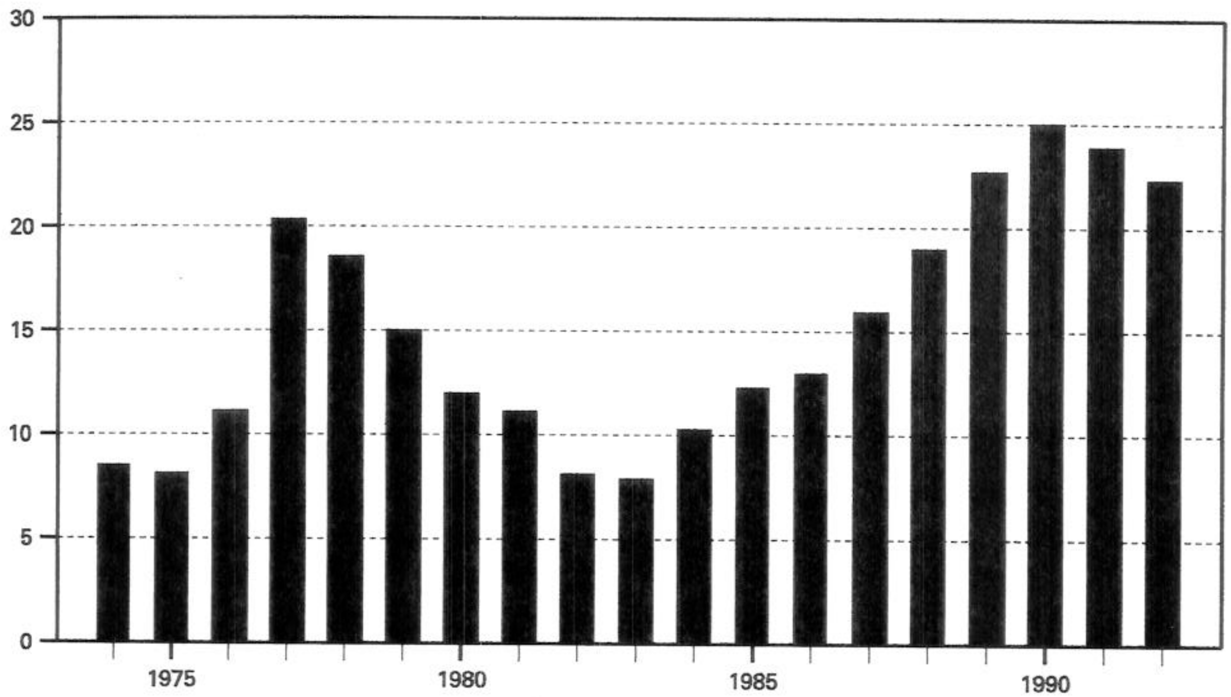
Along the coast, declining ground water levels can allow sea water to intrude into fresh water aquifers. Agencies in these areas are continuing efforts to protect the aquifers. Barrier projects in Los Angeles and Orange counties use recycled water to control sea water intrusion into their ground water aquifers. Recycled water is injected into the aquifer and flows down gradient in both directions—toward the ocean as well as inland. In the Salinas Valley, existing sea water intrusion problems accelerated as a result of increased ground water extraction during the drought. This prompted the Monterey County Water Resources Agency to formulate long-term plans to construct and operate a sea water intrusion barrier using recycled water. On the Oxnard Plain in Ventura County, a record decline in the ground water level in 1989 resulted in a six-month emergency ban on the construction of new wells.

Impact on Wells and Ground Water Use

As the drought continued and the demand for ground water increased, ground water users had two options: (1) deepen existing wells or (2) drill new wells. The number of new wells drilled during the drought peaked in 1990. Figure 18 shows the number of wells drilled annually between 1974 and 1992. More wells were drilled during 1990 than any other year since 1974. Slightly over one–third of the wells reported drilled in 1990 were monitoring wells while many others were either replacement or deepening of existing wells.

As water levels continued to decline, the amount of energy required to extract ground water increased, adding to the cost of water for both urban and agricultural use. Increased energy costs often forced farmers to change either to a higher value crops or let land lie fallow; urban users simply paid more for the water they used.

Figure 18. Number of Wells Drilled In California, 1974–1992
(in thousands– based on well driller reports)



State Emergency Water Bank

In February 1991, after four years of drought and three winter months of meager precipitation, the Governor formed the Drought Action Team and shortly thereafter directed DWR to establish a drought water bank to purchase water from wiling sellers and sell it to areas of critical need. The water bank in 1991 processed 350 purchase contracts from willing sellers and sold it to 12 agencies, representing both urban and agricultural entities. In addition, water was carried over to the SWP in the event that the drought continued into 1992. Tables 8 and 9 indicate the water source and amounts allocated from the 1991 water bank.

Table 8. 1991 Drought Water Bank Purchases

Purchases			
Water Source	**Acre–feet**	**Water Cost Components**	**Cost $/ Acre–foot**
Fallowing	414,743	Basic Purchase Price	125
Ground Water	258,590	Other Purchase Costs	45
Surface Water	147,332	Delta Requirements, Technical Corrections, Administration	5
Total	**820,655**	**Total**	**175***
Delta Water Quality Requirements, Technical Corrections	–165,137	*plus delivery costs	
Net Supplies	**658,528**		

Table 9. 1991 Drought Water Bank Summary of Final Allocations as of December 30, 1991
(in acre–feet)

Purchaser	Total Allocation	Purchaser	Total Allocation
Allocations to Agricultural Demands — 13 %			
Oak Flat Water District	975	Westlands Water District	13,820
Dudley Ridge	13,805	Kern County Water Agency	53,997
Total Agricultural Uses			**82,597**
Allocation to Urban Demands — 42%			
American Canyon Co. WD	370	City of San Francisco	50,000
Contra Costa Water District	6,717	Alameda County WD	14,800
Alameda Co. FCWCD	500	Santa Clara Valley WD	19,750
MWDSC	215,000	Crestline–Lake Arrowhead WA	236
Total Urban Uses			**307,373**
Allocations to State Water Project — 41%			
State Water Project Carryover Storage			265,558
Total Allocations for All Uses			**655,528**

The drought persisted into 1992 and a drought water bank commenced in March. Demands were substantially less than in 1991 due primarily to heavy rains occurring in February. Although reservoir storage was up to 64 percent of average, up from the 48 percent experienced in the previous year, the State was still in a drought. The 1992 water bank processed 19 purchase contracts and sold water to 16 agencies. Tables 10 and 11 indicate the water sources, costs, and amounts allocated from the 1992 water bank.

Table 10. 1992 Drought Water Bank Purchases

Purchases			
Water Source	**Acre–feet**	**Water Cost Components**	**Cost $/Acre–foot**
Fallowing	0	Basic Purchase Price	50
Ground Water	161,541	Other Purchase Costs	17
Surface Water	31,705	Delta Requirements, Technical Corrections, Administration	5
Total	**193,246**	**Total**	**72***
Delta Water Quality Requirements, Technical Corrections	34,478	*plus delivery costs	
Net Supplies	**158,768**		

Table 11. 1992 Drought Water Bank Summary of Final Allocations as of December 30, 1992
(in acre–feet)

Purchaser	Total Allocation	Purchaser	Total Allocation
Allocations to Agricultural Demands — 60 %			
Broadview Water District	255	Panoche Water District	2,000
Del Puerto Water District	300	Quinto Water District	100
Foothill Water District	900	Solado Water District	300
Hospital Water District	200	Sunflower Water District	400
Kern County Water Agency	8,170	Tulare lake Basin WSD	31,550
Orestimba Water District	75	Westlands Water District	51,000
Total Agricultural Uses			**95,250**
Allocation to Fish and Wildlife Demands — 15%			
Department of Fish and Game			24,513
Allocation to Urban Demands — 25%			
City & County of San Francisco			19,000
Contra Costa Water District			10,000
MWDSC			10,000
Total Urban Uses			**39,000**
Total Allocations for All Uses			**158,763**

Both the 1991 and 1992 water banks operated with a Water Purchase Committee, which was comprised of representatives from public water agencies who were the purchasers of bank water. This committee assisted in drafting the model purchasing and sales contracts and assisted DWR in establishing water bank policy and procedures. The Water Purchase Committee also determined the price to be paid for purchased water.

Having established that water banks can be a successful tool for managing drought conditions, DWR has carefully documented the operational methodologies, policies and procedures for use in future drought conditions. It has also prepared a program EIR for future drought water banks. The EIR addresses the analysis of potential future operations, using (1) ground water substitution or conjunctive use, whereby a portion of a water district's or farmer's surface water supply would be acquired and replaced by pumping an equivalent amount of local ground water; (2) purchase of surface water stored in local reservoirs; and (3) fallowing or withholding irrigation of designated farmland. Strategies to minimize environmental and economic third party effects are also discussed.

In any water transfer, a major determinant is the amount of water, "real water," actually available for transfer. In short, real water is that which is not derived at the expense of any other lawful water user. Examples of real water include (1) the water savings resulting from not irrigating a crop that would otherwise have been irrigated or (2) stored water that would not otherwise be released.

Based upon the 1991 and 1992 water bank experiences, there is the potential to provide at least 700,000 acre-feet of real water supplies during drought periods through a water banking program.

Operations of Major Water Systems in California

While no area within California escaped the impacts of the 1987–1992 drought, some areas were impacted earlier and more severely than others. Each water agency was forced to assess its particular water supply/demand situation and implement actions necessary to provide a balance. These actions ranged from merely pumping more ground water to implementing severe mandatory rationing, which in some cases approached a 50 percent reduction in overall water use.

In Santa Barbara, landscape watering was banned and inside use severely curtailed. In the small town of Morro Bay, a desalter was installed to reclaim well water that had become too saline for human consumption. In Mendocino County, water was trucked into some areas as well water supplies were depleted. In the San Francisco Bay Area, successful rationing programs in the 25 percent range were implemented, and citizens responded with even larger water savings than required.

In Southern California, The Metropolitan Water District of Southern California, by agreement with the U.S. Department of the Interior, was able to significantly exceed its Colorado River entitlement and maintain a full Colorado River Aqueduct during much of the drought. These supplies, coupled with mandatory rationing programs, allowed Southern California to weather the drought with somewhat fewer impacts than areas that didn't have as many water supply alternatives.

Each of the water agencies throughout the State implemented the strategy that best balanced water supply and demand for its customers. Actions taken included water conservation, voluntary and mandatory rationing, tiered pricing, and water transfers and purchases.

Additional information regarding actions by local and regional water agencies can be obtained by contacting the individual agency or agencies serving a specific area. The following information pertains to actions taken by State and federal water projects.

State Water Project

During the 1987–92 drought, the SWP would see its reservoirs go from record highs to record lows. SWP reservoir storage figures are shown in Figure 19 and SWP water deliveries are shown in Table 12. The SWP began water year 1987 with reservoir storage at 4.3 MAF. The Project delivered 2.6 MAF, which was 100 percent of requests. SWP reservoir storage at the end of the water year was 3.22 MAF, about 600,000 acre–feet below average.

The cumulative runoff to Lake Oroville was 2.0 MAF, about 50 percent of average, during 1988. Lake Oroville storage peaked at 2.77 MAF on March 13, then dropped to 1.48 MAF by November 9 and total SWP storage dropped from 3.22 MAF to 2.64 MAF. In 1988 the SWP delivered full water requests to 26 Project contractors, about 2.9 MAF, as well as transported non-Project water to 17 other agencies. Also during 1988, Project fish hatcheries produced 7 million fish and about 1.7 million were planted at Project facilities.

Since Sacramento River Basin precipitation was 101 percent of average in water year 1989, storage in SWP reservoirs increased by 0.43 MAF, for a total of 3.07 MAF. In early 1989, the SWP approved delivery of 2.51 MAF. Heavy precipitation in March improved the supply, allowing delivery of requested amounts of 2.85 MAF. The Oroville and Thermalito hatcheries produced 12.3 million fish, of which 1.2 million were planted at SWP facilities.

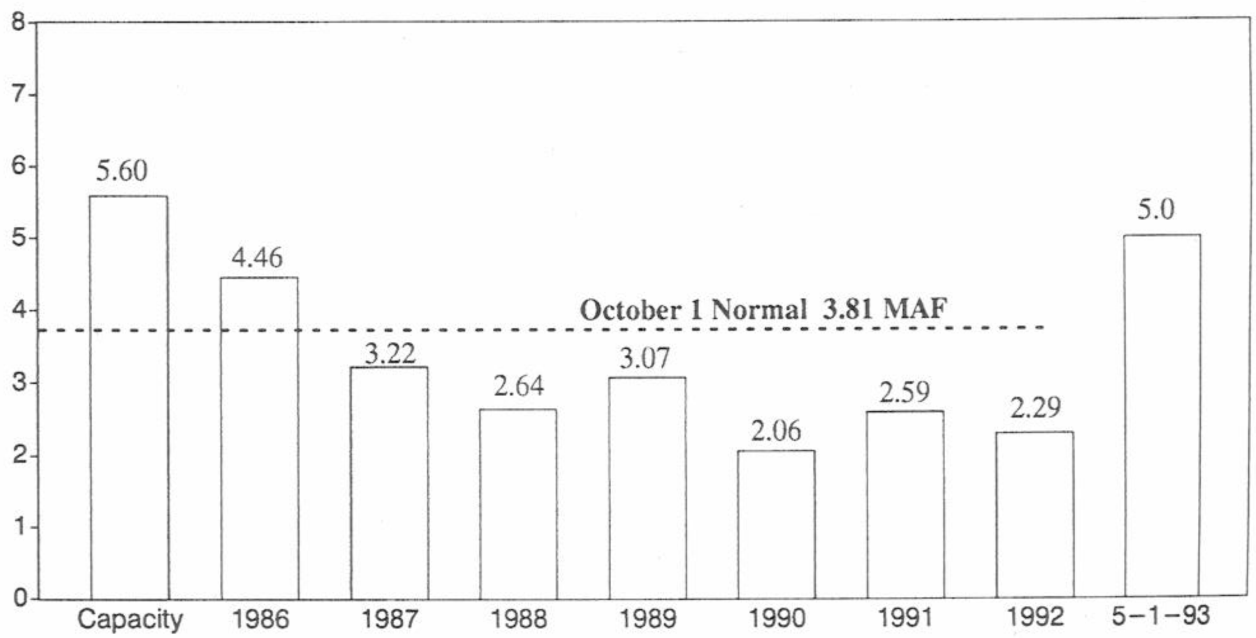
Table 12. SWP Water Deliveries, 1987–1992

	Percent of Entitlements Delivered					
	1987	1988	1989	1990	1991	1992
State Water Project Contractors						
Urban	100	100	100	100	30	45
Agriculture	100	100	100	50	0	45
Agricultural Water Rights	100	100	100	100	50	50

During water year 1990, Oroville Reservoir storage peaked in March at 2.1 MAF and declined to 990,000 acre–feet in December. Storage in SWP reservoirs dropped to 2.06 MAF, the lowest end–of–water–year level during the drought. Under SWP contracts terms, deliveries to agriculture were reduced to 50 percent of requests. Urban deliveries were not reduced.

Sacramento River Basin precipitation in water year 1991 was 23 percent of average through February and despite a 300 percent of normal "Miracle March," the Sacramento River Basin Index runoff for the year ended up at a low 8.4 MAF, or 46 percent of average, and another critically dry year. The SWP delivered only 30 percent of requested water to urban users, and no SWP deliveries were made to

Figure 19. State Water Project Reservoir Storage
Water Years
September 30, 1986–92 and May 1, 1993
(in millions of acre–feet)



agriculture. Storage in SWP reservoirs did rebound during the water year to 2.59 MAF.

Between 1987 and 1992, DWR used a Water Delivery Risk Analysis procedure as a guide in determining the amount of SWP deliveries approved each calendar year. This procedure was developed through extensive hydrologic probability analysis and discussions with SWP water contractors. As the procedure evolved, the criteria for carryover storage for the earlier years of an extended drought were lowered, thus permitting greater deliveries during the more frequent shorter droughts and larger deliveries overall. However, as the number of consecutive drought years increased, it became increasingly difficult to estimate delivery capability. A fundamental problem is the location of storage reserves. Once reserves south of the Delta are depleted, it is extremely difficult to refill those reserves during extended dry conditions. This is partly because Delta diversion capability has been constrained to meet environmental needs.

In late 1991, DWR changed the water delivery approval procedure for the 1992 calendar year from what previously had been used. Delivery approvals for 1992 were determined considering:

1. Increasing requests from long–term SWP contractors for water.

2. Very low water levels in SWP conservation reservoirs.

3. Concern that the drought in California would continue for a sixth straight year. DWR wanted to avoid the situation where deliveries would be approved but, because of continuing drought conditions, it would be necessary to reduce the approved amounts later in the year, causing water and financial hardships to SWP contractors.

4. The possibility that the SWP would be left without reserves.

5. The necessity of meeting environmental and Delta water quality requirements.

6. The understanding that deliveries would be increased as water supply conditions improved.

In December 1991, DWR approved delivery of 20 percent of contract requests for both the agricultural and the municipal and industrial contractors. The initial approved amount was based on projections of what could be delivered during 1992, primarily using water stored south of the Delta. As the year progressed and the water supply picture improved, the approved delivery amount increased to 45 percent of requested deliveries, a total of 1.64 MAF.

January and the first part of February 1992 were dry. The Delta Cross Channel was closed on February 3 to keep the downstream migrating winter run Chinook salmon in the Sacramento River rather than allowing them to drift into the central Delta. Suisun Marsh Salinity Control Gate operation was also restricted to keep salmon from being pulled into the marsh. Runoff from storms in mid–February increased Delta flows, and the SWP and CVP were able to increase Delta diversions to capacity.

At the beginning of April 1992 concern that SWP and CVP exports were causing high losses of winter run Chinook salmon resulted in exports by both projects being curtailed to a combined total of 1,200 cfs until May 1. On May 1, the Cross Channel gates were opened and the 1,200 cfs export limit was removed. Exports, however, remained low throughout the summer because of (1) low outflows and (2) decisions to operate upstream reservoirs to control temperatures on the Sacramento River to improve the winter run Chinook salmon spawning conditions.

The SWP assisted in the temperature control operation by loaning the CVP water through provisions of the Coordinated Operation Agreement. Oroville Reservoir released approximately 100,000 AF during the summer which Shasta Reservoir normally would have made. This loan was repaid during August and September. Storage in SWP reservoirs increased during the water year to the 2.29 MAF level.

Water year 1993 has been a welcome change. The March Sacramento Valley River runoff forecast was 110 percent of average for the year. The San Joaquin River forecast was 140 percent, and the Tulare Lake forecast was 135 percent.

On May 1, the Sacramento River Index was 21.9 MAF, which classified 1993 as a wet year. Given the improved water supply outlook, DWR increased the approved amount of requested water deliveries from 70 percent to 100 percent.

Delta Drought Facilities

During the drought, temporary facilities were built to save water and improve water quality and circulation. These facilities made the most of Delta inflow by alternating existing flow patterns and diversion points to make Delta fresh water barriers more efficient.

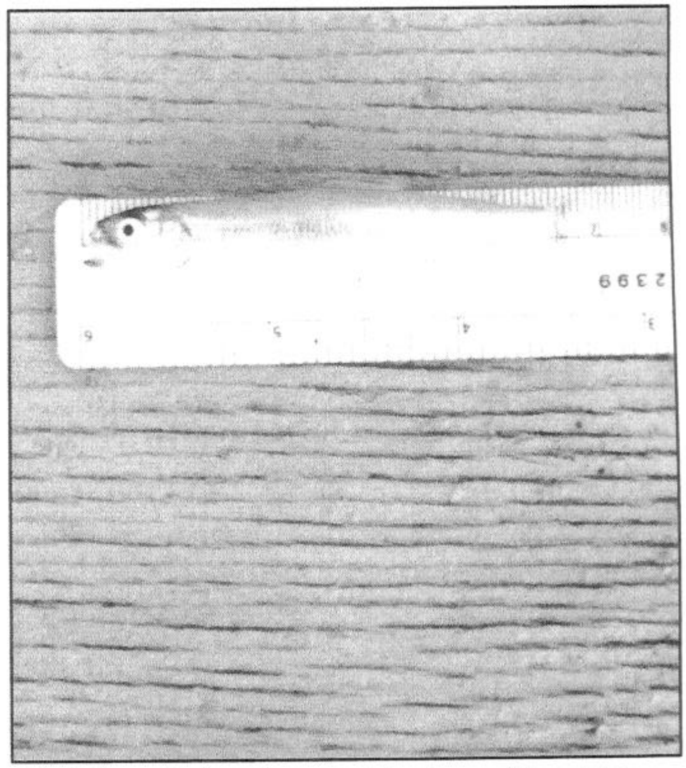
Most of the temporary facilities were rock barriers in the South Delta. These barriers were monitored and evaluated after installation to determine their effectiveness in improving conditions in the South Delta.

During 1992, DWR installed the following test barriers in the Delta:

- The barrier at Old River near Tracy was installed in early May and removed by October 9, 1992. It was installed to help improve conditions for local irrigation.
- The barrier at Middle River near Victoria Canal was installed by April 10 and removed by September 29, 1992. It also was installed to help improve local irrigation conditions.
- The barrier at Old River near the San Joaquin River was installed and removed twice: between May 1 and June 8, and September 11 and December 4, 1992. This barrier was installed to improve salmon migration.

To build these barriers, DWR obtained permits from the U.S. Coast Guard, DFG, the Army Corps of Engineers (with the approval of the National Marine Fisheries Service), the U.S. Fish and Wildlife Service, and the Environmental Protection Agency.

As part of the permits to build these barriers, DWR agreed to monitor fisheries, water quality, and vegetation; these monitoring programs were designed to help determine project impacts.



The Delta smelt, shown here actual size, is one of the species which are limiting factors in Delta exports. Photo provided by Dale Sweetnam, State Department of Fish and Game.

Central Valley Project

The CVP also saw its reservoir storage decline during the drought, and CVP contractors experienced water supply cutbacks sooner than did their SWP counterparts. In water years 1987 and 1988, CVP water deliveries were not reduced. Figure 20 shows CVP storage during the drought.

In February 1989, when the water supply forecasts were indicating a high probability of another critical year, the USBR adopted a strategy for assessing water delivery capability with a reduced water supply. The main elements of this strategy were:

1. Determine CVP water available for delivery by using a forecasted supply that has a 90 percent chance of being exceeded.
2. Establish an objective for the end of water year 1989 system carryover storage for a subsequent critical year.

The desired CVP system carryover storage in a normal water year is 8 MAF.

An initial carryover objective of 3.6 MAF was adopted, allowing the CVP to operate in water year 1990 under conditions similar to water year 1977. In 1977 carryover storage was defined as the level needed to protect project capabilities for one year during a repeat of the historical worst-case conditions.

On March 1, 1989 the CVP announced water allocations at 75 percent for water rights, 50 percent for agriculture and 50 to 75 percent for municipal and industrial. During March 1989, the entire Central Valley experienced extremely wet weather and conditions changed dramatically. Full CVP water deliveries were restored, with the exception of interim and temporary contracts. Forecasts for CVP reservoir storage increased from 4.6 MAF to 5.1 MAF by the end of water year 1989.

In February 1990, the USBR announced that 1990 water deliveries would be 75 percent for water rights, 50 percent for agricultural contractors, and 50 to 75 percent for municipal and industrial contractors. Subsequently, weather conditions were so dry that even the 90 percent exceedence runoff forecasts were reduced during March, April, and May.

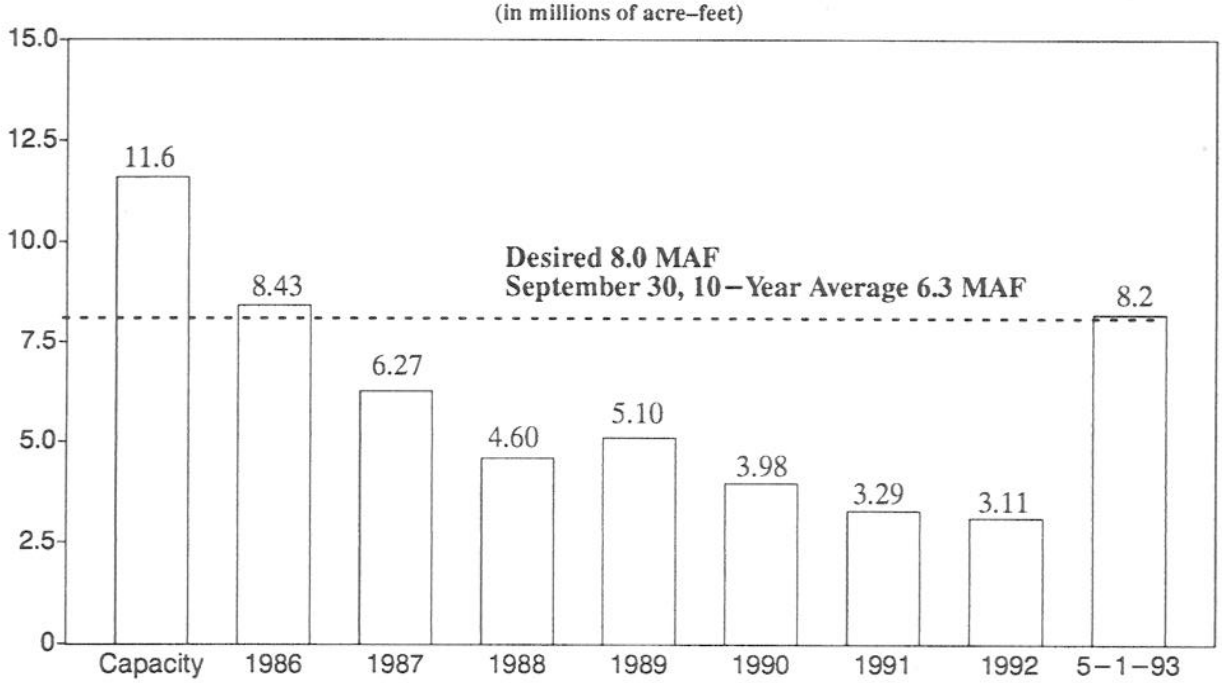
The extraordinary and unseasonal storms of late May 1990 provided a major boost to CVP capabilities. Water rights contractors were restored to 100 percent deliveries, based on the Shasta inflow criteria. Other contractors' supplies were not increased across the board, but additional water was retained in storage and some additional deliveries were made under hardship criteria. Carryover storage at the end of water year 1990 was 4.0 MAF, down from the previous year's 5.1 MAF, but still a major recovery from conditions forecast as late as May.

Water year 1991, until March, was drier than water year 1977. The 90 percent exceedence forecasts based on February conditions indicated that the CVP could only support deliveries at water year 1977 levels (75 percent to water rights contractors, 25 percent to agricultural

Figure 20. Central Valley Project Reservoir Storage (Six Major Reservoirs) At End Of Water Year

September 30, 1986–92 and May 1, 1993

(in millions of acre-feet)



contractors, and 25 to 50 percent to municipal and industrial contractors), and then only by drawing storage down to 600,000 acre–feet. By March, forecasted conditions were unimproved. Then, during "Miracle March," several consecutive storms greatly improved the water supply forecast. Despite the wet March, water year 1991 was still the driest year of the six–year drought. Water deliveries were not generally increased, although hardship deliveries were approved. Carryover storage at year end was 3.3 MAF, down about 700,000 acre–feet from the previous year.

Drought-related impacts from six consecutive years of subnormal runoff hit the U.S. Bureau of Reclamation Mid–Pacific Region hard in 1992. In February 1992, the CVP announced water delivery curtailments for its contractors because of low precipitation and depleted reservoir storage. The announced curtailments were: no supply to agricultural contractors; 50 to 75 percent supply for Sacramento River water rights holders and San Joaquin River exchange contractors; and 25 to 50 percent supply to urban contractors, depending on their contracts. However, a series of large storms later in February significantly increased CVP reservoir storage, allowing adjustments in most CVP water allocations. Specific 1992 allocations were:

- Agricultural contractors, 25 percent supply
- Urban contractors, 75 percent of historical use
- Wildlife refuges, over 75 percent of historical supply
- Sacramento River water rights holders, 75 percent supply
- San Joaquin exchange contractors, 75 percent supply

The Friant Division was able to allocate 83 percent of Class I, but no Class II, water in 1992.

CVP deliveries for the six–year drought are shown in Table 13.

The CVP end of year carryover storage for 1992, excluding Friant Division storage, was 3.1 MAF, far short of the desired 8.0 MAF. With this low carryover storage, another dry year would have produced more dramatic negative impacts than those experienced over the last six years.

During 1992, the USBR took a number of other actions to lessen the impacts of the drought. These included:

- ***Hardship Supplies***: Eight urban contractors and 23 agricultural contractors requested hardship water for a total of 67,431 acre–feet. The USBR approved 65,563 acre–feet.
- ***Conveyance of Non–Project Water***: Twenty contracts for ground water conveyance through CVP facilities were signed. Approximately 96,500 acre–feet of non–CVP water was conveyed by project facilities through September 1992.
- ***Reclamation States Emergency Drought Relief Act of 1991***: The USBR entered into five temporary contracts pursuant to the Reclamation States Emergency Drought Relief Act of 1991. These contracts provided additional water to wildlife refuges free of charge, provided for the water transfer to other entities, relaxed water quality requirements in original contracts, and relaxed the monthly maximum quantities.
- ***California State Drought Water Bank***: Twelve temporary contracts for conveyance of non–CVP water from the California State Drought Water Bank through CVP facilities were completed for a total of 85,430 acre–feet.

Table 13. Central Valley Project Water Deliveries[1]
Water Year 1987–92
(in thousands of acre–feet)

CVP Deliveries	1987	1988	1989	1990 [2]	1991[3]	1992 [4]
Water Rights:						
Sacramento River	1,549	1,407	1,379	1,349	1,155	1,165
Delta–Mendota Canal Exchange Contractors	853	853	834	781	705	626
All Others	172	138	148	136	132	134
Total Water Rights	*2,574*	*2,398*	*2,361*	*2,266*	*1,992*	*1,925*
Project Agricultural:						
Sacramento River	230	650	440	442	332	327
Delta–Mendota Canal / San Luis Canal	1,948	1,930	1,767	1,334	626	419
Friant Division:						
Class I	820	713	756	536	699	673
Class II	0	0	0	0	0	0
All Others	506	518	525	352	175	164
Total Agricultural	*3,504*	*3,811*	*3,488*	*2,664*	*1,832*	*1,583*
Project Municipal & Industrial:						
American River	68	79	77	72	72	76
San Felipe Division	21	75	112	71	53	69
Contra Costa WD	142	126	123	125	91	100
Friant Division	56	44	53	41	58	45
All Others	41	41	37	35	33	39
Total Municipal & Industrial	*328*	*365*	*402*	*344*	*307*	*329*
Waterfowl Conservation	130	179	238	205	110	165
Grand Total	**6,536**	**6,453**	**6,489**	**5,479**	**4,241**	**4,002**

1 *All contractors received their requested amounts except in years noted in Table 7.*

2 *1990 – Agricultural contractors received 50 percent of requested deliveries plus some hardship water. Urban water contractors received 50 to 75 percent of requested deliveries dependent on individual contracts.*

3 *1991 – Agricultural contractors received 25 percent of requested deliveries. Urban contractors received 50 percent of requested deliveries plus some hardship water.*

4 *1992 – Agricultural contractors received 25 percent of requested deliveries plus hardship water. Urban contractors received 75 percent of historical use.*

- ***Conveyance of California State Drought Water Bank Water Transfers in CVP Facilities***: The USBR facilitated the transfer of 30,250 acre–feet to the 1992 State Drought Water Bank subject to ground water exchange contracts with five Sacramento River water right settlement contractors. Under each transfer, ground water was substituted for surface water, making the surface water available for transfer to the water bank. These transfers involved non–CVP water under each contractor's respective Sacramento River water right settlement contract with the USBR. Two additional agreements for water transfers to the State Drought Water Bank were executed: Placer County Water Agency for 10,000 acre–feet, and Oakdale and

South San Joaquin Irrigation District for 50,000 acre–feet.

- ***Water Right Transfers***: Three contracts provided for transfers of 3,878 acre–feet and included a transfer from Byron Bethany Water District and Natomas MWC to Westlands Water District, and an individual transfer to Bella Vista Water District.

- ***Federal Refuges***: The USBR provided 183,844 acre–feet to federal, State, and private wetlands. This is approximately 84 percent of the normal 223,000 acre–foot supply. The target had been 75 percent; however, the USBR and the Sacramento River Water Contractors agreed to purchase approximately 52,525 acre–feet to meet refuge water needs. Some 17,525 acre–feet of the purchased water supplies were allocated for the Sacramento Refuge Complex; 5,000 acre–feet for the Riceland Storage Wetland Pilot Program; 3,000 acre–feet for the Sutter National Wildlife Refuge; and 20,000 acre–feet for the Grassland Water District. The balance of the purchase was required for conveyance and Delta carriage losses.

- ***Trinity River Hatchery Chillers***: The USBR is adding water chillers and modifying the hatchery intake to ensure that sufficient cold water will be available to protect anadromous Trinity River fish.

- ***Keswick Dam Fish Trap***: The USBR is rehabilitating and modernizing the obsolete fish trap facilities at Keswick Dam to more effectively collect migrating anadromous fish in the Sacramento River.

- ***Winter Run Captive Broodstock Program***: The USBR is participating in a program to rear winter run Chinook salmon under controlled conditions until they become reproductively mature adults. Mature adults would then be used as hatchery broodstock for continued propagation of the race.

- ***Lewiston Temperature Curtain***: Temperature control curtains were installed in Lewiston Lake to help cool water shunted to Whiskeytown Lake and to better regulate the environment inside the Trinity Fish Hatchery.

Folsom Lake in January 1974, when water was near flood control level.

Folsom Lake in November 1992 with storage at 16 percent of capacity.