US Army Corps
of Engineers

EXECUTIVE SUMMARY OF LESSONS LEARNED FROM THE CALIFORNIA DROUGHT (1987-1992)

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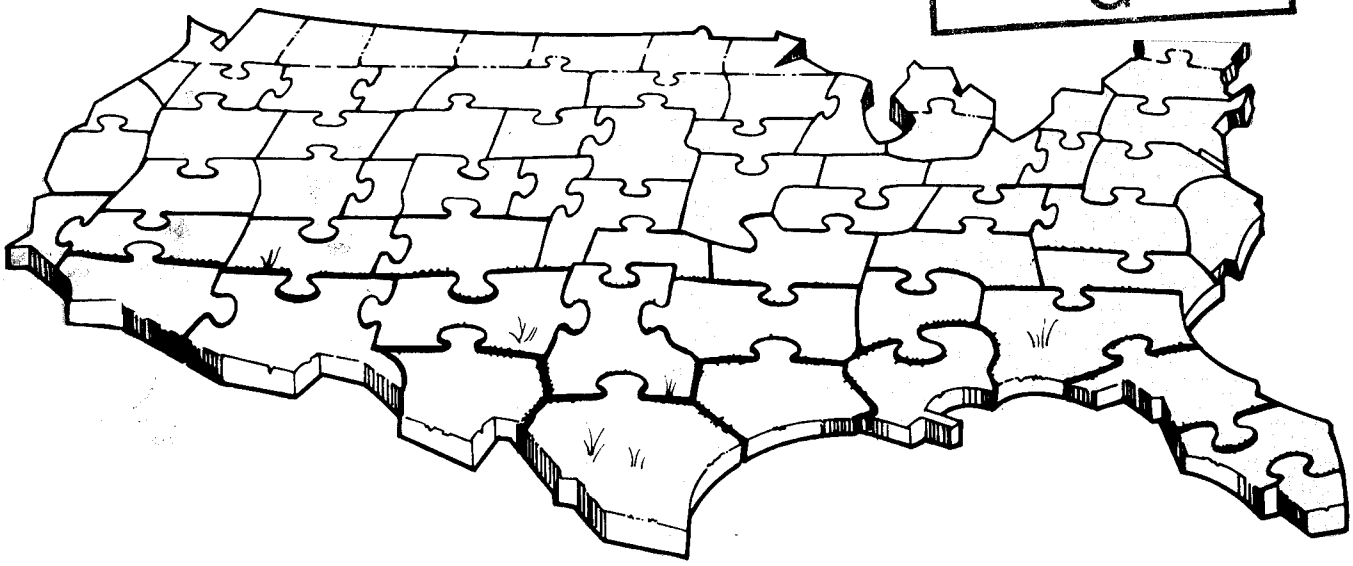

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NATIONAL STUDY OF WATER MANAGEMENT DURING DROUGHT

OCTOBER 1994

IWR REPORT 94-NDS-6

National Study of Water Management During Drought Reports

This report is the one in a series of reports under the aegis of the National Study of Water Management During Drought. The others are:

The National Study of Water Management During Drought: Report on the First Year of Study (IWR Report 91-NDS-1) prepared by the Institute for Water Resources, U.S. Army Corps of Engineers, Fort Belvoir, Virginia.

A Preliminary Assessment of Corps of Engineers Reservoirs, Their Purposes and Susceptibility to Drought (IWR Report 91-NDS-2) prepared by the Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California.

An Assessment of What is Known About Drought (IWR Report 91-NDS-3) prepared by Planning Management Consultants, Ltd., Carbondale, Illinois.

The National Drought Atlas (IWR Report 94-NDS-4) prepared by the Institute for Water Resources, U.S. Corps of Engineers, Alexandria, Virginia.

Lessons Learned from the California Drought (IWR Report 93-NDS-5) prepared by Planning and Management Consultants, Ltd., Carbondale, Illinois (The report on which this executive summary is based).

Computer Models for Water Resources Planning and Management (IWR Report 94-NDS-7) prepared by Ralph Wurbs for the Institute for Water Resources, U.S. Army Corps of Engineers, Alexandria, Virginia.

Managing Water for Drought (IWR Report 94-NDS-8) explains how to apply the "DPS Method", the planning method developed, tested and refined during the National Drought Study. NDS-8 also includes 14 annexes on topics germane to drought studies such as economics, environmental evaluation, alternative dispute resolution, hydrology, water use forecasting, and water law.

A full listing of National Drought Study reports can be found on page 36. For further information on the National Drought Study, contact either:

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LESSONS LEARNED FROM THE

CALIFORNIA DROUGHT (1987-1992)

EXECUTIVE SUMMARY

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Equivalent Volumes

1 acre foot (af) =	43,560	Cubic feet
	1,234	Cubic meters
	325,829	Gallons

Equivalent Flow Rates

1 Million Acre feet per year (MAF) =	1381.3	CFS
	39.1	CMS
	892.7	MGD
1 Cubic foot per second (CFS) =	724	Af/yr
	0.028	CMS
	0.65	MGD
1 Cubic Meter per Second (CMS) =	25,547	Af/yr
	35.3	CFS
	22.8	MGD
1 Million Gallons per Day (MGD) =	1,121	Af/yr
	1.547	CFS
	0.0438	CMS

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PREFACE

The National Study of Water Management During Drought (National Drought Study) was conducted by the U.S. Army Corps of Engineers and managed by the Corps' Institute for Water Resources (IWR). However, its perspectives and conclusions reflect the thinking of a much larger group of people in other Federal agencies, nonfederal governments, universities, and environmental and public interest groups. Several organizations outside the Corps devoted significant amounts of staff time to the study.

The Corps began the National Drought Study in 1989 during the middle of the California drought. As part of the study, they organized a critical review of the experiences from the drought that captured the views of some 100 key members of the California water community, representing 57 organizations. The participating organizations included federal, state, regional, and local water supply agencies as well as environmental, private, and governmental entities that control and influence water management in the state. The results of that study were presented in IWR Report 93-NDS-5 entitled "Lessons Learned from the California Drought."

This is an executive summary of that California study. The complete report includes more background information and documentation, as well as the opinions of the participants. This summary focuses on the findings of the study, and adds some additional findings on the subject from other Drought Study investigations which were still underway when the unabridged report went to print.

The study team identified nine lessons "learned" from this drought and confirmed the validity of four lessons learned during previous California droughts. These lessons are listed in Tables 1 and 2 and are explained beginning on page 22.

The 1987-1992 drought was neither the longest nor most intense drought in 20th century California, but it held the attention of the media and politicians. A shorter, more intense drought in 1976-1977 led to improvements in the operation of California's water management system and gave warning that further, more sophisticated adjustments would be needed. But the length of this drought, and the fact that public views on priorities for allocating scarce water have changed, created support for drought response measures that required significant changes in state and Federal laws and administrative procedures.

Complex sociopolitical systems, which reflect a multitude of competing and conflicting needs, are not particularly well suited for strategic planning and even less so for crisis management. Yet despite these well understood and accepted deficiencies in our democratic decision making process, the overall conclusion is that California not only weathered the drought in a reasonably organized manner, but also introduced a series of useful water management reforms and innovations that will influence future water uses in a positive manner.

Many of the lessons learned are valuable, but intangible in nature, and can be

assigned to the rubric of wisdom and experience - i.e. mistakes that should not be repeated. Others reaffirmed conventional wisdom associated with decisions and practices from previous droughts. Most important are the many tangible, practical, long-lasting changes that were made in the legal and administrative structures of California's water management institutions as well as those of the Federal government.

In addition to explicit lessons and changes that were initiated was the overarching realization that California's vast water storage and distribution network (Figure 1 shows the major components of California's water supply infrastructure, as well as other features mentioned in the report) made many of the long-term structural and institutional changes possible. Water must be conserved and used wisely, and many reforms addressed that important issue. But water banking, storage for instream flow maintenance, conjunctive use of groundwater and surface water, regional interconnections, and economies of scale require a water storage, allocation, and distribution system. The existing system provided California with the flexibility and resiliency to withstand severe droughts, even in the face of a rapidly growing populace and increasing urban and environmental demands on a fixed supply of water.

As this report goes to print in the Fall of 1994, California may be entering another drought. After a wet 1993 in which the drought was declared over, the end of the 1994 water year finds surface water storage levels near 80% of normal for the time of year, and the Sacramento River Index lower than anytime during the 6 year drought.

ACKNOWLEDGEMENTS

This report was conducted under the oversight and benefitted from the extensive reviews and comments of Eugene Stakhiv, Chief, IWR Policy and Special Studies Division. Some of the material used in this summary came from a paper prepared for IWR by: Benedykt Dziegielewski, Hari P. Garbharran, John F. Langowski, Jr., and Eddie Tabora of Planning and Management Consultants, Ltd. Robert Cantave (IWR) provided computer and graphics support.

There are many people who contributed much time and effort to the full report "Lessons Learned During the California Drought, (1987-1992)," and they are acknowledged in that report. For this executive summary, Ray Hoagland and Carl Hauge (California Department of Water Resources - CDWR), Lyle Hoag (California Urban Water Agencies), and Bill Templin, and Wayne Solley (US Geological Survey), clarified many of the issues unresolved when the original document was printed. Jim Hoffsis (California Energy Commission), and Tom Welch (U.S. Energy Information Administration) provided California hydropower and energy information.

Special thanks go to the following people who supplied urban water use information: Marsi Steirer, Loius Generoso (City of San Diego Water Utilities Department), Peggy Williams (Los Angeles Department of Water and Power), Pak Mizuno, Erika Aschmann, Dick Bennett (East Bay Municipal Utility District), Mickey Heo and Kim Knox (San Francisco Water Department), and Ed Craddock (CDWR). Special thanks also go to Doug Priest (CDWR) for his comments during all phases of the study.

Figure 1. California Site Map

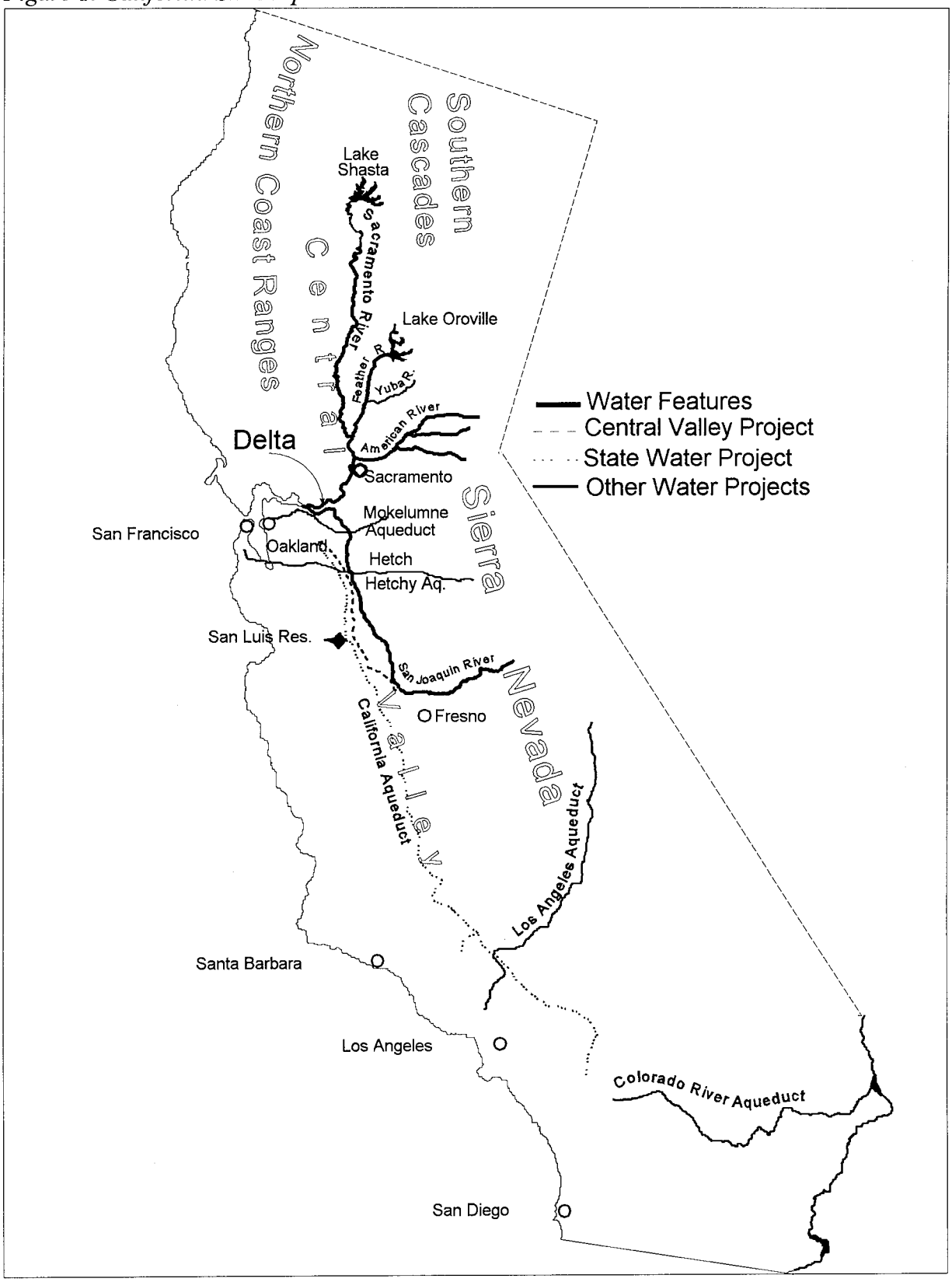


Table 1. *Lessons from the 1987-1992 Drought*

- The complexity of impacts of a sustained drought demands equally sophisticated planning.
- Severe drought can accelerate changes in longstanding relationships and balances of power in the competition for water.
- Irrigation can provide complementary environmental benefits.
- Drought can convince communities to accept water management options that are not seriously considered during normal years.
- The success of drought response plans should be measured in terms of the minimization and equitable redistribution of the impacts (as opposed to simply alleviating shortages), but there is much to be learned about the best ways of accomplishing this goal.
- Severe droughts can expose inadequacies in the existing roles and performance of state and Federal water institutions, stimulating significant institutional and legal changes.
- Increases in water rates should precede or accompany rationing plans.
- Mass media can play a positive role in drought response, but water managers should be involved in designing the message.
- Market forces are an effective way of reallocating limited water supplies.

Table 2. *Lessons from Previous Droughts Confirmed in the 1987-1992 Drought*

- Groundwater use continues to be the most effective single response against drought.
- The surest way to mitigate the adverse social, environmental, and economic impacts of a sustained drought is to ensure that more water is made available in the future through a variety of management measures.
- Early drought response actions and proper timing of tactical measures are essential in the short-term management of droughts.
- Local and regional interconnections among water supply systems are effective and flexible options against severe water shortages.

INTRODUCTION

The 1987-1992 drought in California held public, media, and political attention for years. One of the few benefits of coping with a drought is that the experiences teach the water community lessons that could never be learned in the abstract. The full value of these experiences can be realized only if the lessons are carefully recorded, analyzed and communicated to others.

Study Method

The approach used to identify the important lessons of the 1987-1992 drought consisted of three activities:

- Literature review of published and unpublished documents
- Field interviews
- Critical review of the draft findings by survey participants and other water professionals.

Table 3 lists all organizations that participated in the individual interviews or group interview sessions and classifies them according to hierarchy and their controlling/influencing role. Several other organizations were approached but could not or did not participate for various reasons. An earlier unabridged report presents the complete results of the study (IWR 93-NDS-5). That report also contains relevant background information and data on California's economy, water resources, and existing water management systems, as well as a chronology of major drought events and significant drought response actions during each year of the drought. This report presents a summary of that earlier study as well as additional information not available when the unabridged report went to print.

Definition of Lessons Learned

The new knowledge brought forth by the drought represents the important lessons learned. In general, such incremental knowledge is identified by (1) contrasting "expectations" and "what actually happened," (2) analyzing the basis for decision making during the various stages of the drought, and (3) examining the overall performance of the California water management system. Performance includes the actual delivery of water where needed and the institutional capacity to make the necessary decisions and compromises for allocating scarce water during the drought.

Table 1 lists lessons learned from the 1987-1992 drought, while Table 2 presents the lessons from previous droughts that were confirmed in the 1987-1992 drought. A brief description of each lesson is provided starting on page 22. We encourage the reader to examine the evidence and opinions presented in the complete report in order to form their own conclusions and identify other relevant lessons for water management during drought.

Background - Trends in California Water Management

California withdrew close to 35,100 million gallons per day (MGD) of

Table 3. Organizations Participating in This Study

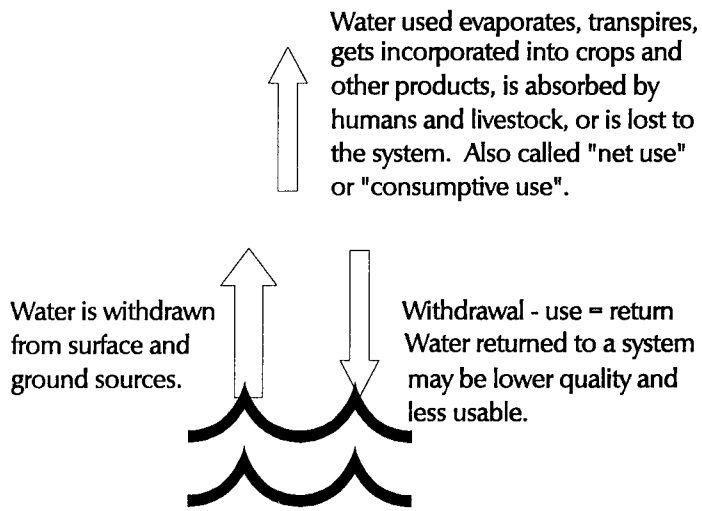
Controllers	Influencers
I. Federal and Nationwide	
U.S. Bureau of Reclamation	U.S. Fish and Wildlife Service
U.S. Army Corps of Engineers	Environmental Defense Fund
	Sierra Club
	Soil Conservation Service
II. State or Statewide	
California Department of Water Resources (CDWR)	California Department of Parks and Recreation
CDWR State Water Project	California Department of Fish and Game
CDWR Drought Center	California Farm Bureau
California Resources Agency	
State Water Resources Control Board	
III. Regional and Wholesalers	
San Francisco Water Department	State Water Project Contractors
Metropolitan Water District of Southern California	Committee for Water Policy Consensus
Westlands Water District	Central Valley Project Water Users Association
Kern County Water Agency	California Urban Water Agencies
Glenn-Colusa Irrigation District	
Santa Barbara County Water Agency	
IV. Community and Retailers	
Southern California Water Company	Sacramento Bee
East Bay Municipal Utility District	Mono Lake Committee
Los Angeles Department of Water and Power	
City of Santa Barbara	
City of Goleta	
V. Commercial and Industrial	
Pacific Gas and Electric	California Landscape Contractors Association
	California Energy Commission
	Green Industry Council

freshwater, more than any other state (Solley et al. 1993). In 1990, California accounted for 10.5% of the country's freshwater withdrawals, slightly less than its share of the U.S. population, (11.8%). These withdrawals, atypically low due to the drought, equaled 1,179 gallons per capita per day (gpcd). The average freshwater withdrawal per capita for the nation was 1,341 gpcd (Solley et al. 1993). In 1985, prior to the recent drought, California's freshwater withdrawals were slightly greater than the national average, 1,419 compared to 1,395 gpcd (Solley et al. 1993). The appendix to this report contains a more detailed account of water use in the state.

While statistics on per capita freshwater withdrawals do not distinguish California from other states, statistics on consumptive (net) water use in California are noteworthy. Consumptive water use refers to the portion of water withdrawals that are evaporated, transpired, incorporated into products and crops, consumed by humans and livestock, or generally lost from the surface and groundwater system (Figure 2). In 1990, California consumed 20,900 mgd, or 22 percent of total consumptive use in the nation (Solley et al. 1993). Most of California's consumptive use can be attributed to agricultural activities. In 1990 agriculture accounted for 78% of all freshwater withdrawals, but over 93% of the total consumptive use in the state (Solley et al. 1993).

California's water supply infrastructure transfers massive

Figure 2. Consumptive Use Diagram



quantities of water, primarily from the Sierra Nevada, Southern Cascades, and northern California coast ranges to the drier interior valleys and coastal areas (Figure 3). A major portion of the state is served by two primary suppliers that operate an extensive system of storage reservoirs and aqueducts: the State Water Project (SWP) and the Federal Central Valley Project (CVP). Their combined distribution system reaches 75 percent of the state's population (CDWR 1987). Both projects export water from the Sacramento-San Joaquin Delta, which has become the focal point of many water related issues. Currently, SWP facilities consist of 22 reservoirs including two jointly built and operated with the CVP. Total storage of the 20 SWP reservoirs is 5.28 million-acre-feet (MAF), with an additional 1.03 MAF of SWP storage in the jointly managed San Luis reservoir.

The CVP includes 20 reservoirs with a combined storage capacity of 13.6 MAF. Five reservoirs represent 92

percent of the total storage (approximately 12.5 MAF). The CVP delivers about seven MAF of water annually to approximately 300 mostly agricultural contractors. In addition to the SWP and CVP, there are four large regional municipal aqueducts: the Colorado River, Hetch Hetchy, Mokelumne River, and Los Angeles aqueducts, which delivered a combined 2.2 MAF in 1990, and many other regional irrigation projects (CDWR 1993). The geography and magnitude of intrastate water transfers is shown in Figure 3.

Groundwater provides about 40% of the urban and agricultural water supply in California in an average year. The statewide total amount of groundwater stored in 450 identified groundwater basins is estimated to be 850 MAF, which is about 100 times greater than net annual groundwater use. However, saline intrusion, land subsidence, and high extraction costs for deep groundwater limit the usable groundwater storage to less than half of the actual storage.

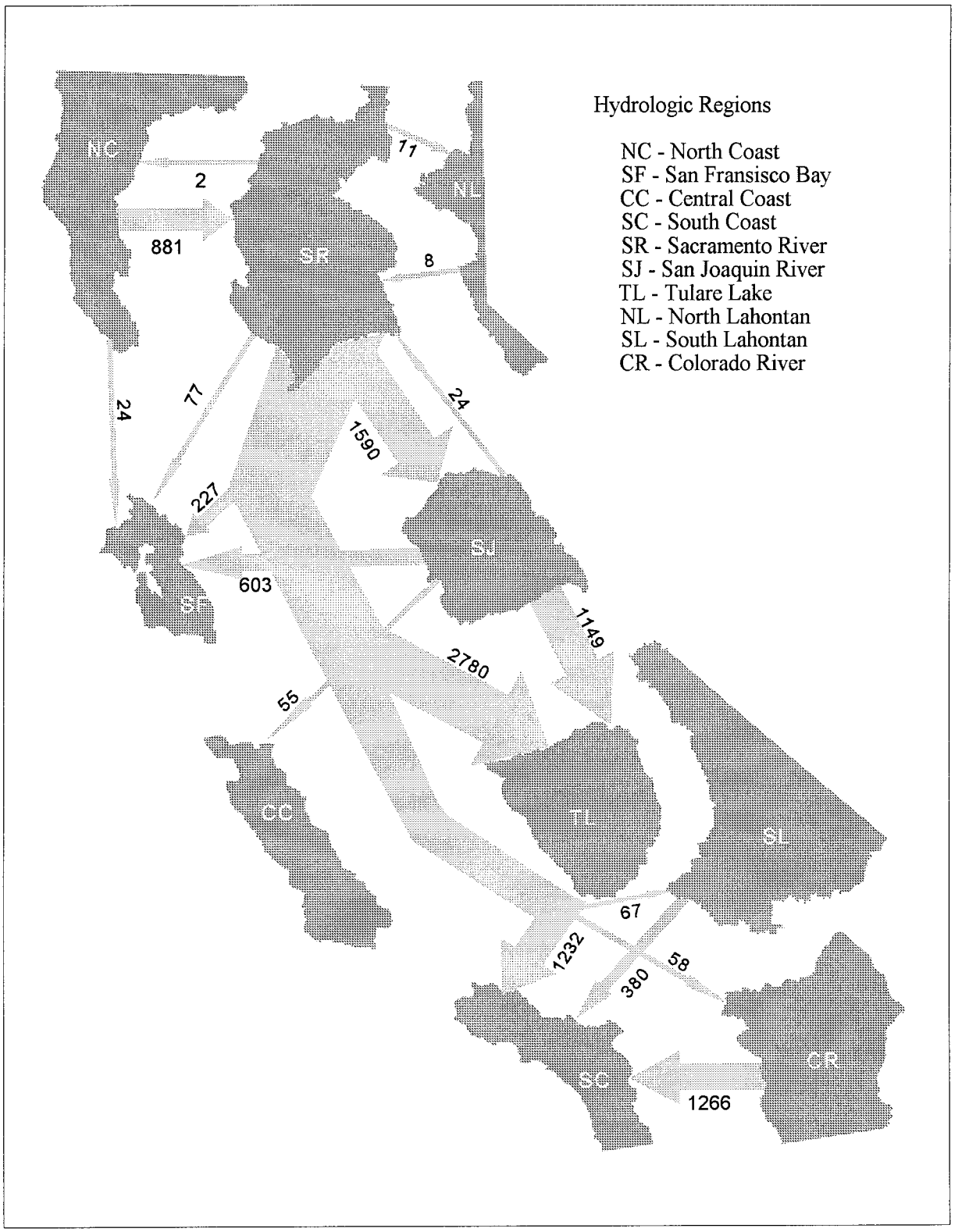
During a year of average precipitation and runoff, an estimated 14 MAF of groundwater is extracted for agricultural, municipal, and industrial use. Of that 14 MAF, approximately 5.5 MAF is returned to the groundwater system from irrigation and conveyance losses, resulting in a consumptive groundwater use of 8.5 MAF (CDWR 1993). Since natural and artificial recharge amounts to approximately 7.5 MAF in an average year, consumptive use exceeds the total recharged by 1 MAF. The 1 MAF overdraft represents an improvement over the historical annual average overdraft of 2 MAF per year (CDWR 1993). Groundwater withdrawals vary from region to region within California, ranging from 20 percent to 90 percent of the total regional fresh water withdrawals.

Until 1992, groundwater management had been primarily a local responsibility. Local agencies and districts have been established by the State Legislature and court decisions including: 13 adjudicated basins (twelve in Southern California); 8 groundwater management agencies authorized by the State Legislature; and 3 water districts with special state authority to tax withdrawals. Many other flood control and water conservation districts, water storage districts, water replenishment districts, and irrigation districts either manage surface water or are involved in minor groundwater management. California Water Code Section 10750 (1992) provides an alternative between no management and adjudication. It includes a plan outline with 12 management components that has served a guideline for local, state and federal officials. Most importantly, it leaves control of groundwater at the local level (McClurg 1993).

Agricultural Water Withdrawals

California's $18.3 billion dollar agricultural sector (California Department of Food and Agriculture, 1992) withdraws much more water than other sectors, although in recent years irrigation withdrawals have declined in absolute and percentage terms. In 1980, agriculture accounted for 80.1 percent of total water withdrawals in the state. By 1985, that total had declined to 78.8 percent (shown in Figure 4). Declines in groundwater withdrawals for the

Figure 3. Existing Intrastate Water Transfers at 1990 Level of Development (1000's of Acre-Feet per Year) (Source: CDWR 1993)



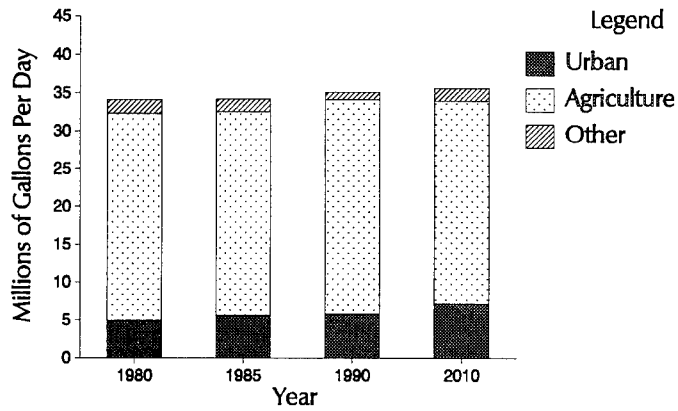
agricultural sector since 1980 are due to the increasing efficiency of irrigation techniques. Agricultural water withdrawals are projected to decrease to 75 percent of the state total by the year 2010 (Figure 4) (CDWR 1993). Although agricultural water withdrawals accounted for 80.7 percent of total state withdrawals in 1990 (Solley et al. 1993), more than in 1985, this is because water withdrawals in other sectors of California were lower during the early and middle years of the drought.

Several factors contribute to high agricultural water withdrawals. As stated earlier, approximately 17 percent of all irrigated land in the United States is located in California, and the size of the livestock industry almost equals that of Texas. The state also has a large food processing industry. These factors and the semi-arid climate of the major agricultural areas contribute to a high withdrawal and consumption of irrigation water.

Urban Water Withdrawals

Eighty-six percent of the California population is served by public water systems. Publicly supplied urban water withdrawals (for domestic, commercial and industrial use) grew from 5,310 to 5,830 mgd between 1985 and 1990, an increase of about 9 percent (Solley et al. 1988, 1993). During that time, the population served by public supplies grew 5 percent. California's projected population growth is expected to result in further increases in urban water withdrawals between 1990 and 2010 (Figure 4). This increase will take place largely in the state's coastal regions, where 80 percent of

Figure 4. Trends in California Water Withdrawals (1990 data from Solley et al. 1993; 1980, 1985, 2010 data from CDWR 1993)



California's current population is concentrated. The percentage of the state's total water withdrawals attributed to urban areas is also expected to increase during this period (CDWR 1993).

SEVERITY OF THE 1987-1992 DROUGHT

The 1987-1992 drought was not of unprecedented or extreme severity. While the rarity of this 6 year drought has not been estimated, no five year precipitation total (i.e., 1987-1991 or 1988-1992) in any of California's ten hydrological regions was rarer than a once in fifty year drought, according to the National Drought Atlas (Institute for Water Resources Report 93-NDS-4). California can expect worse droughts in the future.

Drought in California is measured using several physical indices including precipitation, runoff, the Sacramento River Index, and surface-water storage. According to these measures, the 1987-1992 drought was severe, but not the most severe drought on record. The

hydrologic severity of the 1987-1992 drought can be assessed by comparing it to the two other important droughts of this century, the 1929-1934 and 1976-1977 droughts, using these indices.

Precipitation

The 1987-1992 drought was characterized by below-average precipitation (approximately 77 percent of normal for the six year period), varying from a low of 61 percent in 1987 to a high of 86 percent of normal in 1992 (Figure 5). In comparison, precipitation during the 1976-1977 California drought was 65 percent of normal in 1976, 45 percent in 1977, and 55 percent for the two year period (CDWR 1991).

California experienced at least one month of above-normal precipitation in each water year during the drought. For example, what has been referred to as the "Miracle March" of 1991 and a wet February in 1992 helped improve water conditions over the short term. However, these precipitation "bursts" were not adequate, in most parts of the state, to overcome water shortages that had accumulated during the previous months of the drought.

Runoff

Annual water year runoff in all of California was less than 50 percent of average in each year of the drought, except in 1989 when it was 72% (CDWR 1991). In comparison, runoff during the record low year (1977) was close to 20% of the long term average (Figure 6).

Figure 5. Precipitation: 1987-1992

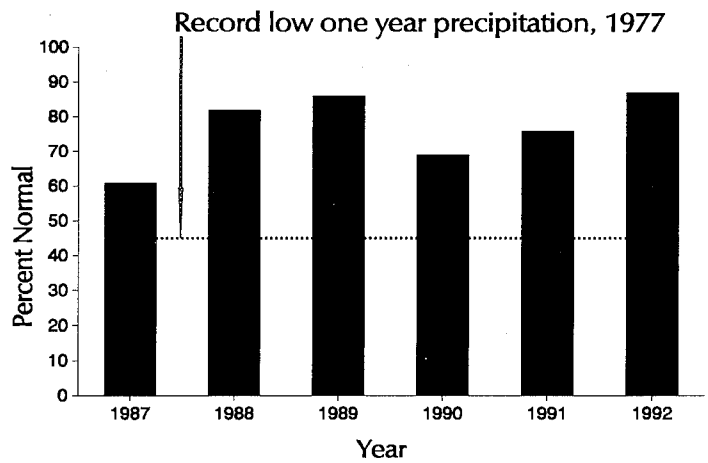


Figure 6. Water Year Runoff: 1987-1992

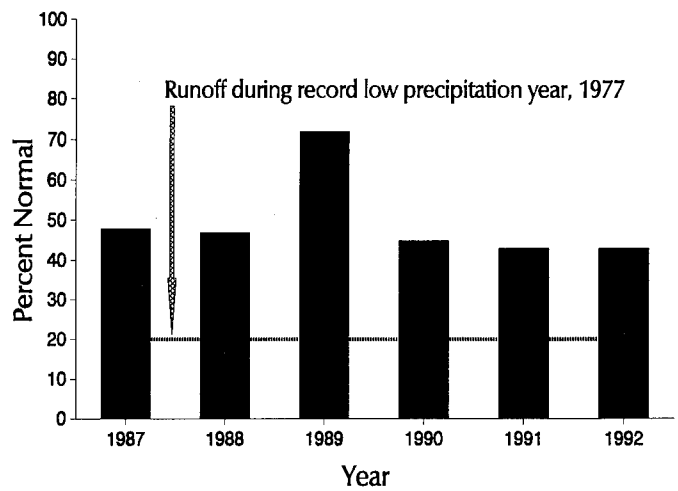
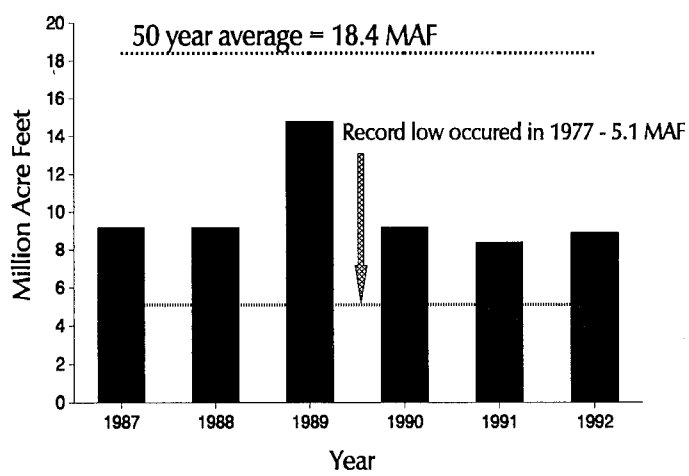


Figure 7. Sacramento River Index: 1987-1992



The Sacramento River Index

The Sacramento River Index (SRI) is the standard index used to measure the water supply conditions in the four major rivers in the Sacramento Valley. The SRI is important because runoff from these rivers (the Sacramento, Feather, Yuba and American) are captured by several of the major reservoirs in the state including Lakes Oroville and Shasta. For five of the six years of 1987-1992 drought, the SRI did not rise above 9.2 million MAF (Figure 7), which is 50 percent of the 50-year average (1941-1990) of 18.4 MAF. These five years (1987, 1988, 1990, 1991, and 1992) were classified as critically dry and the sixth year (1989) as dry. However, by this measure, the 1929-1934 drought was almost identically severe (Figure 8), and the 1976-1977 drought was even more intense, with yearly SRIs of 8.1 and 5.1 MAF (CDWR 1991). Although all four major rivers were largely unregulated through the 1929-1934 drought, the index has been adjusted to account for the effect of storage.

Surface-Water Storage

California's extensive reservoir facilities provide water supplies for a variety of uses, including recreation and winter flood protection. Presently, 155 major reservoirs in the state provide a total storage capacity of almost 38 MAF. Actual storage in those reservoirs averaged about 60 percent during the last three years of the drought (Figure 9). For comparison, reservoir levels fell to 35 percent in 1977 (CDWR 1991).

Figure 8. Two Six Year California Droughts of the 20th Century: Comparison of Cumulative Sacramento River Index over six years.

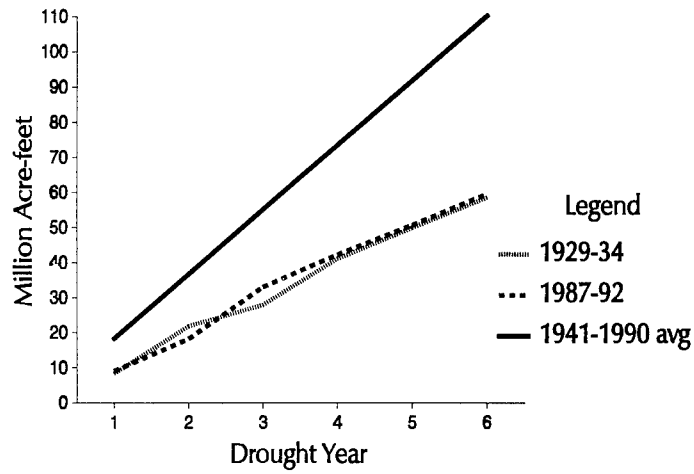
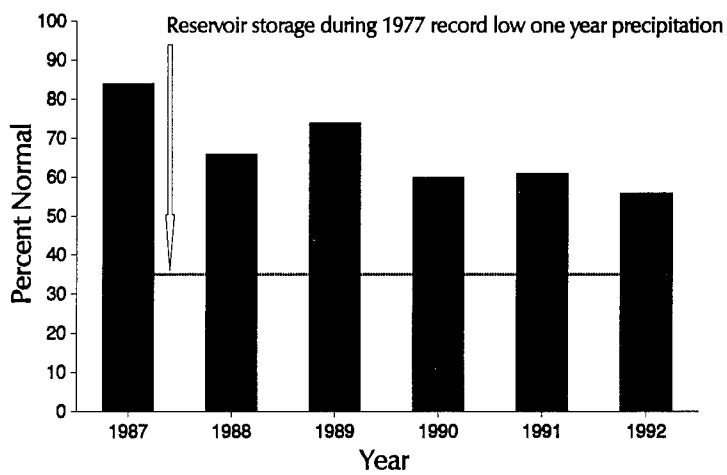


Figure 9. Reservoir Storage: 1987-1992



DROUGHT RESPONSES

There is no sequence of predetermined actions for all circumstances that would constitute an official drought contingency plan. However, the absence of a formal statewide plan does not mean California was unprepared. Federal, state and local water institutions share the responsibility of coping with the impacts of a drought.

Major water providers reduce water deliveries during dry and critically dry years. Local and regional supply agencies also plan for water shortages.

Water Allocation and Deliveries

Holders of water entitlements from the SWP and CVP did not suffer significant reductions in deliveries until 1990. However in 1990, low reservoir levels prompted the first major cutbacks in CVP and SWP deliveries (Figure 10). Drought conditions intensified in 1991, necessitating further reductions in water deliveries. Allocation of those cutbacks (Figure 11) is described below. The SWP provided 7.4 percent and the CVP provided 21.7 of California's supplies during the first three years of the drought.

State Water Project Deliveries

State Water Project deliveries can be categorized as entitlement water (municipal, industrial, and agricultural) and other deliveries (surplus and unscheduled water, Feather River diversions, and other). Deliveries to meet municipal and industrial requests for entitlement waters were not drastically cutback during the first four years of the drought. As the drought worsened in 1990 (the fourth year), SWP reduced agricultural deliveries to 50 percent of 1987 levels. In 1991 only one percent of the requested agricultural entitlements were delivered (CDWR 1991).

Meanwhile, municipal deliveries were cut to 85 percent of 1987 levels in 1990, and reduced to 30 percent in 1991. Total SWP

Figure 10. Deliveries, SWP and CVP, 1987-1992

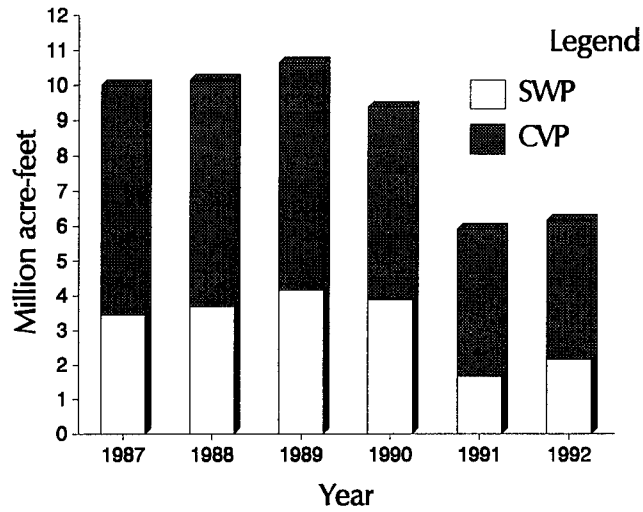
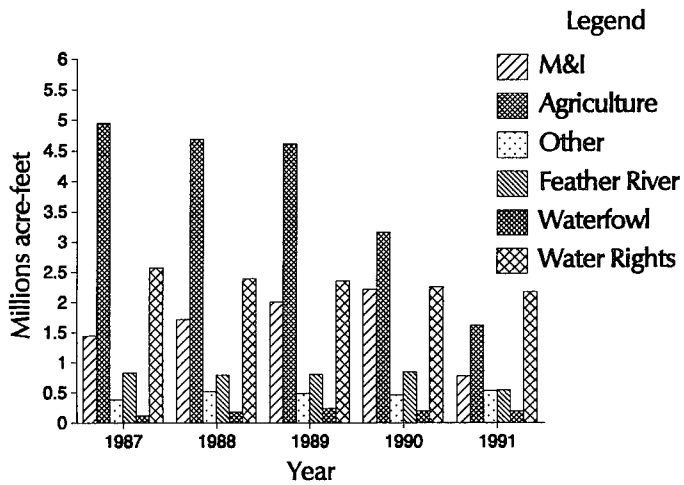


Figure 11. Sectoral Deliveries (SWP and CVP Combined) 1987-1991



deliveries (entitlement and other deliveries) in 1991 were 47 percent of the 1987 deliveries. In 1992, municipal entitlements were cut even further. It should be noted that water deliveries from the Colorado River Aqueduct to the Metropolitan Water District of Southern California (MWD), which supplies much of urban Southern California, remained high during the span of the drought. The SWP resumed normal

operations in April 1993, when the Governor declared the drought over.

Central Valley Project Deliveries

Central Valley Project water deliveries are divided into four categories: water rights, agricultural, municipal and industrial, and waterfowl conservation. The drought did not significantly affect deliveries to water rights holders because they are guaranteed at least 75 percent of their entitlement requests during drought. However, agricultural project water was cut by 36 percent in 1990 and 58 percent in 1991 compared to 1987 deliveries.

Municipal and industrial customers received increased deliveries between 1988 and 1990. However, in 1991, deliveries were reduced to 30 percent of 1987 levels. Conservation deliveries during the drought were increased in 1987 in order to reduce drought impacts on waterfowl populations.

The CVP stopped cutbacks in March 1993 to all but its agricultural users south of the Delta. These agricultural users were not given their full entitlement due to pumping restrictions required to fulfill the objectives of the Endangered Species Act.

Groundwater Withdrawals

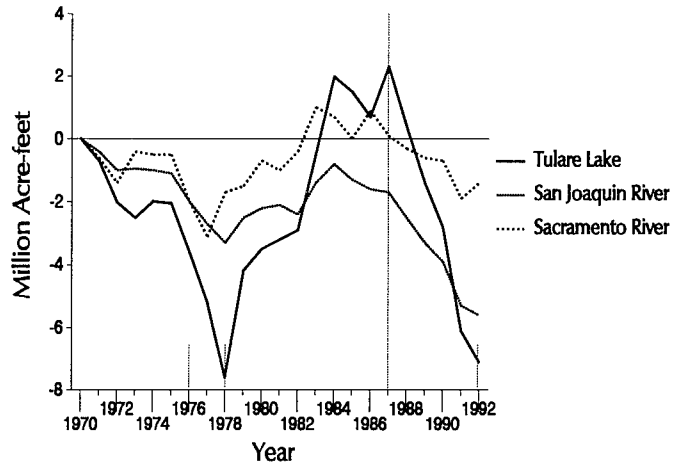
California's groundwater basins were a reliable alternative source of water during the 1987-1992 drought, similar to their role during previous droughts. Groundwater storage declined during the drought as withdrawals increased and natural recharge declined. The change in groundwater storage for three different regions of the Central Valley is shown in Figure 12. These regions are the largest agricultural producers in California, and represent 65% of the average net groundwater withdrawals in the state (CDWR 1993). Annual net groundwater use is groundwater extraction minus the applied water that percolates and recharges the groundwater basins.

During the drought, the Tulare Lake and the San Joaquin River regions in the southern part of the Central Valley experienced rapid declines in groundwater storage (CDWR 1993). Net groundwater withdrawals averaged an estimated 4.55 MAF per year from the Tulare Basin Aquifer during 1990-1991. This more than doubled the region's estimated 1.73 MAF long term average. Similarly, net withdrawals from the San Joaquin Basin Aquifer increased from a pre-drought average of 1.28 to an average of 2.34 MAF per year during 1990-1991 (CDWR 1993). Sacramento River Basin groundwater storage did not decline as drastically; net water withdrawals increased only 15% from a pre-drought average of 2.51 to an average of 2.88 MAF during 1990-91. Groundwater levels dropped because of rapid increases in withdrawals and lower than normal recharge from reduced precipitation. Although Figure 12 shows that groundwater storage recovered rapidly after the 1976-1977 drought, the quick recovery resulted from above average precipitation in several of the following six years. It is unclear how long it will take these groundwater basins to recover fully from the recent drought.

Coastal areas, where groundwater basin storage capacities are relatively small, also experienced declines in storage during the drought. Storage levels in these basins recovered as result of above average rainfall, mainly in Southern California, between March 1991 and December 1992 (CDWR 1993).

The analysis presented above is based on the best available information, but the collection of groundwater extraction data has begun only recently. Actual withdrawal amounts are still not precise. For that reason, it is not clear to what extent groundwater replaced surface water withdrawals in 1990 and 1991. The CDWR is taking steps to improve its ability to monitor groundwater dynamics. Further, California Assembly Bill 3030 passed in 1992 should improve the understanding of groundwater resources. The legislation allows any existing water agency to develop a groundwater management plan (McClurg 1993).

Figure 12. Cumulative Change in Groundwater Storage From 1970-1992 (CDWR 1993)



Urban Water Conservation

During the first two years (1987-1988) of the drought, demand management efforts consisted of both voluntary and mandatory conservation programs with target reductions ranging from 10 to 25 percent. Educational campaigns were also in place during the first two years.

Although 1989 (year 3) was marked by more rainfall than in 1988, the drought did not end, so public agencies were forced to continue drought emergency conservation programs. By mid-1990, water conservation was firmly embedded throughout much of the state.

In 1990, some local governments in Southern California intensified their conservation efforts and prepared for additional water shortages. A survey of local governments in Southern California conducted by the Los Angeles Times newspaper (April 1990), indicated that there were voluntary conservation programs in 45 communities, whereas conservation was mandated in only 17 communities.

As the drought progressed into the fifth year (1991), the "Miracle March" rains and the success of the Water Bank (see page 13) helped most communities cope with water shortages. As a result, some communities relaxed their conservation goals from 45 percent reduction levels to less than 25 percent. Other communities in Southern California, for example those served by Metropolitan Water District (MWD), continued to pursue conservation programs. A survey

conducted in May 1991 showed that water use reduction goals among the 11 members of the California Urban Water Agencies (CUWA) varied from a low of 10 percent for the Los Angeles Department of Water and Power, to a high of 31 percent for MWD (CUWA 1991).

One important development at the end of the fifth year (September 1991) was the signing of the Best Management Practices (BMPs) statewide agreement monitored by the California Urban Water Council. Conservation programs pursued by water agencies in 1992, the sixth year of the drought, included some of the 16 BMPs advocated in the Memorandum of Understanding agreement. Components of this program included educational publications, technical workshops, business conferences, training courses, water use surveys, water management studies, and a telephone hotline.

Responses to the conservation efforts and use restrictions are best illustrated by looking at the results of three utilities; the East Bay Municipal Utility District (East Bay MUD), the Los Angeles Department of Water and Power (Los Angeles DWP), and the City of San Diego Water Utilities Department (San Diego WUD).

East Bay MUD is the major supplier to Oakland and surrounding areas, serving a population of 1.2 million. In the summer of 1987 it implemented a voluntary 10% reduction, and set a target reduction of 25% for the summer of 1988 (East Bay MUD 1994). Also in 1988, East Bay MUD established

Figure 13. East Bay MUD Water Deliveries 1982-1991 (EBMUD, 1994).

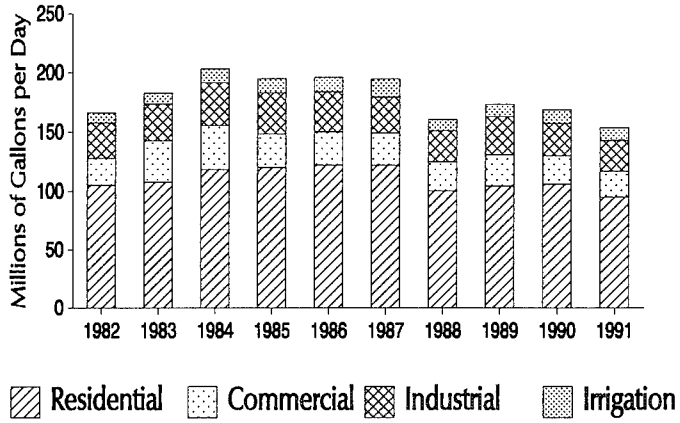


Figure 14. Water Deliveries and Population Growth for the City of Los Angeles (LADWP, 1994).

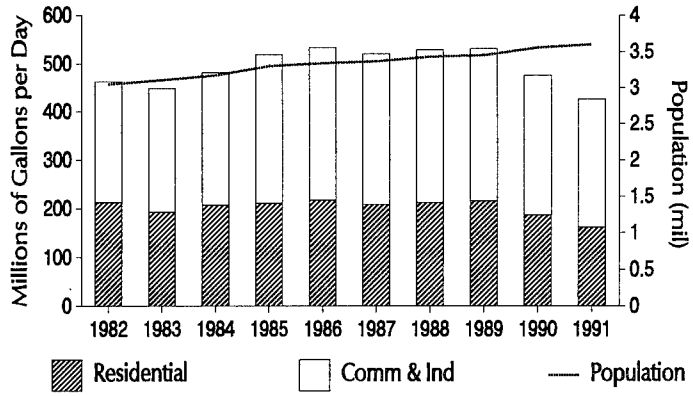
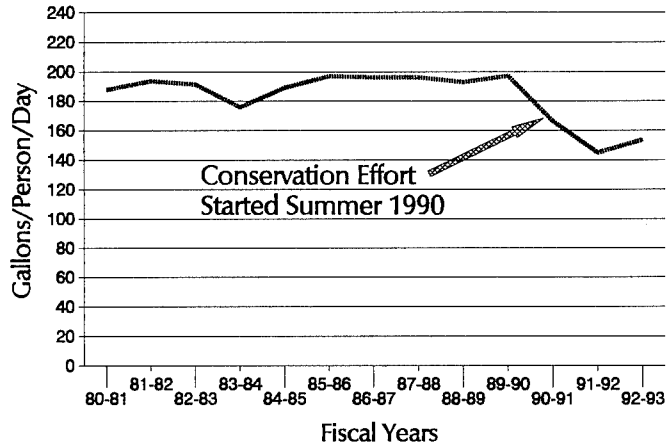


Figure 15. San Diego Per Capita Deliveries, Water Year ending June 30 (City of San Diego, 1992).



public information campaigns, increasing block rate structures, and invoked local ordinances restricting water use. Although these efforts did not enable East Bay MUD to meet its 25% reduction goal in 1988, it achieved overall reductions of 21.6% (Figure 13). Demand reductions exceeded the 15% targets set between 1989 and 1992 and by 1991, all sectors in the East Bay MUD service area showed savings of at least 20% (East Bay MUD 1994).

The Los Angeles DWP, which was spared cutbacks in the early years of the drought, initiated a sequence of emergency drought measures which included voluntary 10% reductions in May 1990, mandatory 10% reductions in March 1991, and mandatory 15% reductions in May 1991 (Los Angeles DWP 1994). These efforts resulted in substantial water savings, as indicated by a drop in gross water deliveries in 1990 and 1991, despite population growth (Figure 14). Per capita deliveries declined from 154 gpcd in 1989 gpcd to 118 gpcd in 1991 (Los Angeles DWP 1994).

The San Diego WUD also generated positive results from conservation programs initiated in 1990 (Figure 15). The campaigns began in the summer of 1990, and by September 1991 the city had reduced actual deliveries to 72% of projected use. By 1992, per-capita deliveries declined from a pre-drought high of 197 to 145 gallons per day (City of San Diego WUD 1992).

These case studies highlight the success of urban conservation measures implemented during the drought for reducing total and per capita water demand and saving significant quantities of water. Much of the success of the urban conservation measures can be attributed to the success of conservation efforts during the 1976-1977 drought. In the first six months of 1977, East Bay MUD achieved savings of 36 percent, while the Los Angeles DWP, and San Diego WUD achieved reductions of 13 and 7 percent, respectively (Table 4). The City of Los Angeles responded to the 1976-77 drought by quickly passing the Emergency Water Conservation Plan (Ordinance No. 149,700) in May, 1977. This ordinance guided the City's water conservation efforts during the recent drought.

While the state's major urban centers were able to reduce total and per capita water deliveries by 1990, state-wide urban water use was greater in 1990 (the fourth year of the drought) than 1985, a pre-drought year (Solley et al. 1988, 1993). Although major urban water districts such as Los Angeles, San Diego, San Francisco, and EBMUD delivered less water in 1990 than 1985, other urban areas continued to increase total deliveries through at least 1990 (CDWR 1994). In some cases, such as Los Angeles and San Diego, districts increased total deliveries up to 1989 and showed their first big reduction in 1990 (CDWR 1994).

The State Drought Emergency Water Bank

The fifth year of drought, 1991, brought increasing water shortages (following the first significant SWP

and CVP cutbacks in the fourth year of drought), and on February 1, 1991, the Governor signed Executive Order No. W-3-91. The executive order:

- Established a State Drought Emergency Water Bank to meet critical water needs.
- Encouraged the adoption of community rationing plans with up to 50 percent cutbacks in water use.
- Directed the California Department of Fish and Game to work closely with the U.S. Fish and Wildlife Service to protect natural habitat.
- Established a $100 million Drought Action Fund to assist with conservation, water supply augmentation, and other drought mitigation activities.

A Drought Action Team also was established to represent the Governor and provide local and state assistance in carrying out the order.

The establishment of the Emergency Water Bank was a major innovation. It created a voluntary market for the transfer of water on an economic basis. However, the Emergency Water Bank would have been impossible without the CVP-SWP conveyance facilities, and the ability to transfer and redistribute water supplies throughout much of the state.

The Water Bank was implemented in less than 100 days from the signing of the order. Water purchase agreements were activated in early April (1991) and by June more than 300 contracts were developed. A statewide total of approximately 820,000 acre-feet was purchased (at $125 per acre-foot) via 351 contracts awarded through December 1991 by the Water Bank (CDWR 1992a). The sources were: fallowing, groundwater and surface water (Figure 16). Water from fallowing represents irrigation water conserved by taking agricultural acreage out of production. Groundwater refers to savings attained by replacing stored irrigation water with local groundwater sources. Surface water was purchased from agencies with surplus supplies, such as the Yuba County Water Agency.

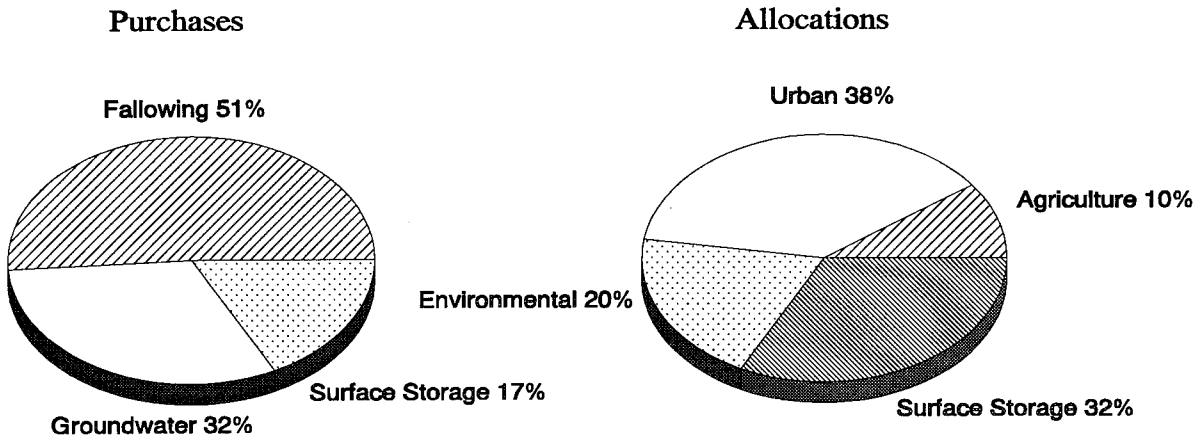
Most of the Water Bank water was delivered to users by SWP facilities and stored in the SWP-CVP system until delivery. Water was sold at $175 per acre-foot. This cost covered delivery as far as the SWP Delta Pumping Plant. Additional expenses were charged for conveying the water to its final destination. Costs varied for SWP and non-SWP contractors purchasing water from the bank.

***Table 4**. Urban Water Conservation: 1991 vs 1977 Percent Reductions. (1977 data from Georgeson 1986; 1991 data from EBMUD, LADWP, SFWD, SDWUD)*

Percent Reductions	**1977 vs 1976[1]**	**1991 vs 1987[2]**
EBMUD	36%	21%
LADWP	13%	20%
SFWD	28%	29%
SDWUD	7%	14%

1. Compares January through June for both years
2. Compares either full water year or calendar year.

Figure 16. 1991 Water Bank Purchases and Allocations - 830,000 AF (CDWR 1993)



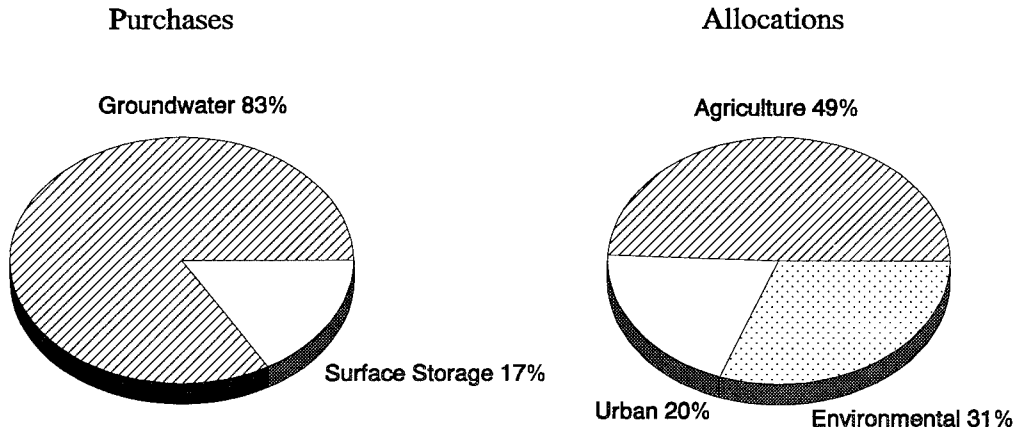
Total allocations of 1991 Water Bank supplies were approximately 390,000 acre-feet, with the allocation to agriculture accounting for 10 percent, and urban communities accounting for 38 percent (CDWR 1992a). The Water Bank design called for any unallocated Water Bank supplies remaining in reservoir storage to be held as carryover storage. When heavy rains fell after critical need estimates and water bank purchases were made in March 1991, the demand for Water Bank water was reduced. Thus, at the height of the drought, roughly 265,000 acre-feet (32 percent) was held as carryover storage for the next year.

Supplies held as carryover storage do not account for all of the difference (about 430,000 acre-feet) between total Water Bank purchases and total Water Bank sales. The remainder (approximately 165,000 acre-feet) was due to carriage water, or transmission losses, in the Delta. An amount greater than one acre-foot of water must be released from storage above the Delta to deliver one acre-foot to the pumps for delivery to southern California. This loss is accounted for in the difference between the purchase price and sales prices of Water Bank supplies. Carriage water satisfies Delta Water Quality Standards and typically accounts for 20 to 30 percent of the contracted sales (Lund and Israel 1992).

The Water Bank continued through 1992, but purchases and sales were reduced because heavy February rains filled most of the reservoirs in Southern California. Groundwater and surface water storage represented all of the 193,000 acre-feet purchased by the water bank, accounting for 83 and 17 percent of the purchases respectively (Figure 17, CDWR 1993).

The 1992 water bank mostly facilitated the transfer of water among agricultural users. All of the purchased water was allocated, with 49 percent for agriculture, 20 percent for urban uses, and 13 percent for the California Department of Fish

Figure 17. 1992 Water Bank Purchases and Allocations - 193,000 AF (CDWR 1993)



and Game dedicated to preserving fish and wildlife habitat (CDWR 1992a). The remaining 18 percent was allocated to Delta outflows (CDWR 1993).

The 1992 Water Bank allocated a much higher percentage of its purchased water than the 1991 Water Bank. This is because the CDWR made purchases for the 1992 water bank only if there were willing buyers that were certain of buying water from the bank (Lund and Israel 1992). Also, in 1992 February rains reduced critical needs prior to purchase, while in 1991 water was purchased prior to heavy rains.

Among the environmental, legal, and third party concerns associated with implementation of water banks are the impact of these banks on the economies of local communities in the source regions. One study that evaluated the economic impact of the 1991 bank in the selling regions concluded that these impacts were not large when compared to the agricultural economy (especially in light of historic variation in the agricultural sector) in the selling region (Dixon et al. 1993). There was no detectable overall impact of the bank in the selling counties because the bank itself injected a sizable amount of money into the selling regions. Negative impacts varied by crop type and by type of contract. Some in those communities thought the bank caused local divisiveness.

Other Responses

Other important responses to the drought were discussions between representatives from the agricultural, urban, and environmental groups referred to as the "Three-Way Process." The Three-Way process began before the drought, but received considerable media attention as the drought intensified. These discussions were an ongoing attempt to reach a consensus in which each group recognized the others' water needs and sought to work together to develop solutions that addressed all parties' needs.

Table 5. Major State and Federal Legislation Passed During the Drought

Year	Legislation or Agreement	Government
1988	**Drought Emergency:** Declared by CDWR	California
	Federal Disaster Assistance Act of 1988: Enabled Secretary of the Interior to assist temporary water transfers.	Federal
1989	**Assembly Bill 982 (AB 982):** Expedited procedures for temporary water transfers.	California
1991	**Executive Order W-3-91:** Established a Drought Action Team, the Water Bank, community rationing plans, urban water conservation, and alliances with environmental groups.	California
	Dire Emergency Supplemental Appropriations (Pub Law 102-27): Appropriated $25 million in drought relief funds for Western States.	Federal
	1902 Reclamation Act Revisions (H.R. 355): Repealed **Warren Act**, which prohibited conveyance of nonproject water. Bars delivery of subsidized water to farms over 960 acres. Farmers receiving Federally subsidized water will pay delivery costs.	Federal
	Memorandum of Understanding: Agreement between Urban and Environmental interests groups. Developed Best Management Practices (BMP's) for Urban Water Conservation.	California
	Department of Fish and Game (AB 12x): Provided $15.3 million to the Department of Fish and Game to protect wildlife.	California
	Water Transfers (AB 10x): Declared temporary transfers of water for drought relief will not affect any water rights	California
	Urban Water Management Plan (AB 11x): Required Urban water suppliers to prepare and submit an urban water shortage contingency plan. Non compliance disqualifies suppliers from State drought assistance.	California
	Water Resources (AB 16x): Authorized the State Water Resources Control Board to adopt drought response emergency regulations for 270 days without Office of Administrative Law approval.	California
1992	**Water Code Section 10750:** Provides an opportunity for existing water agencies to develop groundwater management plans for their basins.	California
	CVP improvement Act of 1992 (U.S. Pub Law 102-575): Reallocates 800,000 acre-feet annually from off-stream to in-stream uses (fish and wildlife), develops water transfer provisions.	Federal

The group was composed of water professionals and activists who understood water issues and their respective interest group's views. No success was realized in terms of formal products during the drought. The process became bogged down by the conflicting agendas of the various interest groups, just as it has for decades. However, the process improved working relationships between competing interest groups, forming relationships which continue today.

In the political arena, significant Federal and state legislation was passed to help water managers navigate through the institutional water control framework. Among the most important of these were the 1902 Reclamation Act revisions. These revisions opened the door for the formation of the Water Bank by repealing the Warren Act, which prohibited the transport of non-CVP water in Federal aqueducts. Other pieces of legislation were also important, and are summarized in Table 5.

At the level of individual water districts, considerable creativity was exercised by district managers to respond to long and short-term shortages. While many of these responses had only minor quantitative importance during the drought, or were not actually implemented, they provide suggestions for water management and illustrate the often creative nature of successful water management. An example is East Bay MUD's aborted attempt to pump low-quality Sacramento-San Joaquin Delta water upstream, to free high quality water in the Sierra Nevada for urban use. This imaginative water quality trade was ultimately unsuccessful due to concerns for introducing unwanted species into upstream river and reservoir reaches and concern from downstream water users. Several water districts have also considered, proposed, or implemented "Cash for Grass" and other systems whereby water customers are paid to implement water conservation retrofits, such as reducing lawn areas or replacing high-flow with low-flow toilets (Lund 1991).

IMPACTS

Impacts of the long duration drought were felt by the agricultural, industrial, commercial and municipal sectors, energy, recreation and the environment. The economic losses of the six-year drought are difficult to quantify because only limited data are available, and it is hard to differentiate drought impacts from other perturbations such as the overlapping recession in California.

According to many observers, including the California Department of Water Resources (1991), it was likely that the most severe impacts of the drought were suffered by the environment. Environmental problems, such as high temperatures recorded in the Upper Sacramento River began during the first year of drought. The drought had a pronounced effect on fisheries and aquatic resources, particularly salmon. The population of the fall-run chinook salmon declined to its lowest numbers in the last two decades despite consistent hatchery production (Figure 18). How much of this population decline is related

to drought is unknown, since its decline might also have been affected by record catches of salmon off the nearby Pacific Coast. The drought also affected striped bass populations which declined to an all-time low of 515,000 in 1990 (Figure 19). Clearly, there are other factors involved, as evidenced by declines in some anadromous fish populations between 1983 and 1985, a non-drought period (Figures 19,20). Other examples of declines in fish populations during the drought abound. However, in some cases fish populations actually increased. The Delta smelt fall abundance index was lowest before the drought during the mid-1980s. It has increased since 1989 (Figure 20).

Impacts to urban water users included rate increases for the industrial and commercial sectors, and water-conserving life-style adjustments for the residential sector. The impacts on individual households, or the residential sector, were primarily behavioral, and to a lesser extent economic.

One study of residential economic impacts in the Los Angeles and San Francisco Bay areas utilized telephone survey data of sample households to estimate their costs associated with the drought (Schulman and Berk 1994). While the total costs for eight structural responses to the drought amount to about $500 million in 1991 for each of the two areas, per household economic costs were less than five dollars per week in the San Francisco Bay area and less than two-and-a-half dollars per week in the Los Angeles region. About 90%

Figure 18. Natural Fall-Run Chinook Spawning Salmon Population: 1980-1991 (CDWR 1991)

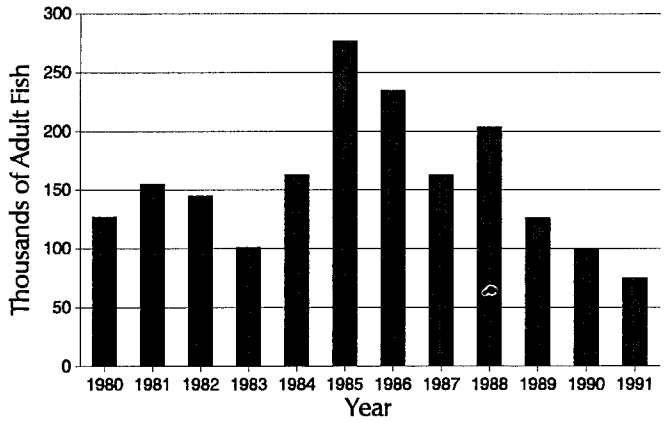


Figure 19. Central Valley Striped Bass Young of the Year Index (CDWR 1991).

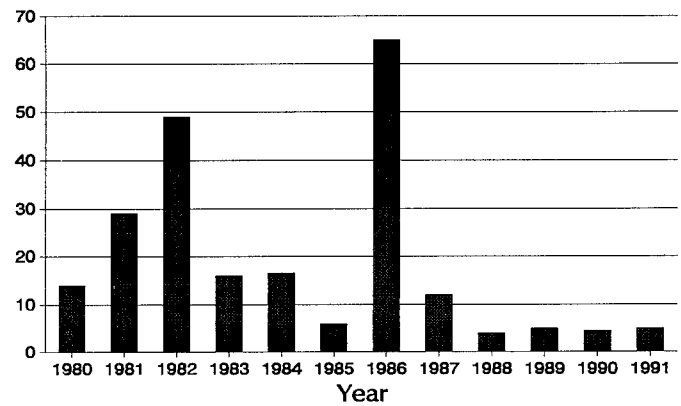


Figure 20. Index of Fall Abundance of Smelt 1980-1991 (CDWR 1991)

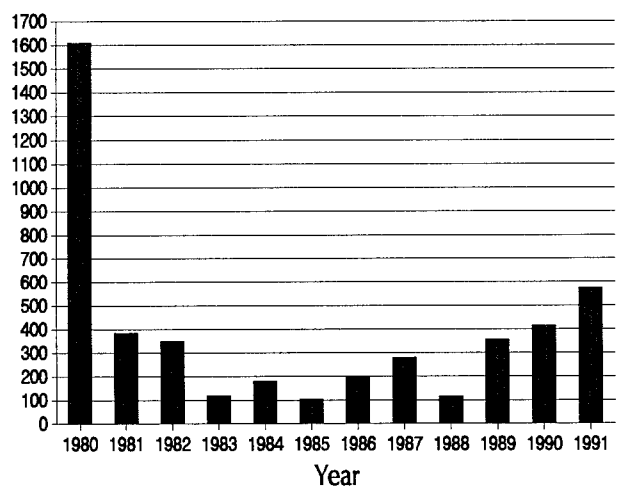


Table 6. Estimates of Economic Impacts

Sector	Revenue Loss (period)	Total Sector Revenue (period)	Study
Agriculture	$250 million (1991)	$18.3 billion (1990)	CDWR 1992b
Green Industry	$460 million (1991)	$7.0 billion (1990)	Cowdin and Rich 1994

of the estimated costs result from replacing dead landscaping, purchasing irrigation water for landscape conservation, and xeriscaping. There are significant qualifications on these household economic impact estimates. For one, these impacts have no obvious baseline. It is difficult to determine what the investment in conservation would have been during normal weather. Thus, these estimates are probably excessive. Second, there are errors inherent in the sampling. Third, adjustments to water scarcity, such as xeriscaping, may reduce future costs, and thus are really investments.

Direct agricultural impacts included significant amounts of land left idle and increased water costs. Agriculture did not suffer substantial impacts until 1991, the fifth year of the drought. While California registered a record agricultural revenue of $18.3 billion in 1990, revenue declined in 1991. However, irrigated agriculture adapted to the drought and direct economic losses were limited to about $250 million in California in 1991 (CDWR 1992b). Among the adaptations were the substitution of groundwater for surface water, the purchase of water in spot water markets, the reduction of low productivity crops, and the concentration of water resources on the most productive soils in the most productive regions (Howitt 1994). It should be noted that much of the reduction in California agricultural output caused by the drought was offset by increases in other regions of the country. A study that modeled the economic impacts (as signified by the sum of producer and consumer surplus) of drought on California and the nation in 1991 indicated that the total national impacts were less than 30 percent of the impacts in California ($80 million versus $276 million, respectively), for the crops modeled (Howitt 1994).

Another industry significantly affected by the drought was the "Green Industry" (Cowdin and Rich 1994), including landscaping and gardening. Drought-induced economic losses in 1991 were estimated to include the loss of about 5,630 full-time jobs, and a reduction of about $460 million in gross revenue from the 1990 total of $7 billion (Cowdin and Rich 1994). The lack of impacts in other

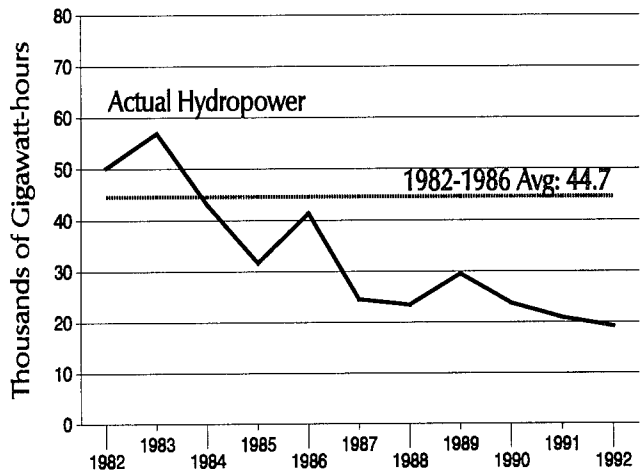
industrial and commercial industries has been attributed to a number of factors, including exemptions for some industries from mandatory water allocation rules, implementation of new water conservation practices, and in a few cases, substitution of groundwater for surface water.

Although the environmental, agricultural, and urban sectors account for much of the adverse impacts of the drought, the drought also affected water quality, recreation and hydroelectric power production. For example, SWP-supported parks and facilities showed reductions in visitor attendance because of water delivery cutbacks. Total recreation days (a recreation day is the visit of one person to a recreation area for any part of one day) declined by 20 percent between 1987 to 1991. The drought also had major impacts on tourist activities such as skiing in the Sierra Nevada, houseboating on reservoirs, and fishing for salmon and striped bass.

The drought reduced hydroelectric power generation, which provides about one third of the state's total electrical energy supply in normal years and up to 40 percent in wet years (CDWR 1991). During the six year drought, hydroelectric energy production declined from 41,459 gigawatt-hours in 1986 to 19,205 in 1992 (Figure 21). Hydropower fell to less than 20% of the state's total electricity production.

The impact to electric utilities is uncertain; they replaced the lost hydroelectricity with more expensive natural gas and out-of-state power

Figure 21. Hydropower Production in California 1982-1992 (U.S. Energy Information Administration, 1994)



purchases. The replacement costs were mostly passed down to consumers. These costs increased marginal electricity costs to consumers by approximately three cents per kilowatt-hour (CDWR 1991). Based on this estimated marginal cost increase, the drought cost state ratepayers an estimated $3.8 billion from 1987 to 1992, or roughly $21 per person per year (calculated by multiplying estimated lost hydropower production by 3 cents per kilowatt-hour). The total revenue from all electricity sold to ultimate consumers exceeded $107 billion during this period (U.S. Energy Information Administration 1994).

While estimated economic losses in California were significant, they pale in comparison to the Gross State Product reported at $619.4 and $631 billion for the years 1990 and 1991 respectively (Economic Report of the Governor 1992).

In addition to impacts on the environment, agriculture, urban economies, and other sectors and activities, the drought also had a significant impact on the public's perception of water use, and the institutions that manage water in California. The human significance of the 1987-92 drought was highlighted by news coverage and political turmoil. Anxiety derived from these impacts was magnified by a number of issues, including: uncertainty about the duration and the anticipated quantum leap in impacts beyond the sixth year; clashes of social traditions and values associated with advocates of growth, environment, and agriculture; and connection with national debates on issues such as the Endangered Species Act and "jobs versus environment." As a result, the 1987-92 drought dominated the news and stimulated innovative solutions to both the immediate and long-term water supply problems.

LESSONS OF THE 1987-1992 DROUGHT

The 1987-1992 drought put long-term strategies of drought protection and short-term drought management approaches in California to a critical test. Water users and managers learned from the experience and saw lessons from the 1976-1977 drought reinforced.

1. ***The complexity of impacts of a sustained drought demands equally sophisticated planning.***

The 1987-92 drought showed that the impacts of drought can surpass the "first order" consequences of not having enough water to support the established off-stream and in-stream uses. Some impacts of the drought propagated and intensified because the affected systems are complex and interrelated.

Production of hydropower dropped to less than 60 percent of normal levels because of the drought. This cost consumers an additional $3.8 billion, because power production had to be supplemented by oil and natural gas fired thermal generating plants. This in turn caused an estimated 25% increase in carbon dioxide emissions (CDWR 1991). Yet air quality impacts are not considered in reservoir operating plans or water allocations.

The impacts of the ongoing drought brought the "environmental standards" approach into question. Aquatic ecology is complex. Just maintaining water quality standards does not prevent devastating effects on some aquatic populations. On December 9, 1992, the State Water Resources Control Board (SWRCB) published a draft of Water Rights Decision (D-1630) which would require the SWP and CVP to maintain stricter water quality standards in the channels of the Sacramento-San Joaquin Delta and Suisun Marsh. This piece of legislation was revoked by the Governor, primarily because it would have been usurped by the Endangered Species Act. However, the EPA and the State have begun a new initiative to achieve the same purpose. Future water management planning for California will undoubtedly reflect more explicit

and integrated consideration of environmental management along with more traditional purposes of California's complex water system. This trend is reinforced by the role of the Endangered Species Act in managing the Sacramento - San Joaquin Delta.

2. ***Severe drought can accelerate change in longstanding relationships and balances of power in the competition for water.***

In the past, the divisions in California's water politics ran between those who diverted water (agriculture and urban water providers) and those who wanted to keep water in the streams (the environmental community).

The drought cracked the urban-agriculture alliance and created an urban-environmental alliance that supported the Memorandum of Understanding on Urban Water Conservation Best Management Practices in December, 1991. But the drought may be longest remembered for its stimulus of the passage of the CVP Improvement Act of 1992 (U.S Public Law 102-575), which has been called one of the most important pieces of environmental legislation ever passed. The Act reallocates an estimated 800,000 acre-feet of California's developed water from off-stream to in-stream uses. It is unlikely the bill would have passed if the long drought did not engage the media and public in a debate on the equity of California water allocation since it was vigorously opposed by the agricultural community.

The fact that the drought accelerated change in the longstanding balance of power in California water politics has implications for water politics elsewhere in the United States.

3. ***Irrigation can provide complementary environmental benefits.***

The competition for water also revealed new possibilities for collaboration between farmers and environmentalists. During the drought it became apparent that flooded rice fields replaced critically important winter habitat for migrating waterfowl that dried up because of the drought. The Nature Conservancy of California (established by the California Rice Industry Association) developed a "ricelands/wetlands conjunctive use project." The project creates upward of 100,000 acres of winter wetland habitat by flooding rice paddies in winter, provides off-stream storage capacity, promotes aquatic biodegradation of the rice stubble (rather than burning stubble that creates air pollution problems), and sustains the communities and economies that have become dependent on rice production.

4. ***Drought can convince communities to accept water management options that are not seriously considered during normal years.***

During the years preceding the drought, some California urban areas pursued local water management options that would have provided water sufficient only for a constrained growth future. These communities rejected the option of

connecting to the State Water Project. That option would have provided more water and removed one constraint on local growth. Many, although not all, believed the reliability of SWP supply would be higher, although some in those communities questioned the reliability. When local water supply options were eliminated for other reasons such as environmental impacts, these communities suffered severe shortages during the drought. This prompted crisis response strategies, including severe rationing, the development of costly alternative supplies, and eventually connections to the SWP.

5. ***The success of drought response plans should be measured in terms of the minimization and equitable redistribution of the impacts (as opposed to simply allocating shortages), but there is much to be learned about the best ways of accomplishing this goal.***

Droughts require cutbacks in water use, and cutbacks often cause economic, environmental, and social disruptions. But the relationship between cutbacks and impacts varies from use to use. Drought response measures can be designed either to allocate water during shortages, or to reduce overall impacts. Traditional drought plans have focused primarily on allocating shortages. The California drought illustrated the value of the impact minimizing approach.

The Water Bank is an example of a drought response plan that allows water to flow where it will do the most good, even if the allocation of shortages is uneven. In a water bank, sellers and buyers voluntarily exchange money and water with the bank if they determine that the transaction is in their interest. This reduces economic impacts yet honors the seller's right to decide whether to temporarily forfeit the right to use water.

Other impact reduction measures include modifying the schedule of releases to the same user so that it is delivered when it is most valuable, dry year leases, water markets, and allocation based on a multi-objective analysis. Unsupervised market-based measures may not completely serve the public interest (as in the case of environmental quality) unless there is a way to buy water for the public good.

6. ***Severe droughts can expose inadequacies in the existing roles and performance of state and Federal water institutions, stimulating significant institutional and legal changes.***

California water resources management is conducted by a mix of Federal, state, and local agencies, although state government regulates the use of natural water resources in California and controls a large portion of the developed water. These agencies experienced varying success in working together to cope with water supply shortages during the drought. The drought exposed some institutional inadequacies which were remedied by either the repeal of laws or the passage of new laws. In other cases, institutional

inadequacies were identified, but no effective changes were made.

The drought exposed the CVP's inability to respond to California's critical needs. This led to revisions in Federal law in 1991 and 1993. While the SWP was scrambling for water and needed Federal conveyance facilities to transport water supplies, it could not do so in several instances because of the Warren Act, which prohibited the use of CVP facilities for moving nonproject water. This law was temporarily relaxed during the fifth year of drought by the Reclamation States Drought Relief Act of 1991.

The Coordinated Operation Agreement of 1986 had made great progress in the direction of increased cooperation in maintaining water quality in the Delta, but it did not cover all the contentious issues. The Bureau of Reclamation, which manages the CVP, understood that they needed to exercise more flexibility in their operations with customers. During the last three years of the drought, the CVP allowed farmers to leave water in storage for next year water deliveries, thus changing the previous "use it or lose it" policy. Towards the end of the drought, the State of California and the U.S. Department of the Interior signed a Memorandum of Understanding which outlined the conditions for a possible transfer of the CVP to the State. However, the memorandum is neither specific nor binding.

The drought led to new state laws and made one of its institutions, the State Water Resources Control Board (SWRCB), function more effectively. Faced with a rush of water transfers, California Assembly Bill 16x authorized the Board to adopt drought emergency regulations for 270 days without review or approval by the Office of Administration. Another law, Assembly Bill 10x, explicitly declared that temporary water transfers initiated under drought relief law in 1991 or 1992 would not affect water rights.

The drought also had a role in accelerating the listing of several species under the Endangered Species Act (Delta Smelt and winter-run salmon). These listings have affected management of the Delta and upstream reservoirs.

Other institutional issues surfaced during the drought. These issues included whether California should have one water "czar" to manage all water resources to meet the state's needs and to protect the public trust. Although many of the study participants held positive opinions about the performance of California Department of Water Resources, some called for more differentiation between the Department and the SWP. Others suggested that CDWR should do more to share their expertise.

7. ***Increases in water rates should precede or accompany rationing plans.***

Rationing plans not accompanied by an immediate increase in water rates often produced revenue shortfalls for water utilities which had to be recouped through later rate increases, after the public had been conserving for some time. Customers viewed

these later rate increases as a sign of poor management, but saw concurrent announcements of water scarcity and price increases as sensible. Water districts that raised rates when they instituted rationing plans fared very well, both in terms of achieving conservation targets and balancing their revenues during the rationing period. Most agencies still believe that curtailing water use through higher prices alone is impractical because of problems in identifying the water price/demand relationships.

8. ***Mass media can play a positive role in drought response, but water managers should be involved in designing the message.***

The media helped mobilize changes in the public perception and actual use of water. They were most effective when they received clear and simple messages from water professionals. Answers to the questions "Are we in a drought?" or "Is the drought over?" were important to the public, since being in a drought implies behavioral changes. The media was most useful in promoting water conservation when water managers were able to articulate the water supply situation and drought response plans in terms the public could understand.

Unfortunately, most drought issues are neither clear nor simple. It is difficult to determine when a drought begins, and when it will end. The social, economic and environmental conflicts that invariably comprise the crux of drought management are extraordinarily complex. The press plays an influential role within an often chaotic political process.

9. ***Market forces are an effective way of reallocating limited water supplies.***

The drought provided an opportunity for water managers to overcome resistance to an idea they had considered before the drought – the 1991 Drought Emergency Water Bank. The bank was established by the Governor to facilitate water sales. It purchased water for $125 an acre foot and sold it for $175. The bank worked to the satisfaction of most interests although some counties expressed serious concern over possible depletion of local groundwater (the source of about a third of the water purchased by the bank), and the environmental community expressed concern regarding the availability of funds to purchase water for environmental purposes. The 1991 Emergency Water Bank showed that: (1) water markets, even when highly regulated and constrained, will work; (2) water has high value for many buyers and there are willing sellers, even during drought; (3) third party interests in market transactions can be protected and; (4) even in the worst year of the drought, hundreds of thousands of acre-feet of water went unsold at $175 an acre-foot. The 1992 Water Bank worked more efficiently as virtually all water was allocated.

CONFIRMED LESSONS OF PREVIOUS DROUGHTS

In addition to new knowledge gained from the recent drought, described in the previous section, the 1987-1992 California drought confirmed several

important lessons and existing operating strategies derived from responding and adapting to previous droughts. These confirmed lessons are presented below.

1. ***Groundwater use continues to be the most effective single response to drought.***

While short-term water conservation, temporary water transfers, and Miracle March rains in 1991 helped California water users survive the six years of drought, the state's urban and agricultural economies were potentially saved from a disaster by the availability of groundwater reserves. During drought, groundwater withdrawals tend to increase in California by at least 50%, representing typically about an eight MAF increase in additional pumping per year.

Statewide carry-over storage did not change between 1990 and 1991. Conservation and groundwater extraction made up the shortfall caused by the estimated 57 percent deficit in statewide water-year runoff in 1991. In 1991, increased groundwater pumping statewide likely produced more than the Miracle March rains and much more water than urban water conservation and water transfers

Southern California has long recognized the value of groundwater supplies and has taken dramatic steps to remove legal barriers that prevented conjunctive groundwater use in several major groundwater basins. The state can help by passing laws to expedite the adoption of groundwater management plans or other forms of self-regulation by local and regional entities. Even more importantly, the state agencies can help with hydrogeologic research to investigate groundwater basins in terms of total and usable storage, recharge areas, water quality problems, and other necessary data for groundwater management. Finally, groundwater recharge and conjunctive use of surface water and groundwater help maintain groundwater as a drought water supply option.

Indeed, California Assembly Bill 3030 passed in 1992 is a major step. The legislation allows any existing water agency to develop a groundwater management plan. This legislation has been rapidly embraced by local water managers as well as state and federal officials. The message of the legislation is that local level managers should not leave a basin unmanaged.

2. ***The surest way to mitigate the adverse social, environmental, and economic impacts of a sustained drought is to ensure that more water is made available in the future through a variety of management measures.***

This lesson was learned in the short, intense drought of the seventies, but the case was made stronger when the complexities of second and third order impacts became apparent in this prolonged drought. It is more difficult to foresee and mitigate second and third order impacts (farm unemployment, reduced farm equipment sales and repair, reduced landscaping sales, poorer air quality, higher stream temperatures, etc). The simplest and most effective

drought response is to provide more water where it is needed.

In the past, more water meant more reservoir storage, with concomitant economic and environmental costs. But there are measures which can increase the reliability of water supply at a nominal or clearly justified cost, such as some forms of water conservation, and improved scheduling of water releases. Other measures, such as investments in conservation technology and supply system interconnections can increase supply yields at a low economic cost.

Survey results indicate that urban, agricultural, and environmental interests are not necessarily strongly polarized with respect to the "more water" options. All three sectors support further improvements in water use efficiency. Irrigators are not opposed to voluntary transfers on a temporary basis if their long-term interests are protected. Finally, the environmental community might support the development of new water storage, especially off-stream storage, if the facilities are operated to accommodate the needs of the environment during drought.

3. ***Early drought response actions and proper timing of tactical measures are essential in the short-term management of droughts.***

The California Department of Water Resources concluded after the 1976-1977 drought that urban water conservation began too late, and that SWP should have reduced deliveries during the drought (Institute for Water Resources Report 93-NDS-5). The lesson learned during the 1976-1977 drought was not lost on urban water providers. They did not believe the drought that began in 1987 would end soon and maintained aggressive demand reduction programs throughout the most critical year of 1991.

The timing of the cutbacks in water deliveries from the major projects must be examined carefully because it affects water use sectors differently. There is no single schedule of cutbacks that would satisfy all users of the CVP and SWP water at the same time. Early cutbacks to agriculture translate into immediate and certain economic impacts. Late cutbacks increase the risks to urban areas and also preempt future options for preventing environmental damages. Generally speaking, urban areas want more water left in storage to prevent deep cutbacks in deliveries at later, potentially more critical stages of drought. On the other hand, farmers may prefer maximum delivery during a given drought year in lieu of supplies the next year. In testimony at the SWRCB's Interim Water Rights Hearing, an agricultural economist testified that some studies show farmers can achieve greater profits with slightly reduced quantities of supply but increased certainty of supply.

4. ***Local and regional interconnections among water supply systems are effective and flexible options against severe water shortages.***

The 1987-1992 drought again demonstrated in several California communities that relying only on

independently owned, operated and isolated sources of water supply may not be effective for protecting against multi-year droughts. This strategy of local "self sufficiency" in water supply can have disastrous consequences during drought.

Examples of difficulties caused by self-sufficiency were found in the San Francisco Bay area and in the Santa Barbara area. For instance, Santa Barbara was not connected to other neighboring systems and as a result, it was difficult to transfer water to it. A complex system of transfers and exchange arrangements by a number of water districts was devised and implemented to deliver emergency supplies to Santa Barbara. The confirmation of this lesson is the increasing number of districts that have hooked up to the statewide "plumbing system."

There is a caveat - the reliability of sources beyond local control may be difficult to specify. Some communities feel they cannot rely on SWP (or CVP) to keep their supplies uninterrupted and must develop more local or independent supplies, even if costs of such development are high.

CONCLUSION

Droughts, floods and other natural hazards will continue to be a normal part of society's existence. Each natural disaster exposes new problems and forces us to react and respond in imaginative ways. Some responses work very well. Others will likely prove to be impediments to the next generation of decision makers who will contend with yet another drought.

Resources are finite, and there is little "cheap" water that can be developed in California for future generations. No one can foresee a drought nor predict its duration, incidence or intensity. We can prepare for most, but not all eventualities. We can organize for more timely and effective responses, and we can learn to use our resources wisely.

While desalinization technology is progressing rapidly, it is still uneconomical for most applications. Groundwater reserves in California are large, but much of the groundwater is inaccessible, or the economic or environmental costs of extraction are too high. In the interim, better management of available supplies must be sought in the face of growing population and development pressures.

The overall lesson of the California drought was that society, through its institutions and political process responded fairly well, albeit in a sometimes inefficient manner. That is the nature of the democratic process when confronted by changes that are required across institutions.

The problems created by the drought of 1987-1992 could have been much worse were there not an existing, highly developed water conveyance system, supplemented by extensive groundwater reserves. These two resources, one man made, the other natural, provided California's population and economic enterprises with enough buffering capacity, resiliency and robustness to withstand the severe drought while seeking other innovative solutions. Effective drought response requires a

constant refinement of knowledge, preparation for uncertainty, and adaptation to the changes in socio-economic structure and public values. It is a difficult and complex undertaking, which California accomplished as well as any state can practically be expected. The lessons learned from this drought can be used by other states and serve as a basis for their tactical and strategic planning efforts.

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APPENDIX: CALIFORNIA WATER USE

In order to appreciate the impacts of the 1987-1992 drought, it is useful to consider California's water use within the context of non-drought and nationwide water use. By comparing pre-drought (1985) and mid-drought (1990) water withdrawal statistics, the change in water use patterns caused by the drought is brought into perspective. The information presented here is derived from two sources; the United States Geological Survey (USGS), and the California Department of Water Resources (CDWR). It should be noted that much of the information presented by the USGS is generated by the CDWR.

Withdrawals and Use: 1990 vs 1985

Despite significant population growth, total water withdrawals in California in 1990 declined 6.2 percent from 1985 estimates, according to the USGS (Solley et al. 1993). Total per capita water withdrawals in California declined 17%, from 1,419 to 1,179 gpcd. (Table 7). Most of the reduction occurred in the agricultural sector, which withdrew 2,500 mgd less water in 1990 than in 1985 as Federal and state irrigation supplies began to be cut back. Reductions in the industrial, mining and thermoelectric sectors amounted to 700 mgd in 1990, but it is not clear if these reductions are drought related or the result of economic factors.

The USGS estimated that in 1990 withdrawals of surface water were 2,100 mgd less than in 1985, while estimated groundwater withdrawals decreased 200 mgd (Solley et al. 1988, 1993). However, these USGS estimates seem to differ from other accounts of the drought which indicate that statewide groundwater withdrawals were higher in 1990 and other drought years (CDWR 1993). As indicated in the main body of this report, groundwater withdrawal information is still not well quantified.

Consumptive water use, of which 92.3% was attributed to agriculture in 1985 (Solley et al. 1988), was 0.9% less in 1990 than in 1985 despite massive cutbacks in state and agricultural project water deliveries. One possible explanation for this discrepancy is that while agriculture withdrew less water, a higher percentage of it was consumed as a result of efficient application and evaporation. Table 7 compares California's water withdrawals to national totals for 1985 and 1990.

Public Supply and Residential Water Withdrawals

California represented 12% of the U.S. population supplied by public systems in 1990, but accounted for 15% of the total public-supply water withdrawals in the country. Although drought conservation measures lowered total and per capita water deliveries in California's major cities, on a state wide basis urban water deliveries were greater in 1990 than in 1985 (Solley et al. 1988, 1993; CDWR 1994). Total public-supply water withdrawals in the state increased

10% to 5,830 mgd from 1985 to 1990, while the population served by public supply increased 5% to 25.5 million. Per capita public supply withdrawals actually increased from 218 gpcd in 1985 to 229 gpcd in 1990. However, during the same time period self-supplied domestic withdrawals increased 113%, from 140 to 318 mgd, and self-supplied commercial withdrawals increased from 53 to 234 mgd (Solley et al. 1993).

Domestic, or residential water use can be categorized as either indoor or outdoor use. Outdoor water use such as sprinkling and car washing varied from 30% in coastal areas to 60% of domestic use in dryer inland regions (CDWR 1993). California's indoor use, estimated to be 80 gpcd in 1990, can be further broken down into end uses (CDWR 1993):

· Toilet	36%
· Bath/Shower	28%
· Faucets	13%
· Laundry	20%
· Dishwashing	3%

These breakdowns of indoor use are dynamic: drought conservation measures such as water-saving fixtures will change end use patterns in the long run.

Agricultural Water Withdrawals

In 1990, agricultural water withdrawals accounted for 81% of the total water withdrawals in the state. Despite reduced irrigation deliveries in 1990, California ranked first in terms of irrigation water withdrawals (Table 8). California withdrew 20% of the irrigation water in the U.S., and accounted for over 25% of the consumptive irrigation losses in the country (Solley et al., 1993).

Summary

This analysis of water use in California is based on data from national, state, and regional sources. The national data (USGS) is meant to provide a comprehensive, but not precise estimate. These estimates, to a large extent, are based on CDWR-supplied data. State estimates are more refined, especially since they do not have reporting deadlines imposed by the USGS's nationwide effort.

The following conclusions appear reasonable:

- urban water use in California is increasing in absolute terms and as a percentage of total California water use;

- urban water use was reduced in many cities during the drought by about 25%;

- groundwater withdrawals increased dramatically when surface water deliveries were cut back, starting in 1990, buffering the effects of the drought.

Table 7. California vs. U.S. Freshwater Withdrawals: 1985 & 1990 (Solley et al. 1993)

All totals in MGD unless otherwise noted.

	California		U.S.		Percent of U.S.	
	1985	1990	1985	1990	1985	1990
Population (x 1,000)	26,354	29,760	242,500	252,330	10.8%	11.8%
Source						
Surface Water	22,600	20,500	265,000	259,000	8.5%	7.9%
Groundwater	14,800	14,600	73,300	79,400	20.2%	18.4%
Total Use	37,400	35,100	338,300	338,400	11.1%	10.5%
GPCD	1,419	1,179	1,395	1,341		
Sector						
Public Supply	5,310	5,830	36,500	38,500	14.5%	15.1%
Domestic	140	318	3,320	3,390	4.2%	9.4%
Commercial	53	234	1,230	2,390	4.3%	9.8%
Irrigation	30,600	27,900	137,000	137,000	22.3%	20.4%
Livestock	199	411	4,470	4,500	4.5%	9.1%
Industrial	431	129	22,300	19,300	1.9%	0.7%
Mining	165	20	2,670	3,310	6.2%	0.6%
Thermoelectric	480	246	131,000	131,000	0.4%	0.2%
Total	37,400	35,100	338,500	339,400	11.0%	10.3%
Consumptive use	21,100	20,900	92,300	94,000	22.8%	22.5%

Table 8. Irrigation Water Withdrawals & Consumptive Use in 1990 for California and Selected States (Solley et al. 1993)

Irrigation withdrawals in order of magnitude for the highest ranked states, 1990. (totals in MGD)

State	Irrigation Withdrawals	Conveyance Losses	Consumptive Use
California (% U.S. Total)	**27,900 (20.4%)**	**1,560 (5.7%)**	**19,500 (25.6%)**
Idaho	18,700	7,160	6,070
Colorado	11,600	2,990	4,960
Montana	9,000	4,620	1,940
Texas	8,490	660	7,130
Wyoming	7,160	2,150	2,590
Oregon	6,860	1,270	2,990
Nebraska	6,100	2,160	3,930
Washington	6,030	997	2,610
Arizona	5,250	368	3,890
U.S. Total	137,000	27,500	76,200

National Study of Water Management During Drought Reports

Previously published reports include:

The National Study of Water Management During Drought: Report on the First Year of Study (IWR Report 91-NDS-1) prepared by the Institute for Water Resources, U.S. Army Corps of Engineers, Fort Belvoir, Virginia.

A Preliminary Assessment of Corps of Engineers Reservoirs, Their Purposes and Susceptibility to Drought (IWR Report 91-NDS-2), prepared by the Hydrologic Engineering Center, U.S. Army Corps of Engineers, Davis, California.

An Assessment of What is Known About Drought (IWR Report 91-NDS-3) prepared by Planning Management Consultants, Ltd., Carbondale, Illinois.

Lessons Learned from the California Drought (1987-1992) (IWR Report 93-NDS-5) prepared by Planning and Management Consultants, Ltd., Carbondale, Illinois.

Computer Models for Water Resources Planning and Management (IWR Report 94-NDS-7) summarizes brand name models in eight categories including river and reservoir system operations.

A number of reports presenting the final results of the National Study are completed and being prepared for publication:

The National Drought Atlas (IWR Report 94-NDS-4) is a compendium of statistics which allows regional water managers to determine the probability of droughts of a certain magnitude and duration.

Executive Summary: Lesson Learned from the California Drought 1987-1992 (IWR Report 94-NDS-6) is a concise summary of NDS-5 (above), with information that became available after NDS-5 was published.

Managing Water for Drought (IWR Report 94-NDS-8) is the main report from the National Drought Study. It describes the planning method developed and tested during the National Drought Study.

Estimating Drought Impacts: A Federal Water Resources Evaluation and Accounting Perspective (IWR Report 94-NDS-9), Human and Environmental Impacts: California Drought 1987-92 (IWR Report 94-NDS-10) NDS-9 shows how drought impacts can be measured in the Federal accounting system of Principles and Guidelines. NDS-10 is a collection of papers by California researchers who attempted to measure the impacts of the drought on the California economy and environment.

Water Use Forecasts for the Boston Area Using IWR-MAIN 6.0 (IWR Report 94-NDS-11).

National Study of Water Management During Drought: Report to Congress (IWR Report 94-NDS-12) summarizes the results of the entire study.

Trigger Planning for the MWRA Service Area (IWR Report 94-NDS-13).

Governance and Water Management During Drought (IWR Report 94-NDS-14). Prepared by the Advisory Commission on Intergovernmental Relations (ACIR). NDS-14 addresses the general subject of technical water management within the American democratic process.

Colorado River Gaming Exercise (IWR Report 94-NDS-15) documents the use of a shared vision model in a gaming exercise to evaluate operational and institutional alternatives for the management of the Colorado River. This report was prepared as a joint project with the Study of Severe Sustained Drought in the Southwest United States.

Shared Vision Models and Collaborative Drought Planning (IWR Report 94-NDS-16), prepared by the University of Washington for the Corps of Engineers.

Lessons Learned from the National Drought Study Case Studies will be published in Spring 1995.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1994 - 386-776 - 814/22410

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1994

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
Excutive Summary of Lessons Learned from the California Drought (1987-1992)

5. FUNDING NUMBERS

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
USACE, Directorate of Civil Works
20 Massachusetts Avenue, NW
Washington, DC 20314-1000
USACE, Institute for Water Resources
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Alexandria, VA 22315-3868

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
IWR Report 94-NDS-6

11. SUPPLEMENTARY NOTES
Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161, (703) 487-4650

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report is part of the National Study of Water Management During Drought conducted by the U.S. Army Corps of Engineers Institute for Water Resources (IWR). IWR conducted several substudies in California as part of the national study; among them is one which captures the views of some 100 interview participants representing 57 organizations in California that manage or influence the management of water. Those results were presented in IWR Report 93-NDS-5 entitled "Lessons Learned from the California Drought". This report summarizes findings of that report and includes findings from the other national study investigations conducted by IWR in California.

Many of the lessons learned are valuable, but intangible in nature, and can be assigned to the rubric of wisdom and experience. Other lessons reaffirmed conventional wisdom associated with decisions and practices from previous droughts. Most important are the tangible, long-lasting changes that were made in the legal and administrative structures of California's water management institutions as well as those of the Federal government.

14. SUBJECT TERMS
California water management, California drought management, 1987-1992 Drought in California, Lessons from California Drought

15. NUMBER OF PAGES
44

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclasssified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
Unlimited