The Societal and Environmental Costs of the Continuing California Drought

July 1991

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Pacific Institute for Studies in Development, Environment, and Security

Research Report

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California Energy Commission
California Farm Bureau
California Farm Water Coalition
California Fertilizer Association
California Public Utilities Commission
California Ski Industry
California Waterfowl Association
Contra Costa Water District
Environmental Defense Fund
Glenn-Colusa Irrigation District
Green Industry Council
Kern County Water Agency
LSA
Natural Resources Defense Council
Nimbus Hatchery
Northwest Economic Associates
Pacific Coast Federation of Fishermen
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Pacific Gas and Electric Company
Pacific Nurseries
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United States Fish and Wildlife Service
United States Forest Service
United States Interior Department
University of California, Berkeley
University of California, Davis
University of California Marine Extension Service
Wells Fargo Bank
Western Area Power Administration
Westlands Water District

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EXECUTIVE SUMMARY

Since 1987, the State of California has been in the grip of a severe drought. Water availability throughout the State has been far lower than normal for each of the last five years when measured in any of a variety of ways: total precipitation, runoff, ground-water overdraft, or reservoir storage. The current drought is comparable in severity to the drought of the late 1920s and early 1930s, considered to be the worst drought on record, and there is no guarantee that next year will be any wetter. The California Department of Water Resources has classified four of the last five years as "critically dry", while the fifth was classified as "dry".

We present here the information on impacts and economic costs of the drought where they are available, for a wide variety of sectors. We also assess what the current drought tells us about California's vulnerability to global climate change. We have avoided making an overall dollar estimate of the costs of the drought to California in part because such estimates can be misleading. They tend to focus attention on those impacts that can be easily quantified while undercounting those impacts that cannot be readily assessed in economic terms. Indeed, our study suggests that many of the most severe effects of the first four years of the drought have been in those sectors that are not adequately evaluated by economic measures, the State's ecological resources: its fish, wildlife, forests, and natural ecosystems.

Based on the information collected for this report, we believe that the greatest impacts are currently falling on the environment, and that, moreover, many of the ecological effects may be irreversible. In addition, California will see substantial economic costs, totaling roughly $3 billion, as a result of decreased hydroelectric potential. Limited portions of the agricultural sector are also bearing heavy costs, although the effect on California's overall farm income will be relatively small. While urban areas have suffered shortages, they have been manageable in most cases and have not caused major economic dislocations. The additional rainfall that the State received in March of this year helped to avert much more serious impacts in the municipal and industrial sectors, but only modestly improved the condition of ecosystems and the water supply for agriculture.

The drought is not over. Without doubt, another dry year would result in much more severe situation than California has experienced thus far. Reservoir reserves have been drawn down to extremely low levels, some fisheries populations have been brought to the verge of extinction, if indeed they have not already been pushed over the edge, and ground-water reserves have been severely depleted in many agricultural regions.

Presented below is a summary of what we currently know about the impacts of the drought.

Summary of Impacts

Natural Ecosystems

Human activities have made natural ecosystems more vulnerable to droughts than they would otherwise be, and, consequently, the current drought has had severe impacts on a wide range of California's ecological resources. While the impacts of the drought on natural ecosystems are not easily separated from other factors such as habitat destruction, pollution, and overexploitation, the drought is exacerbating downward trends in many populations. Given the poor condition of the most threatened species, the greatest concern is that some species may not be able to recover once the drought is over. Among the effects observed as of July 1991 are:

- The coho and chinook salmon catch off the coast of California has declined from a record 14.8 million pounds in 1988 (reflecting the success of the year class raised in the wet year of 1986) to only 4.4 million pounds in 1990. The current estimate for 1991 is 2.5 million pounds.

- The winter-run chinook salmon, already classified as a threatened species, has reached such low numbers that it is threatened with extinction.

- The population of striped bass in the San Francisco Bay/Delta has been declining since the beginning of the current drought in 1987. In 1990, the index of larval abundance was the lowest ever recorded. While the decline of the striped bass may have many causes, the striped bass index shows a strong correlation with Delta outflow.

- The herring fishery in Tomales Bay has been destroyed, at least temporarily, due to low freshwater inflows and consequent increases in salinity. It is possible that this herring population will not recover.

- Waterfowl populations in California have been declining dramatically over the last decade for many reasons. The drought is exacerbating these losses by reducing the quantity and quality of wetlands habitat in the Central Valley.

- Tree mortality has been extremely high in large areas of the Sierra Nevada. In some forest areas, 30 to 80 percent of the trees are dead or dying.

- A wide range of endangered and threatened plant and animal species are directly threatened by low water conditions, including: nesting and wintering bald eagles in the Santa Ynez basin; the ten listed species of native annual and short-lived herbs; the threatened giant garter snake, which depends on seasonal and permanent sloughs and creeks; and almost all of the nine species of endangered butterflies, which are experiencing severe population declines because of drought-induced losses of host plants.

Agriculture

Undoubtedly, the drought has reduced California's agricultural income over what it might have been in 1990 and 1991, although it is has not been the disaster that some expected. Certain agricultural sectors and individual farmers have been hard hit by cutbacks in water deliveries. But we also find that the California agricultural community as a whole has experienced manageable losses, in part because the agricultural sector was in a strong financial position before the drought began and because it has been buffered by ground-water availability and the ability of farmers to alter planting patterns.

- Until 1990, agricultural water deliveries were not affected by the drought, and no significant economic impacts were observed. In 1990, some water deliveries were reduced, but overall impacts were minimal. Strong demand for California farm products has kept both prices and revenue high. Gross cash receipts in 1990 reached an all-time high.

- Greater agricultural impacts will occur in 1991, but it is too early to quantify these effects. A preliminary estimate by the California Department of Water Resources puts direct losses at roughly $400 million in cash receipts out of an estimated $18 billion total. In addition to these direct losses, there could be substantial indirect costs throughout the State.

- The statewide averages hide local effects. Some agricultural communities have been hard hit, including the southern San Joaquin Valley, where ground-water supplies are scarce, and the Central Coast region, where there is extensive dryland agriculture and a high dependence on ground water and precipitation.

- Ground-water storage in the San Joaquin Valley has declined dramatically since the onset of the drought, and will decline even more in 1991. Between 1987 and early 1991, ground-water levels in Tulare County had dropped by over 30 feet and 3.3 million acre-feet. In Madera County ground-water levels have dropped by over 25 feet and 1.4 million acre-feet. Should the drought persist, the decreased availability of ground water will have major impacts on the agricultural sector.

Livestock and Grazing

The reductions in rainfall over the first four years of drought have had a direct effect on the condition of California's grazing lands but, as of January 1991, no visible effect on total livestock populations or on the economic health of the livestock industry. Overall cash receipts for cattle and hogs reached a record high in 1990. Receipts for sales of sheep and lambs has dropped to 1983 levels, although it is unclear if this drop is related to the the drought.

- Despite the relatively good economic conditions prevailing for most ranchers, some counties have been hard hit. Herd sizes in some parts of central coastal California have been substantially reduced, even though overall State populations remained at their historical levels through the end of 1990.

- The lack of rainfall has contributed to overgrazing in many areas of the State, in part because ranchers were slow to reduce herd sizes, and because the Federal and State agencies responsible for range conditions were slow to close or restrict vulnerable grazing sites. The subsequent overgrazing, combined with the extremely heavy March 1991 rains, led to serious local erosion, particularly in the Central Coast region. In spring 1991, several small Bureau of Land Management grazing areas were formally closed to protect them from further overgrazing.

Energy

The drought in California has affected both the supply of and demand for energy. California is highly dependent on hydroelectricity production -- about one-third of all electricity produced in-state is hydro -- and the drought has greatly reduced hydroelectric generation. As a result, more fossil fuels have been purchased and burned by California utilities. Electricity used for ground-water pumping has also risen with the increased demand for ground water by the agricultural sector.

- Because the cost of generating electricity with natural gas is higher than the cost of producing hydroelectricity, the drought has led to a direct increase in electricity costs to California ratepayers. We estimate that the first four years of the drought (1987 to 1990) cost California ratepayers an extra $2.4 billion.

- Hydroelectricity production in 1991 will also be well below average, and the additional costs to ratepayers this year may exceed $500 million.

- The burning of extra fossil fuels has also increased air pollution. We estimate that the added fossil fuel combustion has increased California's electric utility emissions of carbon dioxide, the principal gas responsible for the greenhouse effect, by over 25 percent from levels emitted during a normal water year.

Forestry and Fire

The five years of the drought have had an enormous impact on the forests of California. Trees have become highly susceptible to both disease and pest infestation. There has already been a significant die-back of trees throughout the State, particularly in the Sierra Nevada, while many more trees are sick or infested. In addition, dead and downed trees have created substantial amounts of dry fuel that substantially increases the risk of intense and destructive forest fires.

- The California Department of Forestry estimates that 12 billion board feet of merchantable timber has been lost on State lands; over 5 billion of that in 1990 alone.

- The U.S. Forest Service estimates that 10 percent of the trees in 18 National Forests have been killed by the drought and related insect infestations. On the approximately 6.5 million acres managed by the U.S. Forest Service for commercial lumber, 2.6 billion board feet of timber was killed by the drought in 1990. Estimates for August 1989 and August 1988 were each approximately 1 billion board feet.

- Of the 2.6 billion board feet of dead trees in U.S. National Forests as of August 1990, the Forest Service estimates that only 1.6 billion will be salvaged -- about 800 million board feet each in 1990 and 1991.

- The drought has led to greater expenditures for fire protection, fire control staffing, and operational expenses. State and Federal emergency expenditures for fire suppression and fighting exceeded $100 million in 1990. These expenditures are over and above the regular costs of maintaining fire-fighting equipment and personnel.

Recreation and Tourism

Recreation and tourism is the largest single industry in California. These activities account for nearly 700,000 jobs and generated $50 billion in revenue in 1989. Extreme weather conditions affect this industry in many ways. Reduced precipitation affects mountain snowpack, while reduced water supply affects reservoir accessibility and aesthetics. Greater fire frequency and risk reduce recreation visits to State and Federal parks, while reductions in wildlife populations affect fishing and hunting opportunities. Some of the impacts recorded until mid-1991 include the following:

- Bad snow conditions have reduced business to California's ski industry. We estimate that the ski-resort industry lost about $85 million during the 1990-91 winter alone. In addition, the industry employs 7,000 to 10,000 people during a normal season; during 1990-91 industry employment was about half this amount.

- Water-borne recreation on California State Water Project facilities and other reservoirs and rivers around the State has begun to decrease due to low water levels.

- In mid-summer 1990, 500,000 acres of the Stanislaus National Forest were closed to recreation due to high fire danger, and other fire-restriction closures are under consideration for 1991.

- Two U.S. Forest Service campsites in the Tahoe National Forest have been closed for 1991 due to outbreaks of bubonic plague in the resident squirrel populations, which are indirectly attributable to the drought. Other sites in Sequoia National Forest may be closed later this year for the same reason.

Municipal and Industrial Users

Municipal effects have been modest, with the exception of several isolated communities dependent on limited ground water and reservoir storage. For these communities, the March 1991 rains were especially valuable. Prior to receiving this additional precipitation, many large urban areas were facing unprecedented shortfalls. Throughout the State, residential water conservation programs have been widely implemented and largely successful. While some water districts eased rationing after the heavy March rains, many municipalities are maintaining voluntary restrictions.

Most water-intensive industries are not expected to face any declines in production due to water cutbacks in 1991, but if the drought continues for one more year, more severe industrial impacts could begin to appear.

- Water quality will be affected in some regions due to low fresh water flows and increased salinity intrusion. Contra Costa Water District, which takes its water from the Sacramento-San Joaquin Delta, expects to spend an additional $200 million in 1991 to control trihalomethane formation associated with increased salinity concentrations.

- Some communities in California have imposed temporary bans on new water hook-ups, effectively preventing new construction. The number of cities imposing such bans is small and primarily limited to areas heavily dependent on imported water. One side effect of such bans is to drive up housing prices, increasing real estate values while causing a social welfare loss.

- Some industries have benefitted from the drought. Well drillers are experiencing a boom in business, and sales of water-conserving fixtures and micro-irrigation systems have increased dramatically.

The Drought as an Analogue of Climate Change

Given the current concern over global warming, the question of whether this drought is a manifestation of "global climatic change" invariably arises. While the drought could be associated with larger scale changes in the climate, we are unlikely to know for several more years. Nevertheless, if the drought is merely an extreme of the current climate rather than a manifestation of anthropogenically induced climate change, it may still serve as an analogue of a future climate that is more severe than that of the present. The drought does not provide any information on the effects of increases in global and regional temperature, changes in climatic variability, the hydrologic effects of sea level rise, or a host of other issues. But it does illustrate the impacts of decreased precipitation and runoff, one possible change that might accompany global warming. More importantly, however, the drought is indicative of our society's ability to adapt to climatic variations and the vulnerability of California to long-term shifts in hydrology and water availability.

The impacts of the current drought suggest that the California economy can withstand five years of reduced water supply, but that we are running up against severe limits and facing difficult choices. Specifically, ground-water supplies and reservoir storage, which so far have buffered the impacts in the agricultural sector, have been heavily depleted and will be of limited value if the drought continues. Many threatened wildlife populations are so strained by five consecutive years of drought that their ability to recover is being questioned. If the drought were indicative of long-term changes in the State's water supply, it would imply fundamental changes in the State's economy and environment.

Although an imperfect analogue to global warming, the drought highlights the vulnerability of the economy and the environment of California to variations in climate. The worry, however, is that climatic changes would be even more extreme than the drought we are currently experiencing. Moreover, our response to the drought suggests that we will tend to discount the future and adopt the easiest responses first. On the positive side, the drought has forced California to re-analyze its water policies and has spurred an important debate about vulnerability, tradeoffs, and priorities. In this sense, the drought may provide the impetus to plan for and to adapt to global warming.

THE SOCIETAL AND ENVIRONMENTAL COSTS OF THE CONTINUING CALIFORNIA DROUGHT

INTRODUCTION

Despite our high standard of living and high level of technological advancement, industrial society remains vulnerable to variations in climate. By implication, we are also vulnerable to future, unpredictable climatic changes. Climate disasters occur throughout the world -- there are disastrous floods in Bangladesh, lethal droughts in sub-Saharan Africa, recurrent crop failures in parts of the USSR, the Indian subcontinent, and the Brazilian northeast, and as the last five years have shown, severe and persistent shortages of water in the western United States.

This report evaluates the economic and environmental costs of the current California drought. Among the impacts studied are reductions in hydroelectricity generation and subsequent increases in fossil fuel combustion, agricultural and livestock losses, impacts on natural ecosystems, and economic costs to industry and recreation. This analysis makes use of diverse drought assessment activities underway at the Pacific Institute and throughout the State of California.

The report also explores whether there are lessons to be learned from this drought about the vulnerability of the region to future climatic changes. We include an analysis of the applicability of the current drought as an analogue for the types of impacts that might be expected to arise from future global climatic changes (see, for example, Glantz 1988 and Gleick 1988).

In the future, natural climatic disasters may be aggravated by major human-induced climatic changes caused by growing atmospheric concentrations of carbon dioxide and other trace gases. One method for evaluating the nature of these threats is to study the consequences of recent events, such as extremes of temperature, precipitation, or water availability. These so-called historical analogues provide insights into where future changes might be most strongly felt, and they suggest appropriate responses for mitigating the worst climate-related effects.

By reviewing the impacts of past climatic extremes we can identify sectors of the economy most sensitive to changes in hydrologic conditions. Lessons learned from these periods can then be used to identify appropriate societal responses for reducing vulnerabilities to climate. Responses might include changes in the physical structure of resource-management systems such as reservoirs, changes in the operation of these systems, and a range of socioeconomic actions, including pricing and market mechanisms, institutional initiatives, and regulatory responses (Frederick and Gleick 1988).

California is vulnerable to long-term changes in water availability: California's agricultural productivity is largely dependent on reliable irrigation supplies; continued development and population growth in the southern California depends on water transfers from outside of the region; the rich ecosystems of California rely on water availability and quality; and water supplies are already constrained by large and growing demand. Given the rising demand for water by both the agricultural sector and the growing population in water-poor southern California, any climatic change that altered the timing, magnitude, or quality of freshwater resources would be cause for concern.

Approach and Limitations

We present in this report information on the economic and environmental impacts of the drought. In compiling this information, we have relied primarily on data from State and Federal agencies and personnel, on information from independent businesses, municipalities, and academic sources, and on our own independent estimates of certain agricultural and energy sector effects. Our approach has been to present and to compare existing information and estimates and to make judgments about their reliability and accuracy. We have avoided making quantitative comparisons of impacts among sectors. In part, this is because of the incomplete nature of the data. It is also because the value of ecological resources is highly dependent on the discount rate that one chooses to apply and on the ability of traditional economics to place dollar values on ecological goods and services.

One of the greatest difficulties encountered in an attempt to estimate the impacts of the drought is determining an appropriate baseline. In all sectors, the drought has been but one variable amidst many that are affecting economic performance or ecological health. For instance, many investigators have chosen a recent "normal" year as a baseline for estimating agricultural impacts. This approach, however, ignores important variables such as relative prices, varying effects of the Federal set-aside programs, changes in land values, and other climatic variables. It assumes instead that all changes are attributable to reduced water availability and increased water costs. For example, estimates of drought-idled acres do not take into account the complicated effect of Federal programs on planting decisions. For crops such as rice and cotton, the Federal programs are perhaps the most important factor affecting planted acreage.

Many estimates of declines in production implicitly incorporate the effects of an extremely severe and persistent freeze that hit California during December 1990. Low temperatures prevailed over much of the State for over three weeks, with widespread mortality of vegetation, including some permanent agricultural crops such as oranges that are incapable of withstanding long cold periods. Ornamental plants in gardens throughout the State were also killed. In some areas, identifying whether plant mortality was due to the drought or the freeze is extremely difficult and we provide no quantitative estimates here.

In addition, California experienced an unusually wet and cold March 1991. During this month, a highly persistent set of storm fronts swept California, dropping three times the normal amount of precipitation. While these storms greatly improved the overall water situation, they had some adverse impacts. Grazing conditions on range lands improved to the point that ranchers held onto cattle herds rather than sell them, despite the only temporary improvement in conditions. In addition, several agricultural sectors suffered losses due to the heavy rains. For example, almond production may be reduced by 20 percent from the average.

In the environmental area, similar problems exist. Population declines in most species are attributable to several factors. For instance, while winter waterfowl populations in California have declined dramatically over the last decade, they have been suffering not only from the drought in California but also from a drought in Canada and Alaska, and from habitat destruction here and elsewhere.

One important conclusion of this work is that State, Federal, local, and private organizations are ill-prepared to actually evaluate the costs of climatic extremes, such as the current drought. For example, although representatives of the U.S. Forest Service and the Department of the Interior believe that recreational use of Federal lands has decreased over the last few years, data on total annual visits to many facilities are not kept, not compiled, or not up-to-date. Analyzing data from other recreational activities, such as skiing, is complicated by the reluctance of ski resorts to share information with their competitors. Federal and State agencies coordinate their wildfire fighting activities very effectively, but data on actual acreage burned in the State as a whole is inconsistent and confusing. Similarly, estimates of crop acreage and agricultural impacts could be improved by gathering both satellite data and conducting detailed surveys on a regional basis. Ecological monitoring throughout the State is woefully inadequate for a comprehensive study. And, given the current budget constraints, most government agencies are compelled to seek quick answers rather than to invest in long-term monitoring and modeling.

Finally, the drought is not over. For the most part, this study looks only at the first four years, 1987 through 1990. Many of this year's impacts have yet to be measured: final agricultural production and prices are unknown, the summer fire season has just begun, and the salmon counts are currently underway. With these caveats, the following sections present a summary of what we know to date of the effects of the continuing drought on California.

THE WATER SITUATION: 1987 TO PRESENT

The current drought in California began in 1987 and has continued for five consecutive years into 1991. There are no guarantees that 1991 will be the last year of the drought, and there are hints that California has experienced longer and deeper droughts in the distant past. In some parts of the State, the current drought is the worst in the last century (good long-term records are available for over 80 years in many parts of the State). Other parts of the State are in reasonably good shape to weather the dry season that has just begun.

There are many ways of measuring drought, including total precipitation received, the volume of streamflow expected, the condition of soil moisture, and quantity of water stored in reservoirs for future use. To give some examples, precipitation statewide is about three-quarters of normal, Lake Tahoe has reached record low levels, runoff in the Sacramento Basin is predicted to be below "critical" levels, and so on. Each measure has is only a part of the overall picture. Table 1 and Figure 1 summarize the State water conditions as of June 1, 1991.

One standard index used to measure water supply in California is the Sacramento River Index. This is the sum of the unimpaired water year (October to September) runoff from the Sacramento River (near Red Bluff), the Feather River (inflow to Oroville), the Yuba River (at Smartville), and the American River (inflow to Folsom). The index annual average is 18.91 million acre-feet (MAF), approximately 30 percent of California's total fresh water runoff. The California Department of Water Resources has classified the Sacramento River Index into five categories: Wet, Above Average, Below Average, Dry, and Critically Dry. Approximately one-third of all years are Wet, one-third are Dry or Critically Dry, and one-third are Average. Certain below normal years are classified as Dry if they are preceded by a Critically Dry year.

Using the Sacramento River Index, 1991 is predicted to be the seventh worst year on record in the last 85 years. Of the five years of drought, four are classified as Critically Dry (1987, 1988, 1990, 1991), and the fourth as Dry (1989).

Another measure of the severity of the current situation is the Palmer Drought Index (PDI), which measures the total moisture in the soil available to vegetation. As of May 18, 1991, the entire State south of Sacramento and San Francisco is experiencing "extreme drought" with a PDI of -4 to -8. The entire State north of Sacramento (with the exception of the small Great Basin region in the northeast corner) is experiencing "severe drought" with a PDI of -3 to -4. Only a small portion of the State is experiencing "mild" drought conditions. Figure 2, from the California Department of Forestry and Fire Protection shows the distribution of drought in the State. Figure 2 also shows rainfall totals for each region as of March 18, 1991.

Precipitation and Surface Runoff

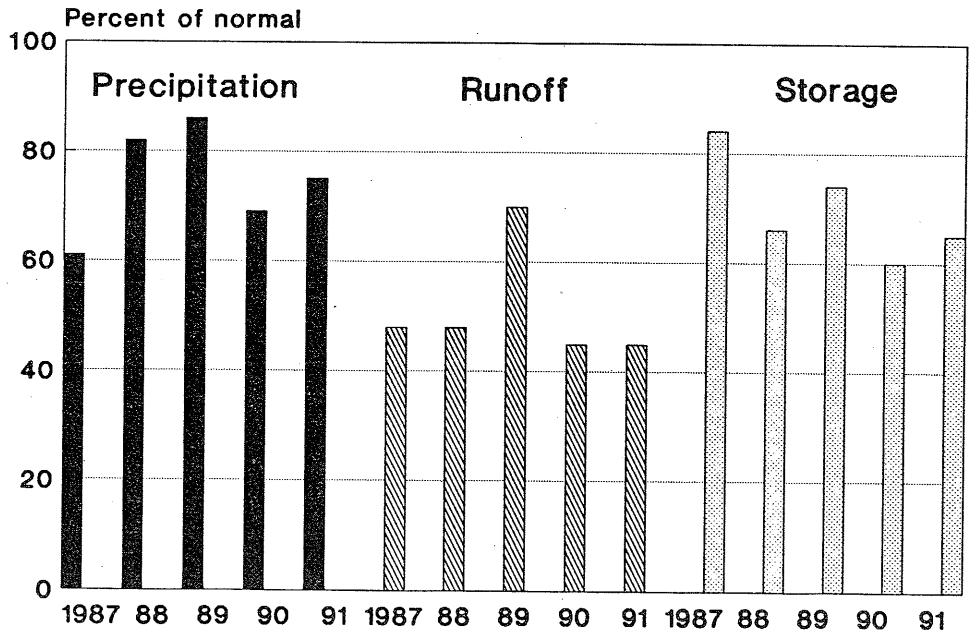
Using the volume of water that falls and runs off in California as a measure, the present five-year drought is comparable in severity to the drought that occurred in the late

Table 1: Summary of California Water Conditions, 1987–1991

	1987	1988	1989	1990	1991 (a)
Precipitation (% of average)	61	82	86	69	71
Water Year Runoff (% of average)	48	48	70	45	35
Reservoir Storage (% of average)	84	66	74	60	65
Sacramento River Index (b)	9.2	9.2	14.8	9.2	8.6
California DWR Classification:	Critical	Critical	Dry	Critical	Critical

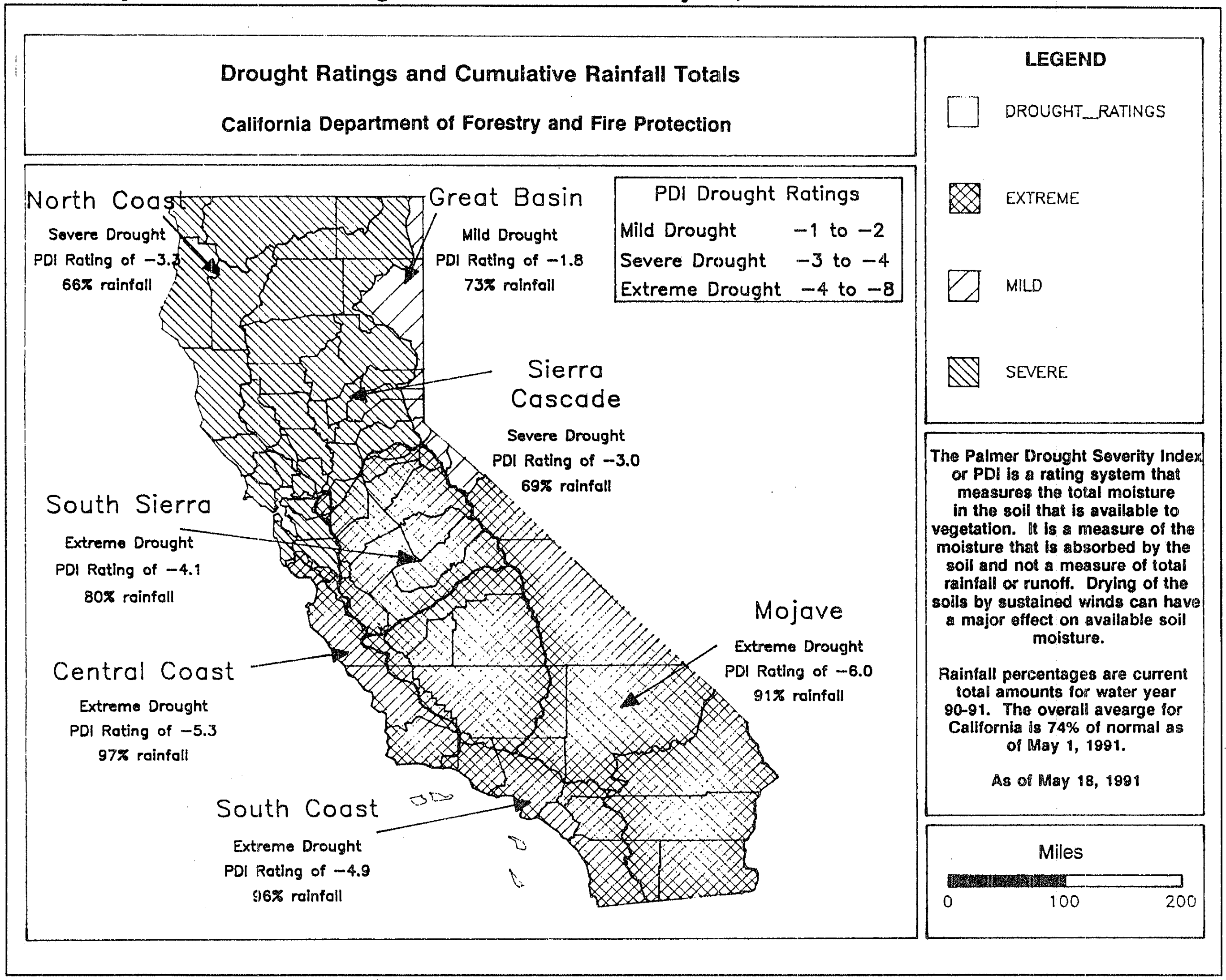
Notes: (a) 1991 data as of June 1.
(b) Average Sacramento River runoff is 18.9 million acre-feet.
Source: CDWR, 1991b.

Figure 1
Statewide Water Conditions



Source: CDWR, 1991c.

Figure 2
Summary of Statewide Drought Conditions as of May 18, 1991.



Source: CDF

1920s and early 1930s -- considered to be the worst drought on record. Figure 1 shows precipitation, reservoir storage, and runoff for the State for the drought years 1987 through 1991 (estimated). In 1991 for the State as a whole, precipitation as of the end of the rainy season (June 1st) was about 75 percent of normal, while total surface runoff is expected to be only 45 percent of normal.

For Northern California, the first four years of the drought were slightly less severe than the worst four-year drought on record -- 1929 to 1934. In contrast, for the Central Coast and central Sierra Nevada, the first four years of the current drought have become the most severe four-year period of record; the continuation into 1991 has made it even worse. In the southern Sierra Nevada region, the first four years are almost identical to the previous worst four-year series -- 1928 to 1931 (CDWR, 1991a). Precipitation totals through May 1991 are shown in Figure 3.

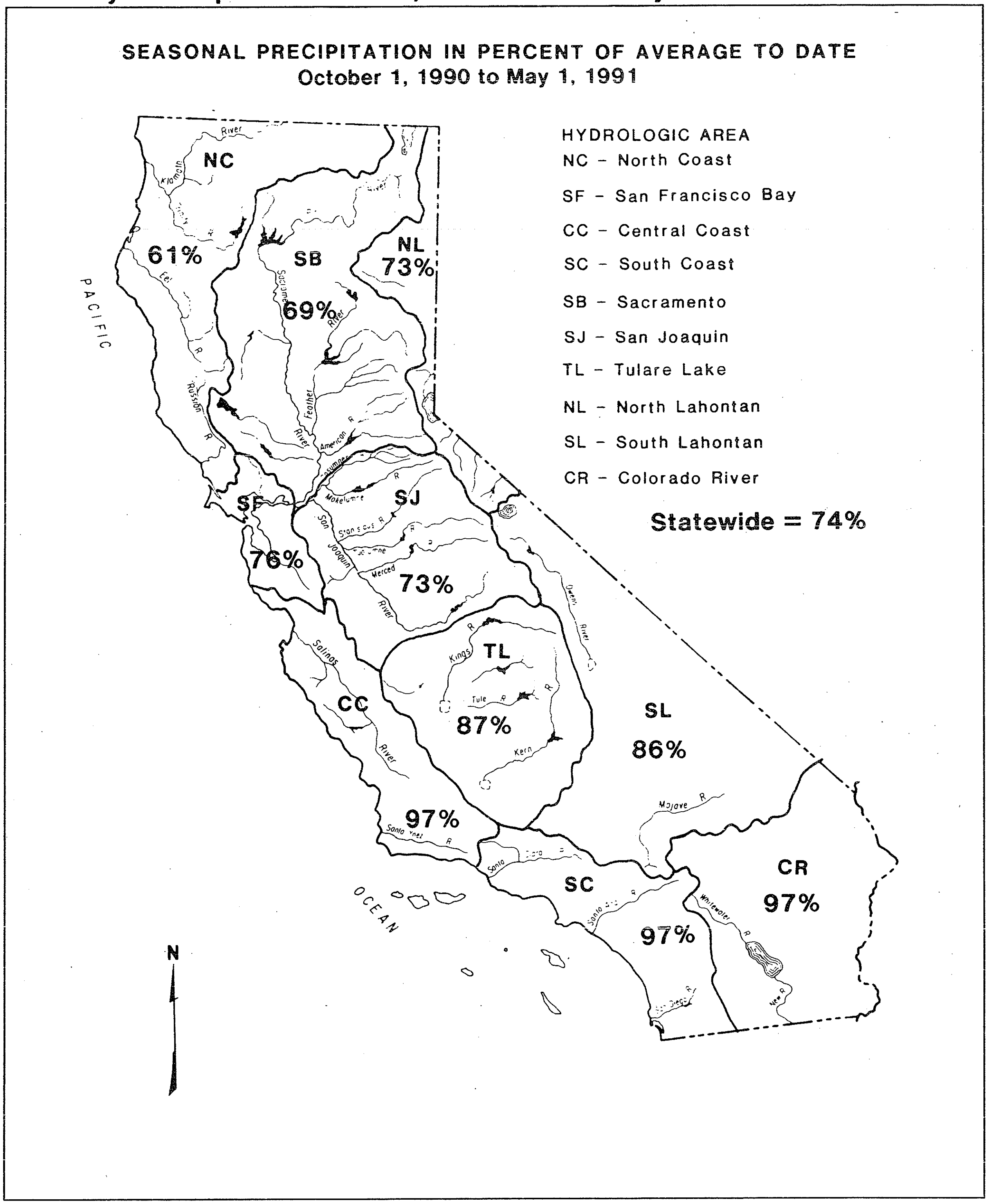
A significant portion of water used in Southern California comes from the Colorado River. Runoff in the Colorado for 1988 to 1990 was also very low -- the lowest cumulative total on record. But these low flows were buffered by two things: the large amount of storage in this basin, particularly in Lake Powell and Lake Mead, and high runoff in the early part of the 1980s, which filled that storage. In May 1991, combined storage in Lakes Powell, Mead, Mohave, and Havasu was 36.6 million acre-feet, which is 101 percent of average (CDWR, 1991b). Full deliveries of contracted water from the Colorado are expected.

Reservoir Storage

Extensive reservoir storage has been built in California to help prevent flooding in winter, to maintain long-term storage of water for a variety of human uses, and to provide opportunities for recreation. There are over 150 major reservoirs in the State capable of storing over 37 million acre-feet of water. Table 2 shows water stored in California's major reservoirs as of June 1, 1991.

California reservoirs are at their lowest levels since the severe drought of 1976-1977. During the first four years of the drought, these reservoirs helped enormously to buffer the State from the effects of water shortages. But each additional year of drought has reduced the total volume of water in storage until, by June 1991, total statewide storage was down to about 65 percent of normal and 55 percent of capacity, with some reservoirs almost completely dry. New Melones on the Stanislaus River is down to 17 percent of capacity; Indian Valley reservoir on Cache Creek is down to 14 percent of capacity; Camanche on the Mokelumne River is at 26 percent of capacity. Even the largest reservoirs have been drawn down -- the two largest reservoirs in the State, Shasta and Oroville, are at 45 percent and 47 percent of capacity. The plentiful rains in March improved the overall storage picture, but critically low reservoir levels still exist at many sites. Figure 1 shows statewide reservoir storage as a percent of normal for the five years of the drought.

Figure 3
Summary of Precipitation Received, October 1990 to May 1991.



Source: CDWR, 1991c.

Table 2: Water in Storage in Major California Reservoirs (1000 acre-feet)

Area	Number of Reservoirs	Total Capacity	Historical Average	June 1 1990	June 1 1991	Percent of Average	Percent of Capacity
North Coastal	7	3,148	2,643	2,021	1,648	62	52
San Francisco Bay	18	696	500	350	386	77	55
Central Coastal	6	947	698	119	284	41	30
South Coastal	29	1,978	1,341	1,327	1,386	103	70
Sacramento Valley	43	16,009	13,701	9,567	9,127	67	57
San Joaquin Valley	33	11,358	8,386	5,964	5,338	64	47
Tulare Lake	6	2,045	1,274	638	835	66	41
North Lahontan	5	1,072	717	248	120	17	11
South Lahontan	8	403	274	205	220	80	55
Total	155	37,656	29,534	20,439	19,344	65	55

Source: CDWR, 1991b.

Ground Water

In some regions in California, surface supplies fail to provide sufficient water even in normal years and ground water is pumped from aquifers to make up the difference. In the San Joaquin Valley -- California's largest and most productive agricultural region -- ground water normally provides over 50 percent of all water used.

When the current drought started in 1987, ground-water levels in the San Joaquin Valley were relatively high, due to a number of prior wet years. Beginning in 1987, increases in ground-water pumping and reductions in precipitation have led to declines in ground-water levels and increases in pumping costs (discussed in the section Impacts: Energy). Since 1987 ground-water storage has decreased in every Valley county (see Figures 4 and 5). Table 3 shows the volume of ground water pumped and not replaced from the seven San Joaquin Valley counties. In some areas of the valley, ground-water levels have dropped even more than shown in Table 3 due to a high reliance on ground water. In the southern part of the Valley, in particular, extreme water level fluctuations are apparent. Much of the surface supply in this region comes from important State Water Project and Central Valley Project imports. During 1990 and continuing into 1991, these supplies have been cut back, leading to greater volumes of pumping from aquifers.

Deliveries to Users

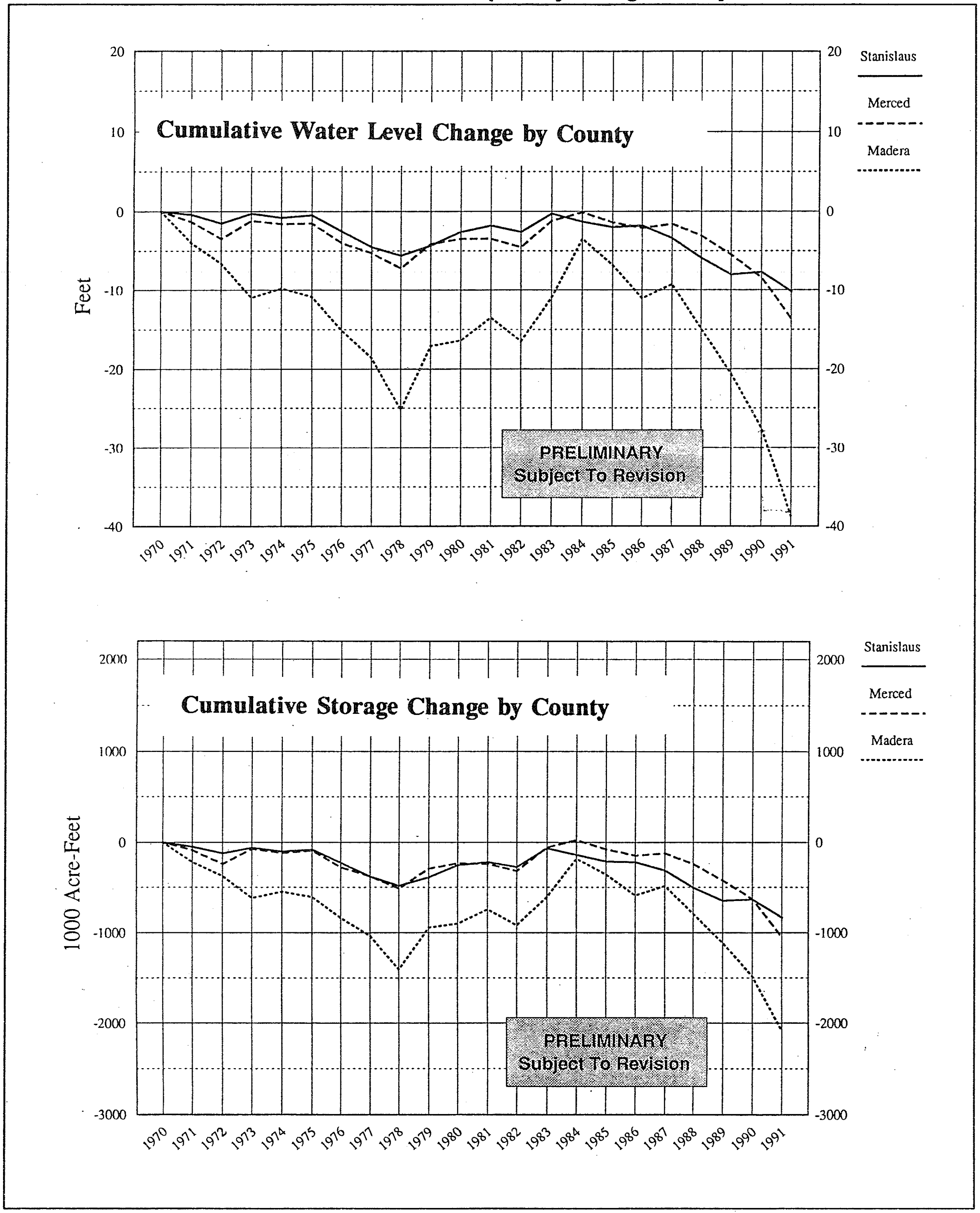
The two major projects that deliver California water to agricultural and municipal water users are the State Water Project (SWP) and the Federal Central Valley Project (CVP). Figures 6 and 7 show deliveries of water from these projects over the last 8 years with expected 1991 deliveries. The long drought and the drawdown of water in project reservoirs led to the first cutbacks of water to agricultural users in 1990, when the CVP cut most agricultural users by 50 percent. There were moderate reductions to SWP agricultural users as well. In 1991, the CVP expects to deliver about 4 million acre-feet of water -- about half the normal deliveries. Most CVP agricultural contractors will receive only 25 percent of their normal entitlement, most water-rights holders will receive 75 percent of their entitlements, and municipalities will get about 50 percent of contract amounts plus some hardship water. The SWP has completely eliminated deliveries to most agricultural users.

During 1990, the California Department of Water Resources permitted -- even encouraged -- water exchanges. By November 1990, nearly 20 exchanges involving about 300,000 acre-feet of water had been negotiated or completed. Many more are now being proposed, and the California Department of Water Resources has formed a committee to facilitate such transfers. The State of Colorado has also offered to transfer a significant quantity of water to the Metropolitan Water District in return for guarantees about future water allocations and improvements in water-use efficiency.

The California Water Bank

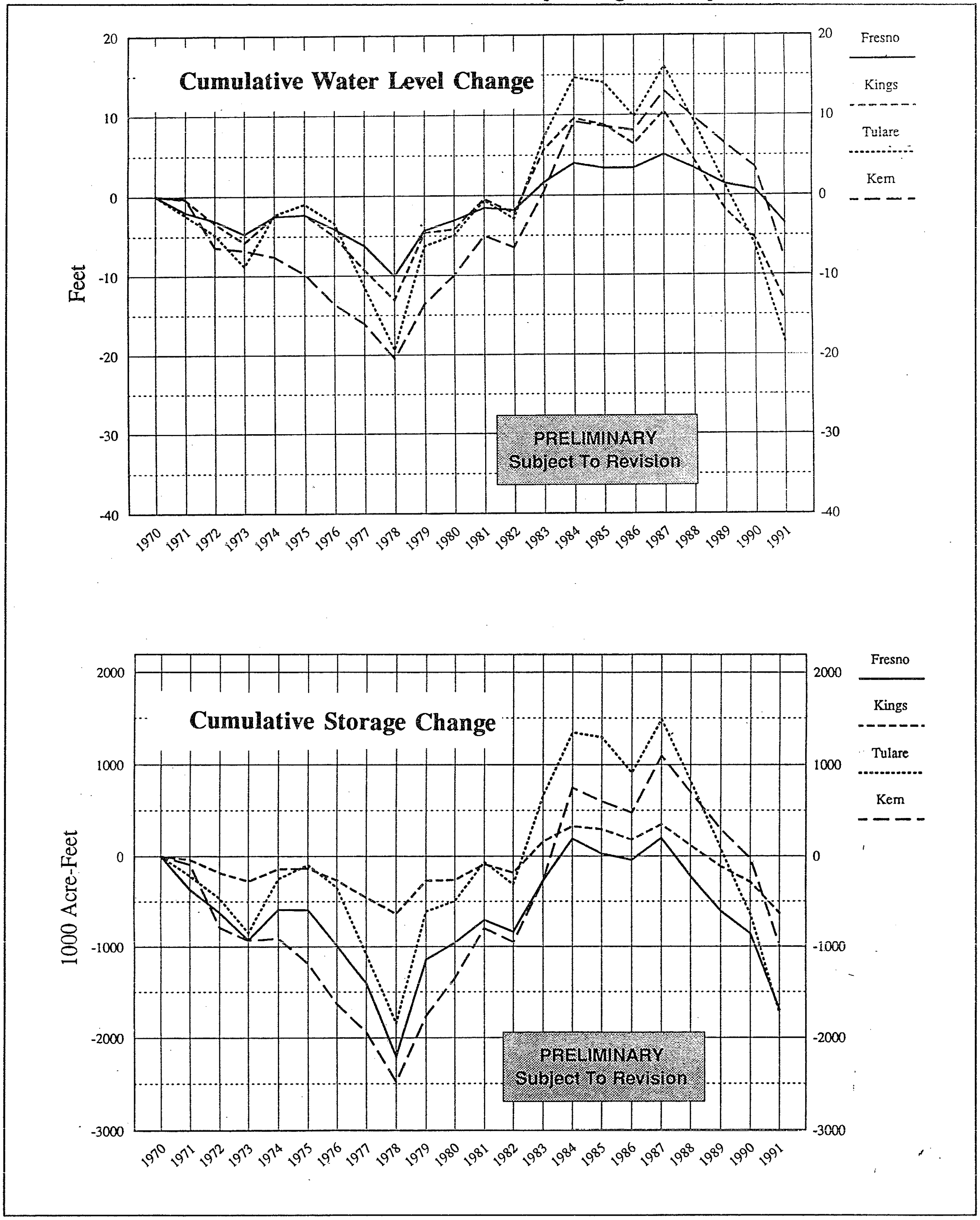
In early February 1991, Governor Pete Wilson signed Executive Order No. W-3-91, which among other drought actions called on the Department of Water Resources to form

Figure 4
Ground-Water Conditions in the San Joaquin Hydrologic Study Area



Source: CDWR

Figure 5
Ground-Water Conditions in the Tulare Lake Hydrologic Study Area



Source: CDWR

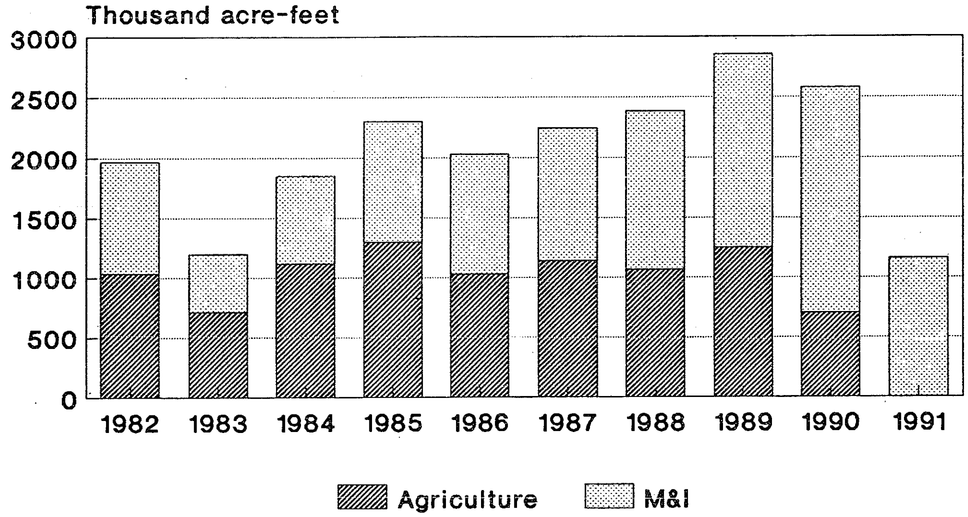
Table 3: Ground Water Withdrawals and Water Levels in Seven San Joaquin Valley Counties (1987 to April 1991)

County	Loss of Ground-Water Storage (1000 acre-feet)	Decline of Water Level (feet)
Tulare	3300	32
Merced	1000	13
Stanislaus	500	7
Kings	1000	17
Kern	1100	13
Madera	1400	25
Fresno	1900	7

Note: Water level declines are county averages. Substantially larger declines may have been observed in local area.

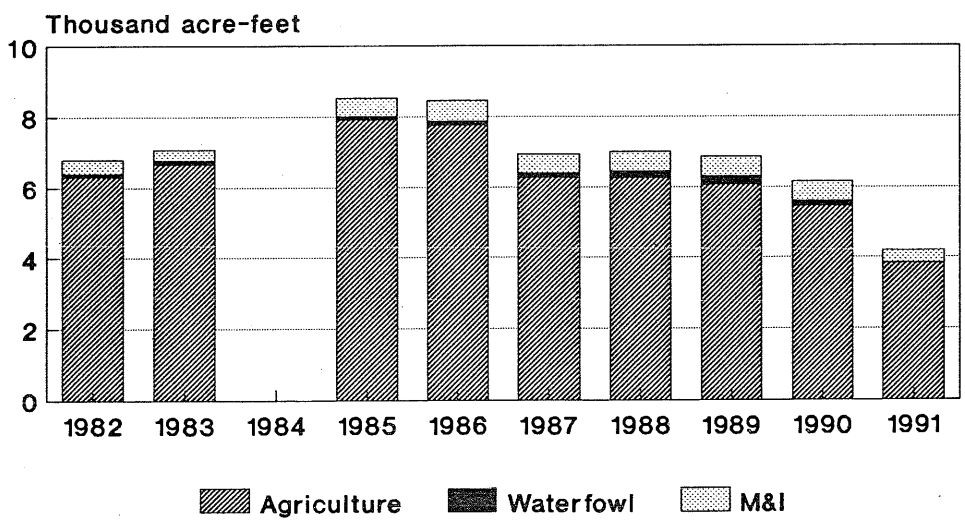
Sources: CDWR 1990a; P. Romero, pers. comm. May 1991.

Figure 6
State Water Project Deliveries
1982-1991



Note: 1991 figures are projections by
CDWR staff.
Source: CDWR, 1990d.

Figure 7
Central Valley Project Deliveries
1982-90



Note: 1991 figures are rough estimates
as of April 1991.
Source: USBR 705 reports.

a Water Bank to assist in the transfer of water resources. The State Water Bank was set up to "broker" the distribution of water through existing State and Federal water distribution systems, and to meet critical water needs for (1) urban areas, (2) the agricultural community, (3) fish and wildlife, and (4) a continuation of the drought into 1992.

Water for the Bank is being acquired from three sources: (1) the idling of farm land, (2) additional ground-water pumping, and (3) surplus surface water in reservoirs. The Water Bank is paying $125 per acre-foot of water, and charging $175 per acre-foot of water (plus additional costs of transporting the water from the Sacramento/San Joaquin Delta to the point of use).

Water purchased by the Bank can be allocated among five categories of demands.

1. Emergency water needs of cities and communities;

2. Critical water needs for permanent crops and for urban areas with a greater than 25 percent water deficiency;

3. Other "critical" needs, such as the requirement for carryover water in 1992;

4. Additional water needs for permanent crops and urban areas to reduce economic harm; and

5. Water for the State Water Project, which is serving as final purchaser of surplus Water Bank supplies.

As of June 19, 1991, 751,233 acre-feet of water had been purchased (signed contracts or contracts in review). Over 420,000 acre-feet of water had been allocated, all to category 2 users. Table 4 lists water purchased by the Bank and the sources of that water. The Water Bank expects to allocate considerably more water over the next few months, with sales totalling 650,000 to 700,000 acre-feet.

Some of the water purchased by the Bank cannot be delivered to agricultural and municipal users because of losses in the system. For example, some fraction of the water that flows through the Delta is lost to San Francisco Bay. Other than these losses, no water has yet been explicitly reserved for natural ecosystems and wildlife refuges.

Table 4: California State Water Bank — Water Purchased as of June 19, 1991.

By Region	Contracts Signed	Contracts In Review
Delta		
Number of Sellers	265	32
Acre-Feet	307,817	26,285
Sacramento River		
Number of Sellers	12	8
Acre-Feet	62,673	29,261
Yolo County		
Number of Sellers	4	3
Acre-Feet	38,141	16,116
Yuba/Feather/Elsewhere		
Number of Sellers	9	4
Acre-Feet	117,106	147,100
Above Shasta Reservoir		
Number of Sellers	14	0
Acre-Feet	6,734	0
TOTAL		
Number of Sellers	**304**	**47**
Acre-Feet	**532,471**	**218,762**

By Source of Water	Acre-Feet
Fallowing agricultural land	391,778
Ground water purchase	222,455
Excess stored water	137,000
Total water purchased	**751,233**

Source: CDWR, "Drought Water Bank Update" (June, 19,1991). D. Marty, CDWR, pers. comm.

IMPACTS OF THE DROUGHT

The focus of this study is to evaluate the economic and environmental implications of the current California drought. The drought is not yet over, and many of the costs have yet to be felt, including the agricultural losses, the effects on natural ecosystems, and impacts to national forests and the timber industry that will be suffered in the summer and fall of 1991. Nevertheless, many impacts have already occurred and can be evaluated today.

Among the most important consequences of the prolonged drought in California are the widespread effects on natural ecosystems, including the diverse fresh-water and anadromous fisheries of the State, increased costs for fossil fuel energy to replace lost hydroelectric generation, penetration of salt water into the Sacramento-San Joaquin Delta, shifts and losses of agricultural and livestock production, and substantial forest damage from pests and fire. These impacts are described below; where possible, hard data and economic estimates are presented.

Major State and Federal resources have been mobilized to handle the drought. The California Department of Water Resources (CDWR) has set up a State Drought Center to coordinate drought education, information dissemination, and planning. The 1992 fiscal year budget includes an extra $50 million for technical and financial assistance to communities for conserving water and developing new supplies, for water reclamation, and for fighting fires.

Natural Ecosystems

Throughout California, natural ecosystems have been diminished and weakened as a result of human encroachment. Consequently, ecosystems are now more vulnerable to extreme droughts than they might otherwise have been. In many cases, the drought has exacerbated long-term trends, particularly in the case of aquatic and riparian resources.

In this report, we discuss those trends and problems that in our opinion have been exacerbated by the drought and for which information is available. We have not attempted to establish a quantitative baseline for ecological impacts because it is not possible to disaggregate the effects of pollution, overexploitation, habitat destruction, and introduced species. Nor is it possible to assess ecological impacts in their entirety. Most changes in ecological systems are not discovered until long after they have occurred, and it is impossible to study systems comprehensively. Consequently, scientists and policymakers alike must rely on indicators of ecological health and try to infer the broader impacts.

A final problem is that ecological impacts cannot be easily or adequately quantified in economic terms, making it difficult to equate and compare impacts across sectors. Thus, although we provide some economic information for fisheries where it is available, most comparisons across sectors are necessarily qualitative.

Salmon Fisheries

The impacts of the drought on fisheries and aquatic resources are more obvious than terrestrial impacts, particularly for those species such as salmon in which survival shows a good correlation to flow (USFWS, 1987). The following information on salmon harvest and abundance is drawn from the Pacific Fishery Management Council publication, Review of 1990 Ocean Salmon Fisheries (PMFC, 1991).

Coho and chinook salmon catch off the coast of California have been declining over the past four years. In 1988, a record 14.8 million pounds were harvested, representing $45 million in revenue (1990 dollars). In part, this reflected the success of the year class raised during the high runoff year of 1986. In 1990, the salmon harvest was only 4.4 million pounds; the current estimate for 1991 is still less, 2.5 million pounds, which represents only $12 million. Annual salmon catch and catch value are shown in Figure 8.

In addition to ocean harvest, spawning escapement -- the number of fish that successfully complete the trip upstream to spawn -- may be an indicator of drought impacts. Spawning escapement has been declining on all major California rivers during the current drought, with the greatest declines occurring during 1990. This most likely reflects the combined effects of reduced water flows in 1990 and weak year classes that were spawned during the first years of the drought.

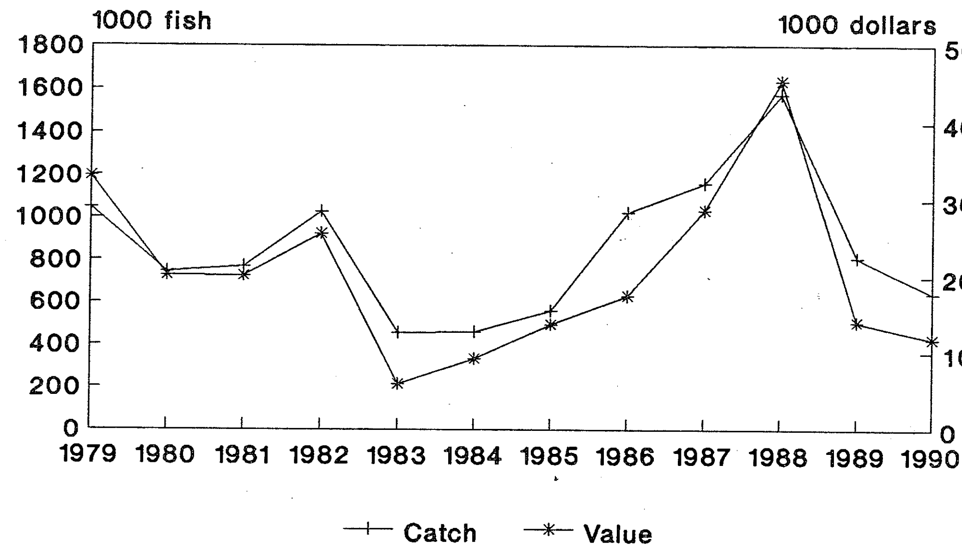
The major salmon runs in California occur within the Sacramento-San Joaquin system. In 1990, a total of 120,000 fall-run chinook salmon returned to spawn in the Sacramento River Basin, 21 percent below the 1989 escapement and 26 percent below the 1971-75 average. In the San Joaquin River, escapement of fall chinook was estimated at 1,100 fish, was only 8 percent of the 1971-75 average and was the lowest run since the 1976-77 drought (Figure 9).

Although the fall-run chinook comprise the major salmon fishery in California, three other distinct runs also occur: late-fall, winter, and spring. All of these runs have undergone significant declines over the last 5 years (Table 5). The winter run, which is already classified as a threatened species, has reached such low numbers that it may be near extinction.

Outside of the Sacramento-San Joaquin area, salmon populations are also declining. Spawning escapement on the Klammath River in 1990 decreased 70 percent over the previous year and was the lowest since 1978. Harvests also declined substantially. Preliminary estimates of 1990 escapement on the Mad and Eel rivers indicate that virtually no salmon spawned in these areas. One of the major spawning tributaries was inaccessible due to low flows.

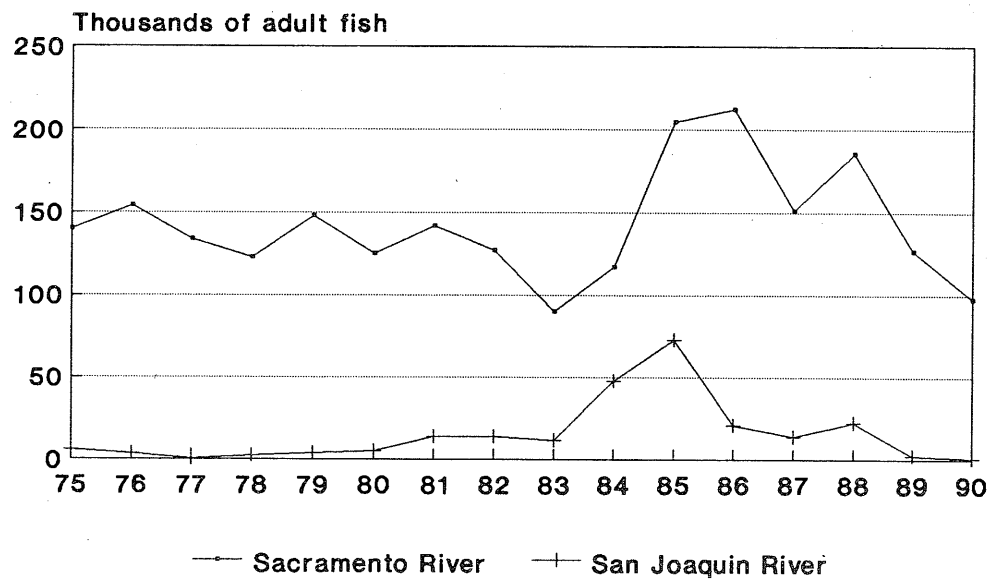
Several attempts have been made to estimate the economic value of California salmon, primarily in order to compute benefit-cost ratios for various water-development projects. Values can vary widely, depending on whether they represent values to the user only, or include secondary and non-consumptive estimates (Meyer Resources, 1987). Richardson and Harris (USFWS, 1990) give a range of values derived from various

Figure 8
Troll salmon (chinook and coho) landed in California, 1979-1990



Note: Value is given in 1990 dollars.
Source: PFMC, 1991.

Figure 9
Central Valley natural fall-run chinook salmon spawning escapement, 1975-90



Source: PFMC, 1991.

Table 5: Sacramento River late-fall, winter, and spring chinook salmon spawning escapement estimates, 1981-1991.
(Thousands of fish)

Year	Late-fall	Winter	Spring (b)
1971-75 (a)	19.0	30.6	7.2
1976-80 (a)	11.2	15.4	11.7
1981	7.0	20.0	22.0
1982	4.9	1.2	27.4
1983	15.2	1.8	8.0
1984	10.4	2.6	9.4
1985	10.2	5.0	14.9
1986	7.0	2.3	17.2
1987	15.7	2.3	12.4
1988	16.6	2.1	16.7
1989	11.4	0.5	10.8
1990	8.4	0.5	8.3
1991	7.1	na	na

na== not available.

Notes: (a) 5-year average.

(b) Spring-run totals include Feather River hatchery fish.

Source: PFMC, 1991.

investigators for the consumptive-use value of salmon spawners. They indicate that the value of a spawning chinook salmon in the upper Sacramento exceeds $300, in 1990 dollars. Thus, an overall decline of approximately 50,000 fish between 1985 and 1990 could represent at least $15 million in direct economic losses on the Upper Sacramento River alone. Because this value does not reflect non-consumptive values, it is minimum value and should be considered an underestimate. Moreover, it does not include indirect economic losses resulting from overall declines in economic activity such as decreased demand for fishing and canning services and equipment.

San Francisco Bay and Delta

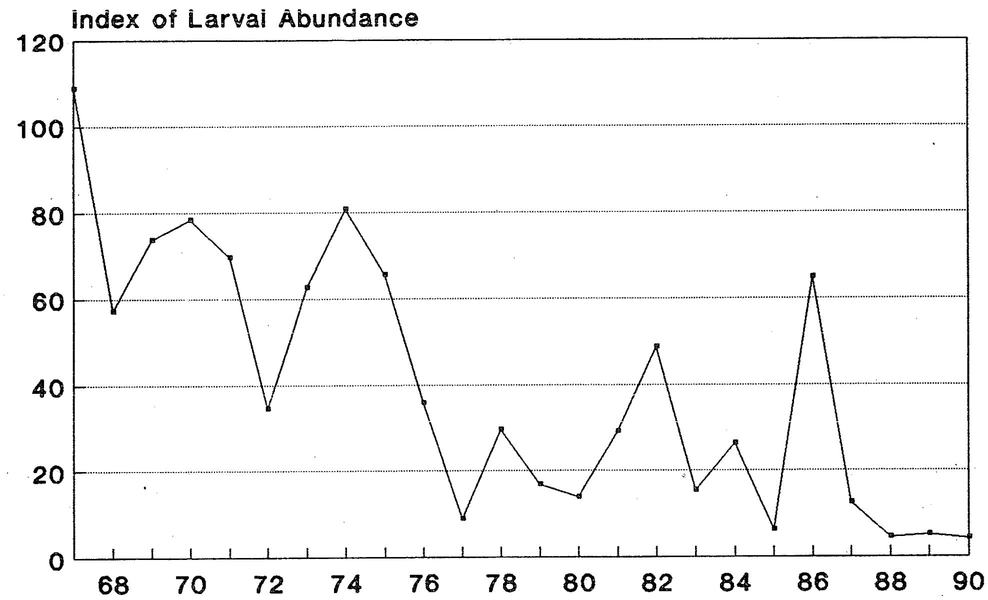
San Francisco Bay is one of the world's largest estuaries and is recognized as one of California's most unique ecological resources. The Bay is vulnerable, however, to reduced freshwater inflows from the Sacramento and San Joaquin Delta (referred to as Delta outflow). Although the overall impact of reduced freshwater inflows is a contested topic, for certain species reduced Delta outflow is highly correlated with declines in abundance. In February of 1991, CDWR formally requested that the State Water Resources Control Board relax Delta water-quality standards so that greater reservoir storage could be retained without further reducing Delta exports; however, this request was dropped following the March rains.

The most widely cited indicator of the Bay's ecological health has been the striped bass, an introduced species that comprises the principal sport fish in the estuary. The subsidiary industries surrounding striped bass fishing are estimated to bring $45 million into the local economies, while declines in the fishery since 1970 are estimated to have cost the State more than $28 million (Meyer Resources, Inc., 1985).

Striped bass populations have been declining since the beginning of the current drought in 1987. In 1990, the index of larval abundance was the lowest ever recorded (Figure 10). Although there are many hypotheses concerning the causes and mechanisms of declines in striped bass population, the striped bass index has shown a strong correlation with Delta outflow. Herbold, et al. (1991) recently argued that the most likely mechanism for declines in striped bass during low-flow years is the increased entrainment of eggs in Delta water pumps. Estimates of effective reduction from entrainment were 73 and 84 percent in the dry years of 1985 and 1988, respectively (cited in Herbold, et al., 1991). Although other mechanisms of mortality may be equally or more important, declines in freshwater inflows are likely to be exacerbating the problems that the fishery faces.

For the past five years, the reduction of freshwater inflows into the estuary (referred to as "Delta outflow") have permitted extensive summer salinity intrusion throughout the Delta and have altered the location of the entrapment zone, which is critical to the overall health and ecologic productivity of the estuary. As the entrapment zone moves further upstream, it reduces the overall abundance of phytoplankton, the base of the estuary's foodweb (Williams, 1989; Arthur and Ball, 1979). During 1988 (the most recent year for which data have been compiled), overall phytoplankton activity in the northern bays and the Delta was lower than before the current drought began. Standing crop levels remained below background levels throughout 1988. A review of historical data suggests that

Figure 10
San Francisco Bay Striped Bass Index



Source: CSWRCB, 1991;
D. Daniel, CDFG, pers. comm.

reductions in chlorophyll *a* concentrations coincide with periods of abnormally low flows (CDWR, 1990; Williams, 1989).

One particularly disturbing change in the estuary has been the recent invasion and success of an accidentally introduced clam species, Potamocorbula amurensis, into San Pablo and Suisun Bays. This species has been able to establish itself in part as a result of low Delta inflows, and because it can tolerate a very wide range of salinities and therefore may not be easily dislodged by the return of higher flows (P. Moyle, UC Davis, pers. comm.). This invader is linked with the decline of copepod and other zooplankton populations in Suisun Bay and is believed to be successfully out-competing native invertebrate populations and reducing the food supply for fish populations as well (Herbold, et al., 1991).

Reduced freshwater inflows also affect the migration of anadromous fish, particularly salmon, through the estuary. When Delta outflow is reduced, smolt survival is greatly reduced due to increased temperature, predation, diversion pumps and reverse flows (USFWS, 1987, 1989).

The reduction of freshwater inflows has also affected the survival of the Delta smelt, currently under consideration for listing as a federally threatened species. The abundance of Delta smelt declined sharply after 1984 and is closely correlated with the frequency of reversed flows in the Delta. The drought is believed to have exacerbated the smelt's decline (Herbold, et al., 1991; Williams, 1989).

Impacts on Other Fisheries

While most of the attention to environmental impacts has thus far focused on the San Francisco Bay-Delta region, fisheries have suffered throughout the State as a result of reduced water supply, increased temperatures, and decreased water quality.

In Tomales Bay, located north of San Francisco along the Point Reyes National Seashore, the local herring fishery has been destroyed, at least temporarily, due to several years of low flows. Historically, spawning biomass in Tomales Bay has ranged from 6,000 to 10,000 tons; in 1990-91, spawning biomass was down to 1800 tons (Table 6). The California Department of Fish and Game has closed the fishery to harvest since 1988. CDFG biologists believe that reduced freshwater inflows and consequent increases in salinity are the most likely explanations for the decline (F. Henry and T. Moore, CDFG, pers. comm.) The primary inflow into the Bay is Lagunitas Creek, the primary source of municipal water for Marin County, which has been hard hit by the drought. In response to concerns over urban water supply, Marin County has been increasing its water storage and consequently decreasing inflows into Tomales Bay. A major concern is whether the current trend is reversible. Because herring "home" to their spawning grounds, it is possible that once the spawn drops below a critical level, it will not recover (T. Moore, CDFG, pers. comm.).

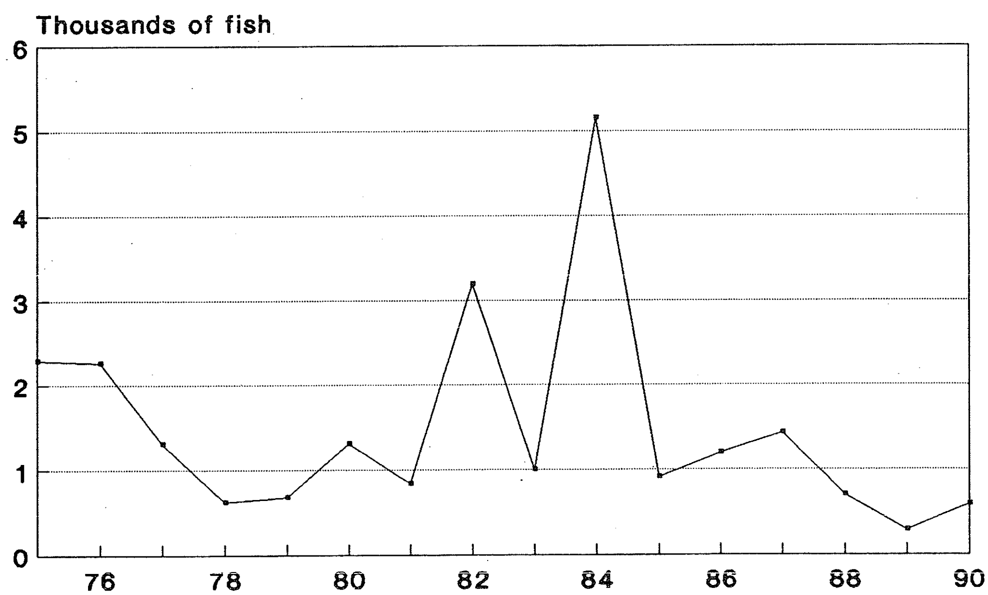
Steelhead runs on the Sacramento River system have also been declining dramatically over the past several years. Returns to the Nimbus hatchery on the American

Table 6: Spawning biomass of herring in Tomales Bay.

Year	Biomass (tons)
1987–88	6000
1988–89	300
1989–90	245
1990–91	799

Source: F. Henry, CDFG, pers. comm.

Figure 11
Annual returns of steelhead to the Nimbus Hatchery on the American River



Source: Ducey, 1991.

River suggest that the low flows and high water temperatures brought on by the drought have exacerbated this trend (Figure 11).

Due to the highly altered condition of California's rivers, substantial quantities of fish are now reared in hatcheries. While this may be a problem in itself, the drought has had substantial effects on hatchery success over the past four years. The major problems include:

(1) Reduced or inadequate water supply on the Eastern slope of the Sierra Nevada to support inland trout hatcheries (Hot Creek, Fish Springs). At one hatchery (Hot Creek), flow has decreased by more than one-third (K. Hashagen, pers. comm.).

(2) Elevated temperatures at anadromous fish hatcheries. Elevated temperatures may reduce spawning success and survival, while critical temperatures (usually above 68°F) will immediately kill salmonid larvae. Temperature problems are directly related to reservoir storage levels. When reservoir storage is low, water that is released comes from the near the surface and is consequently warmer. In the last two years, some temperature problems have occurred below all the major dams but have been particularly severe at the Nimbus hatchery on the American River. In 1988, temperatures above 65°F occurred on 105 days, while the number of days exceeding 62°F was 143 (F. Meyer, CDFG, pers. comm.)[1]. During September and early October of 1990, water temperature at the hatchery was in the high 60s to low 70s (Smith, 1991), resulting in the loss of two batches of hatchery fingerlings. An indirect effect of elevated temperature is that it has delayed spawning on the American River. While spawning usually begins around the first week in November, last year it did not begin until the last week in November. Because the rivers are so highly managed, this delay has a substantial negative effect on survival (F. Meyer, CDFG, pers. comm.).

(3) Increased predation by birds, due to lack of other avian food sources. For example, 40,000 catfish were lost at the Salton Sea hatchery. The Salton Sea has dropped to such low levels that natural fish spawning habitat has virtually disappeared, forcing birds to prey on hatchery ponds. Private aquaculture is also suffering (K. Hashagen, CDFG, pers. comm.).

Impacts on Waterfowl and Wildlife Refuges

The Central Valley of California lies in the Pacific Flyway and supports millions of wintering waterfowl. These populations have been declining dramatically in California over the last decade. Long-term averages place the wintering population at between 10 and 12

[1] Generally 57°F is cited as the upper temperature threshold for successful salmon egg incubation, although many researchers consider this too high (USFWS, 1990).

million in 1980, while last winter's population was estimated at around 2 million.[2] While waterfowl populations are being affected by several factors aside from the drought, the current drought is exacerbating these losses by reducing the quantity and the quality of wetlands habitat in the Central Valley.

Most wetlands that support these populations lie in State and national wildlife refuges that are flooded by water from the SWP and the CVP. From 1975-1985, average annual water deliveries to the refuges have been 381,550 acre-feet. However, in order for the current potential of refuges to be fully used, an annual water supply of 493,000 acre - feet would be needed (Table 7).

In 1990, refuges received about 250,000 acre-feet, a decline of 35 percent compared to past average annual deliveries. In 1991, the refuges have a firm supply of 121,713 acre-feet, but are likely to obtain at least 200,000 acre-feet (R. Daniel, CDFG, pers. comm.). Reduced water supply may be managed in several ways: reducing the depth of flooding, reducing the period of flooding, and planting less water-intensive grasses and plants. The actual acreage that is flooded is unlikely to change substantially; however, the quality of the habitat will decline, which in turn will adversely affect the health and survival of avian populations (R. Daniel, CDFG, pers. comm.).

Private duck clubs in the Central Valley also provide substantial waterfowl habitat. Last year, overall water reductions to private duck clubs were on the order of 25 percent to 50 percent (D. Daniel, CDFG, pers. comm.); this year, the cutbacks have been significantly greater. Among the areas most dramatically affected are the west side of the Sacramento Valley, and the Bakersfield-Kern County region. However, duck clubs are often able to secure additional supplies at the last minute, and an unofficial estimate places likely water supplies to private duck clubs at about 50 percent to 75 percent of normal in the current year (D. Chapin, pers. comm.).

Impacts on Forest Ecosystems

The current dry conditions are resulting in the mortality of many forest plants including perennial shrubs and tress. In some forest areas there are contiguous stands, measured in thousands of acres, where from 30 percent to 80 percent of the trees are dead or dying while in other areas mortality occurs in scattered clumps. The most significant mortality is occurring in the conifer forests of the central Sierra Nevada, with red and white firs suffering the most extensive damage (for the impacts of the drought on the forest industry and wildfire risks, see section below on **Forestry and Fire**).

The effect of drought and tree mortality on aquatic resources is most pronounced at the mid- and lower-slope zones in the Sierra Nevada. Until vegetation is restored to normal, runoff will be early and of short duration. The loss of streamside shade will cause

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[2] Testimony of John Turner, Director, US Fish and Wildlife Service, before the Subcommittee on Water, Power, and Offshore Energy Resources, House committee on Interior and Insular Affairs, regarding the impact of the California drought on fish and wildlife resources.

Table 7: Water Supply Needs (in acre-feet) for Wildlife Refuges in the Central Valley.

Refuge	Level 1		Level 2	Level 3	Level 4
Modoc NWR	18,500		18,550	19,500	20,550
Sacramento NWR	0		46,400	50,000	50,000
Delevan NWR	0		20,950	25,000	30,000
Colusa NWR	0		25,000	25,000	25,000
Sutter NWR	0		23,500	30,000	30,000
Gray Lodge WMA	8,000		35,400	41,000	44,000
Total Sacramento Valley	26,550		169,800	190,500	199,550
Grassland RCD (a)	50,000		125,000	180,000	180,000
Volta WMA	10,000		10,000	13,000	16,000
Los Banos WMA	6,200		16,670	22,500	25,000
Kesterson NWR	35,000		3,500	10,000	10,000
San Luis NWR	0		13,350	19,000	19,000
Merced NWR	0		13,500	16,000	16,000
Mendota NWR	25,463	(b)	18,500	24,000	29,650
Pixley NWR	0		1,280	3,000	6,000
Kern NWR	0		9,950	15,050	25,000
Total San Joaquin Valley	95,163		211,750	302,550	326,650
TOTAL	121,713		381,550	493,050	526,200

Level 1: Existing firm water supply.
Level 2: Current average annual water deliveries.
Level 3: Full use of existing development
Level 4: Optimum management if refuge were fully developed.

(a) As of 1985, Grassland RCD no longer recives agricultural drainage flows due to water-quality concerns.

(b) Only 18,500 acre-feet can be delivered to the Mendota WMA without modifications of existing facilities.

Source: USBR, 1989

water temperature increases that will in turn affect fish.

There is also a concern that seral habitat will be severely reduced by drought, fire, insects, and harvest. Ultimately this could result in insufficient amounts of diversified habitat to meet the needs of all species (USFS, 1991).

Other Terrestrial Impacts

Data illustrating the impact of the drought on terrestrial species is largely unavailable at this time. To date, several pieces of anecdotal evidence have been collected that suggest the drought is having tremendous impacts throughout the State. According to the US Fish and Wildlife Service[3], some of the major impacts include:

- Both nesting and wintering bald eagles may be affected by the reduction in reservoir pools statewide. Nesting bald eagles in the Santa Ynez basin in particular are a major concern. Elimination of an entire reservoir pool may occur and will certainly affect that populations' success.

- The drying up of riparian zones will adversely impact populations of the endangered Least Bell's Vireo and their proposed critical habitat.

- The native annual and short-lived herbs of California, including the ten species already listed on the endangered species list and the numerous high-priority candidate plants from the Central Valley, are being severely affected. The lack of sufficient rainfall has brought about the temporary disappearance of numerous populations of listed and candidate annual plants. Moreover, the drought has caused a reduction in annual seed production, reducing the "seed bank" that maintains these fragile populations.

- This reduction in vegetation, especially in seeds, has adversely impacted the three federally listed kangaroo rats and numerous other small mammals. Some kangaroo rat populations have collapsed in the southern San Joaquin Valley. These losses of small mammals have adversely affected the listed San Joaquin kit fox, which preys primarily on small rodents. The blunt-nosed leopard lizard has been adversely impacted by reduced availability of food as well.

- The giant garter snake, a species that is listed as threatened by the State of California, depends on seasonal permanent sloughs and slow-moving creeks. It is suffering widespread habitat loss due to the drought.

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[3] Testimony of John Turner, Director, US Fish and Wildlife Service, before the Subcommittee on Water, Power, and Offshore Energy Resources, House committee on Interior and Insular Affairs, regarding the impact of the California drought on fish and wildlife resources.

- Invertebrate populations are being severely impacted. The endangered California fresh water shrimp is suffering critical loss of habitat because of reduced stream flow.

- Almost all of the 9 species of endangered butterflies in California are experiencing population declines verging on extinction because the drought has virtually eliminated growth of their host plants. Vernal pool species, such as the candidate fairy shrimp, are undergoing major habitat loss as desiccated vernal pool areas are also reduced. The valley elderberry longhorn beetle, a species dependent on riparian vegetation, is declining as efforts to cope with the drought cause habitat loss.

In summary, in spite of the fact that the impacts of the drought on ecological resources have yet to be well-documented, available evidence indicates that the impacts are severe and may, in some cases, even be irreversible. Many of the State's ecological resources were already declining; the drought has exacerbated these existing problems. The impact of the drought can be seen more directly on aquatic species, such as salmon, and waterfowl; however, the impacts on many other species have yet to be considered, but may be equally or more severe.

The loss of ecological resources may have direct economic impacts on the State as well. Tourism and recreation, the State's most important industry, is affected by the declines in wildlife and natural resources. This is discussed more in another section of this report. In addition, the fishing industry, both recreational and commercial, is affected by the loss of aquatic resources. And, as in agriculture, the impact is not uniformly distributed across the State, but falls heavily on a few local communities. The greatest concern with respect to ecological resources is whether or not they have the ability to recover once the drought ends. The evidence indicates that some species, such as winter-run chinook salmon and delta smelt, may become extinct during the drought. This suggests that some ecological losses, unlike economic losses, may be irreversible. We will not know the full cost of these losses until long after the drought is over.

Agriculture

Undoubtedly the drought has reduced agricultural income over what it might have been in 1990 and 1991, although it has not been the disaster that some had expected. Although the drought began in 1987, surface-water deliveries to agricultural users were not reduced until 1990. Prior to 1990, there were no significant impacts on the agricultural sector, and, for the most part, impacts in 1990 appear to have been minimal (Cannon, 1990; CDOC, 1990)[4]. Planted acreage for most crops increased (CASS, 1991a,b). Gross cash

[4] One exception to this conclusion is found in an estimate released by the California Department of Water Resources in October of 1990 that estimated that should the drought end in 1990, the direct losses in gross agricultural income would be $537 million over two years and that most of this would come as a result of fallowing productive land. Indirect impacts (i.e. overall decreases in economic activity through things such as lost equipment sales) were estimated to be an additional $206 million (CDWR, 1990b). The DWR estimate

receipts for farm products reached nearly $18 billion in 1990, a record high and a 3 percent increase over the previous year, despite the drought (R. Borten, CASS, pers. comm.) (Table 8). In 1991, farmers have suffered much greater shortages of surface water and consequently economic impacts in the farm sector will be greater. However, impacts in 1991 will largely be mitigated by firm prices, the availability of groundwater, and the overall strong financial position of the agricultural sector.

In general, declines in surface water availability may be met with four possible responses: (1) increases in ground-water use; (2) investments in water-saving irrigation technology; and (3) switching to less water-intensive and/or higher value crops; and (4) the fallowing of land that would otherwise be planted. Conversations with farm officials and water-district managers suggest that little investment in new irrigation technology has occurred thus far, and that the overwhelming response to the current drought appears to be increases in ground-water use. In addition, some crop-switching and fallowing has occurred.

Increased Ground-Water Usage

The most recent estimates of changes in ground-water supply indicate that ground-water storage in the San Joaquin Valley has declined dramatically over the last two years (Figures 4 and 5). For example, in Kern County, ground-water storage declined by 1 million acre-feet between 1989 and 1991 and the water table dropped by 10 feet. In Tulare County, storage levels declined by 1.7 million acre-feet and ground-water levels dropped by almost 20 feet. In 1988, DWR estimated the cost of ground-water pumping in the region to be between 42-44 cents/acre-foot per foot of lift, with average lifts ranging from 95 to 100 feet. Assuming conservatively a lift in 1988 of 95 feet in Kern and Tulare counties, the increase in the average per unit cost of ground-water pumping would be $7.50 in Kern (to $48/acre-foot) and $11.76 in Tulare (to $52/acre-foot).

Crop-switching

Reduced water supplies are augmenting a trend away from low-value field crops and toward higher value fruit, nut, and vegetable crops. This trend is largely in response to increased demand growth, increased farm income, and an increase in agricultural land values. Debt in the farm sector has decreased from $10.7 billion in 1983 to $7.9 billion in 1990 (Howe, 1991). Land values have been increasing over the last two to three years, reversing a downward trend that began in the early 1980s. According to a Bank of America estimate, the value of row-crop land in the San Joaquin Valley reached a nadir of $1,967

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used 1989 acreages and prices as the baseline and calculated the revenue loss from additional fallowing. In retrospect, this appears to have been an overestimate for two primary reasons. First, the analysis over-predicted the amount of fallowing that actually occurred as a result of the drought. New data on agricultural production and planted acreage suggests that the initial CDWR estimates were too high (CASS, 1991a,b). Secondly, the estimate assumed that prices would not rise as a result of declines in California output. In fact, prices have been firm or rising.

Table 8: Economic Indicators for California Agriculture
(In billions of dollars)

	1986	1987	1988	1989	1990 (a)
Cash Receipts	$14.81	$15.80	$16.62	$17.50	$18.30
Exports	$2.84	$3.33	$4.00	$4.00	$5.00
Gross Farm Income	$15.72	$17.12	$17.74	$18.40	$19.35
Production Expenses	$10.90	$11.42	$11.54	$11.90	$13.08
Net Farm Income	$4.82	$5.70	$6.20	$6.50	$6.27

Note: (a) 1990 export figure is a Bank of America estimate.
Source: Cannon, 1990 for most figures; CASS, 1990a;
R. Borton, C. Weems, CASS, pers. comm.

per acre in 1987 and climbed by 12 percent to $2,218 per acre in 1990 (Cannon, 1990). In 1991, there is additional evidence for crop-switching, notably in cotton-growing regions, where the reduced availability and higher price of water make it profitable to invest relatively more in an acre of land (R. Borten, CASS, pers. comm.; M. Henry, CFB, pers. comm.; CASS, 1991a; Krauter, 1991).

Idling of Farmland

In addition to increased ground-water pumping, some land has been idled as a result of the drought, although it is very difficult to determine to what extent the drought, independent of other factors, has altered planting decisions.

In mid-May, the California Farm Bureau published estimates of idled acreage that indicated that total acreage would decline by 600,000 acres over 1990 (Table 9) (Krauter, 1991). This estimate, however, included idling from all causes and indicated that the freeze, the wet spring weather, and sales to the Water Bank had all had a major impact on planting decisions and acreage. As of June 1, sales to the Water Bank had idled an estimated 162,000 acres (Table 10). While sales to the Water Bank are drought-induced, they do not necessarily represent hardship or economic losses. In fact, to the extent that water is transferred to higher bidders, the fallowing of land by water sales should represent an economic gain. Consequently, it is not appropriate to attribute all of these idled acres to reduced water supply.

The crops most likely to be fallowed in response to reduced water availability are field crops. In 1990, however, cotton acreage actually increased, while rice acreage declined only modestly, and crop revenues remained high. More generally, Figures 12 and 13 show how cotton and rice acreage and crop value have varied even in the absence of a drought. Industry representatives currently predict that cotton acreage in 1991 will be only 965,000 acres, down from 1,070,000 in 1990; and rice acreage will be 325,000 acres, down from 390,000 planted in 1990 (J. Roberts, Rice Industry Association, pers. comm.; G. Lundquist, Calcot, pers. comm.) Both rice and cotton acreage, however, are affected by federal set-aside programs, as well as by reduced water supplies.[5] Winter wheat was planted on only 390,000 acres, well below the 620,000 acres seeded last year. Sugar beet plantings will be reduced to 150,000 acres, compared to 173,000 in 1990 (CASS, 1991c). In addition, some of the crops most likely to decline as a result of the drought are also declining as a result of sales to the State Water Bank. As of mid-June, 162,000 acres had been fallowed by water sales, most of these coming from corn and irrigated wheat.

[5] In order to obtain set-aside benefits, a rice farmer must cut back his base acreage by an announced percentage each year. The base acreage is an average of the acres planted over the preceding five years. For the past 3 years, a 20% to 25% set-aside has been required and rice acreage has declined accordingly. For cotton, 12.5% of a farmers "payment acres" must be set aside to qualify for the program. In Kern County, the major cotton-producing region, 30,000 acres of cotton were set aside in 1990 while the harvested acreage for the county was 290,000.

Table 9: California Farm Bureau estimates of idled land in 1991.

Crop	1000 acres
Safflower	30
Corn for grain	50
Dry Beans	25
Wheat for grain	140
Sugar beets	25
Cotton	217
Rice	95
Other	15
Total	597

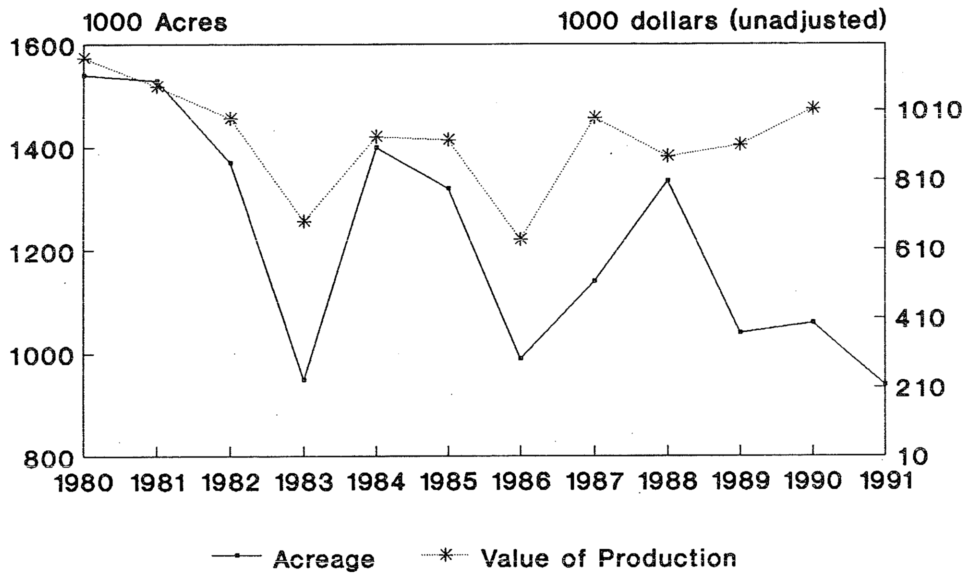
Source: Krauter, 1991.

Table 10: Acres fallowed by sales to the State Water Bank (As of June 1, 1991)

Crop	Acres
Corn	58,384
Wheat	41,121
Pasture	13,799
Sugar beets	9,648
Alfalfa	9,500
Dry beans	4,026
Other	
Total	161,732

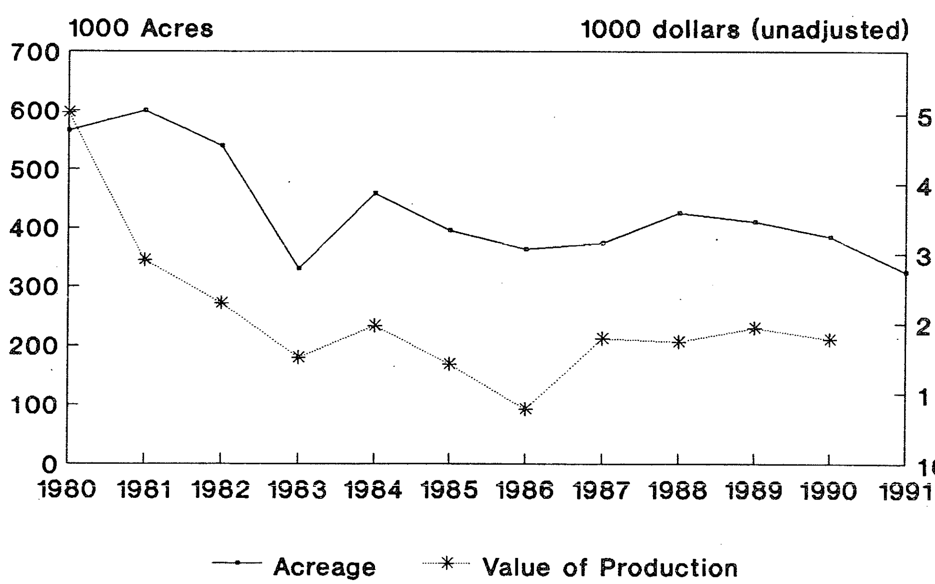
Source: D. Marty, CDWR, pers. comm.

Figure 12
California Cotton Production
1980-91



Source: CASS, 1990b, 1991b.

Figure 13
California Rice Production
1980-91



Source: CASS, 1990b, 1991b.

It appears that no permanent crops (trees and vines) will be lost to the drought this year. Water from the State Water Bank has been made available for perennial crops, although there has been only modest interest from farmers in purchasing this water at $175/acre-foot plus transportation costs. (See preceding section on the State Water Bank).

It is difficult to predict the economic impact of fallowing because, in general, farmers will fallow their most marginal land, therefore average income-per-acre calculations tend to overstate impacts. In the case of field crops, some farmers will also benefit from set-aside programs.

Estimates of Statewide Economic Impacts on Agriculture

While many estimates have used a recent "normal" year (e.g. 1989) as a baseline for comparing acreages and agricultural profits, this ignores the fact that several other variables affect the agricultural economy in any given year and thus results in an overestimate of drought impacts. Among the most important factors that vary on an annual basis are current prices, the amount of debt in the farm sector, subsidy and set-aside programs, and climatic variables. In 1990-91, for example, harvested acreage and yields were affected dramatically by a winter freeze. Yields of nuts, citrus, and winter vegetable crops have been lower. Similarly, yields of sugar beets, another crop largely affected by the drought, have also declined due to the freeze. In addition, the cool, wet spring has reduced both the acreage and yields of some crops, notably cotton (G. Lundquist, Calcot, pers. comm.).

Recently, DWR analysts have prepared a preliminary estimate of impacts expected in 1991. Relying on estimates of drought-idled land provided by the California Farm Bureau in mid-May (Krauter, 1991) as well as their own research, DWR's preliminary estimate is that roughly 600,000 acres will be idled and that the corresponding decline in cash receipts would be roughly $400 million. Using a multiplier to estimate indirect impacts of these losses, CDWR concluded that total losses to the California economy as a result of idled land would be roughly $1 billion (Kershen, 1991; D. Priest, CDWR, pers. comm.). As mentioned above this estimate may be too high because it attributes all declines in acreage to the drought and because of the relatively strong prices that are expected for agricultural products in 1991.

A different estimate of potential agricultural impacts in 1991 was made by Professor Richard Howitt, an agricultural economist at UC Davis. Using a quadratic programming model calibrated to 1987 cropping patterns and water usage, Howitt assumed that surface water deliveries would decline by 80 percent statewide, ground-water use would increase by 70 percent, the average cost of water would double, 95 percent of the State's perennial crops would receive enough water to produce normal yields, and the per-acre yield of annual crops would be close to normal. Howitt's model predicted that overall acreage in the State would decline by 14 percent compared to 1987 levels, with the major reductions coming in alfalfa, cotton, grain sorghum, and irrigated pasture. The net loss in farm income using these assumptions was predicted to be $650 million.

Local Impacts

The impacts of the drought have not been equally distributed across the State but have been concentrated in a few regions. Southern California farmers rely on Colorado River water and are not currently facing any reductions in surface-water supply. Among the regions hardest hit are the southern San Joaquin Valley, where ground-water supplies are scarce or non-existent, and the Central Coast region, where there is extensive dryland pasture and a high dependence on ground water. Most areas of the State will not fallow any land as a result of the drought. The major exception is the southern San Joaquin Valley. More detailed information is presented below for two of the major irrigation districts in the Southern San Joaquin Valley -- Kern County Water Agency and Westlands Water District -- as well as for the Glenn-Colusa Irrigation District, a large district in the Sacramento Valley, which is the State's major rice-growing region.[6]

(1) Kern County Water Agency

Kern County Water Agency (KCWA) is a large agricultural water district in the southern San Joaquin Valley. Because of its reliance on State Water Project water and the unavailability of ground water in much of its service area, it has been among the districts hardest hit by agricultural water cutbacks.

There is no strong evidence that fallowing due to the drought occurred in the region last year. In fact, total harvested acres in the county continued to increase, from 850,000 in 1989 to 915,000 in 1990. This year, however, KCWA's surface-water supply is expected to be only 783,000 acre-feet compared to an average supply of 2,154,000 acre-feet over the last 10 years.

In early 1991, KCWA funded a study of the economic impacts of proposed water cutbacks on 5 water districts that rely solely on deliveries from the State Water Project. They concluded that if no water were available to produce annual crops, gross output would decline by $221 million and that lost wages and salaries, both direct and indirect, would total $113 million (Northwest Economic Associates, 4/17/91). Although widely cited as an authoritative estimate of economic impacts, this study assumed that no annual crops would be produced and that some tree crops would be permanently destroyed. At this time, these appear to have been overly harsh scenarios. Acreage of annual crops has been reduced but not eliminated, while most trees and vines will receive adequate water. In addition, some water from the State Water Bank has been made available to KCWA. More accurate estimates of actual planted acreage in 1991 are not yet available from the district.

(2) Westlands Water District

Westlands is a very large irrigation district in the Southern San Joaquin Valley that receives most of its water from the federal Central Valley Project. In 1990, surface water deliveries were slightly curtailed, and ground-water pumping was increased to make up the

[6] Unless otherwise noted, the information in this section has been provided by the districts themselves.

difference. Westlands' own estimates indicate that ground-water pumping went from 175,000 acre-feet in 1989 to 300,000 acre-feet in 1990. Total water supply for the year dropped slightly, from 1,333,000 acre-feet to 1,221,000 acre-feet. Crop acreage actually increased slightly over the same period (Figure 14).

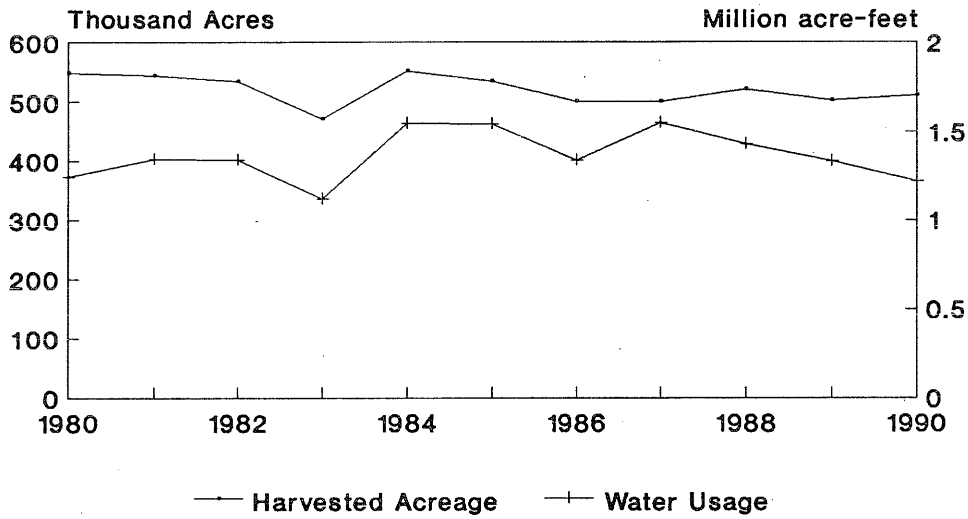
In 1991, surface water supplies for the district will only be about 337,000 acre-feet. Ground-water pumping is expected to increase to 475,000 acre-feet. If pumping in a normal year is estimated to be 130,000 acre-feet, and the average cost of ground water is $50/acre-foot, this would represent an additional expenditure of roughly $17 million, which can be compared to an annual gross revenue in the district of $700 million. The District has calculated dramatic decreases in planted acreage for 1991, 140,000 acres, based on average per-acre water use and estimated water availability. The district has subsequently estimated a decline in income of $1400 per acre, for a total predicted income loss of $200 million. This appears to be an unrealistically high estimate because: (1) the average applied water per acre may vary considerably by crop and soil type; (2) given a water shortage, the applied water usage for most crops is likely to decline; and (3) the crops most likely to be taken out of production are those that are relatively more water intensive and less valuable. In fact, average per-acre crop values in Westlands Water District during 1988 show that the gross value of annual field crops ranged from $95/acre for pasture to $1065/acre for cotton. A more accurate estimate of impacts would require information on planted acreage and planting intentions for 1991. As of July, these data were not available from the District.

(3) Glenn-Colusa Irrigation District

Glenn-Colusa Irrigation District supplies water to more than 100,000 acres in the Sacramento Valley, which is the State's major rice growing region. Their water is supplied by the CVP. Their water deliveries were cut by 25 percent in early 1990, and, although they eventually received their full allocation, many farmers had already reduced their planted acreage. This year, deliveries have been reduced by 25 percent. Ground-water supplies in the district are minimal, comprising only about 1 percent of total water supply (R. Clark, GCID, pers. comm.). The district has been aggressive in trying to implement water-conservation programs. Over the last 10 to 12 years, most rice farmers have used laser-levelling to decrease water requirements.

Reduced water supplies have decreased planted acreage in Glenn-Colusa. In 1987 and 1988, planted acreage was roughly 100,000 acres. In 1990, it was only 87,000, and in 1991, it will be about 75,000. Most of the declines have come in rice, sugar beet, and corn acreage. But rice acreage has been declining in the district since the mid-1980s in response to federal set-aside programs, and some corn acreage was taken out of production by sales to the Water Bank. Meanwhile, tomato plantings have gone from 1,700 acres in 1985 to 4,869 acres in 1991, a record for the district. Alfalfa acreage has also increased, partly in response to predicted decreases in alfalfa production elsewhere. In summary, acreage in Glenn-Colusa Irrigation District will be reduced by about 25 percent this year, although not all of this decline is attributable to the drought.

Figure 14
Planted acreage and water usage
in Westlands Water District, 1980-90



Note: Water usage includes surface
deliveries and ground water pumping.
Source: WWD annual crop reports

Summary

Because few water districts are currently predicting extensive idling of acres due to reduced water supply, the preliminary CDWR estimate of a $400 million decline in cash receipts may prove too high. There are obvious declines in rice, wheat, and cotton acreage that are partially -- but not totally -- attributable to the drought. In addition, there have been increases in acreage of alfalfa, tomatoes, and some other crops (CASS, 1991; R. Borten, CASS, pers. comm.) Nonetheless, some farmers are facing increased costs and declining revenues, and some local communities are suffering from reduced activity. The various estimates of statewide and local economic impacts on agriculture are summarized in Table 11.

To date, California agriculture has shown considerable resiliency to the impacts of the drought. The overall effects of the drought on farmers will be mitigated in part by the relatively strong condition of the State's farm economy and the availability of ground water. The decline in reservoir storage combined with the exhaustion of ground-water supplies, however, pose a serious concern about the ability of the farm sector to endure future dry years. Although the farm sector has been able to manage the drought reasonably well in the short run, the long-run costs may be substantially higher.

Livestock and Grazing

The reductions in rainfall over the first four years of drought have had a direct effect on the condition of California's grazing lands, but as of January 1991 no visible effect on total livestock populations or on the economic health of the livestock industry (see Table 12). Beginning in early 1991, there were reports of large livestock sales as ranchers sought to reduce herd size in anticipation of another drought year; heavy March rains apparently ended those sales (J. Tippett, State Statistician, California Agricultural Statistics Service, pers. comm.).

Overall prices in the industry have been excellent for the last few years. Cash receipts for cattle, hogs, and poultry were at high levels during 1987-1990, and overall receipts for cattle and hogs reached a record high in 1990, as shown in Table 12 and Figure 15 (CASS, 1991c.) We note that it is possible that receipts would have been even higher in the absence of the drought, but no estimates of this effect are available. Receipts for sales of sheep and lambs has dropped to 1983 levels, although it is unclear if this drop is related to the effects of the drought.

Despite the relatively good economic conditions prevailing for most ranchers, some counties have been hard hit. In Contra Costa and Alameda counties, for example, the drought had caused an estimated 95 percent loss of forage production prior to the March 1991 rains, and ranchers had begun to sell off livestock. In 1990, the East Bay Regional Park District reduced the number of cattle allowed to use their land by about 80 percent and several parks are presently off-limits to grazing (Gottschalk, 1991). Herd size in other counties -- particularly in central coastal California -- have been substantially reduced, even though overall State populations remained at their historical levels through the end of 1990. Herds in Monterey, San Luis Obispo and Santa Cruz Counties have been reduced 27, 20,

Table 11: Summary of Estimates of Economic Impacts on the Agricultural Sector in 1991.

Study	Predicted Loss	Comments
Statewide		
DWR, 1991 (DRAFT)	$400 million (gross receipts) for 1991 impacts.	Acreage predictions by CFB (May, 1991) and include idling from all causes. Economic impact calculated by DWR.
Howitt, 1991	$640 million (net) for 1991.	Based on model predictions. Assumptions include 80% reduction in surface water; 70% increase in groundwater usage.
Local		
Northwest Economic Associates, 1991	$221 million (gross) for Kern County alone in 1991.	Assumed no production of annual crops (now appears too high).
Westlands Water District	$200 million (gross) within the District for 1991.	Overestimate of fallowing and Overestimates of per-acre value.

Table 12: California Livestock Populations and Cash Receipts

	Population (1000 animals) (a)			Cash Receipts (1000 dollars) (b)		
Year	All Cattle	Sheep and Lambs	Hogs and Pigs	All Cattle	Sheep and Lambs	Hogs and Pigs
1981	4760	1205	180	1,262,907	37,867	29,627
1982	5000	1210	160	1,481,400	52,541	28,169
1983	4900	1115	160	1,325,141	44,358	27,952
1984	5000	1115	155	1,463,485	51,209	26,811
1985	4960	1065	140	1,275,693	51,771	22,142
1986	5000	1065	145	1,347,044	57,830	28,134
1987	4750	980	150	1,350,012	74,034	33,414
1988	4650	970	140	1,616,615	61,250	20,860
1989	4700	940	130	1,575,944	53,698	21,617
1990	4800	1000	140	1,739,859	44,583	38,486
1991	4750	1015	180	—	—	—

Notes:
(a) Population numbers are for January 1981 to January 1991.
(b) Cash receipts are for marketings ending December 1 of each year.
Source: CASS 1991c.

and 44 percent respectively between 1987 and 1991. Overall in 13 central California counties, herd size has been reduced nearly 20 percent from 1987 levels. In Kern County in the southern San Joaquin Valley, herd populations have been reduced 22 percent, while in nearby Kings County, cattle populations have risen by 70 percent (CASS, 1991c).

Statewide, the drought has dramatically reduced the quality of Federal, State, and private grazing lands, forcing ranchers to buy commercial grain to supplement range supplies. Several Bureau of Land Management grazing areas have been formally closed to protect them from further overgrazing. In spring of 1991, 56 allotments of land in Kings and Kern Counties normally used for grazing, totaling 171,000 acres, had been closed and no grazing permits issued. In nearby Fresno and San Benito Counties an additional 8 allotments totaling 65,000 acres were closed. In addition, some ephemeral grazing was prohibited during 1988 and 1989 (J. Morrison, Bureau of Land Management, pers. comm.).

Figure 16 shows the conditions of grazing lands in the State over the last few years. Since 1987 range conditions have steadily deteriorated to conditions typical of severe drought. The heavy rains in March temporarily improved grazing conditions on some lands, however, and several grazing areas in the Sierra Foothills that had been closed in February were reopened in April.

Many areas in the State have been overgrazed because ranchers held onto livestock too long and were slow to reduce herd sizes, and because the Federal and State agencies responsible for range conditions were slow to close or restrict vulnerable grazing sites. Even in early 1991, the hopes for a wet -- or even an average -- precipitation year caused overstocking and overgrazing to continue in many parts of the State. This overgrazing, combined with the extremely heavy March 1991 rains, led to serious local erosion, particularly in the Central Coast region (G. Greenwood, California Department of Forestry and Fire Protection, pers. comm.).

Beginning in 1987, the first year of the drought, the U.S. Department of Agriculture instituted an emergency cost-sharing assistance program (the "Livestock Feed Program") to help ranchers bear the costs of providing emergency feed for livestock herds. This program is entirely drought-related, and has grown in size since its inception. In 1990, expenditures for this drought program exceeded $20 million. Table 13 shows Federal expenditures under this program.

There are some bright spots for grazing lands and ranchers: by mid-1991, livestock herds statewide had begun to be reduced, and there are hopes that the reduced pressures on rangelands will give them time to recover. At the same time, livestock prices nationwide were relatively high, reducing the economic cost to ranchers of thinning their herds (J. Brown, U.S. Department of Agriculture, pers. comm.; CASS, 1991c).

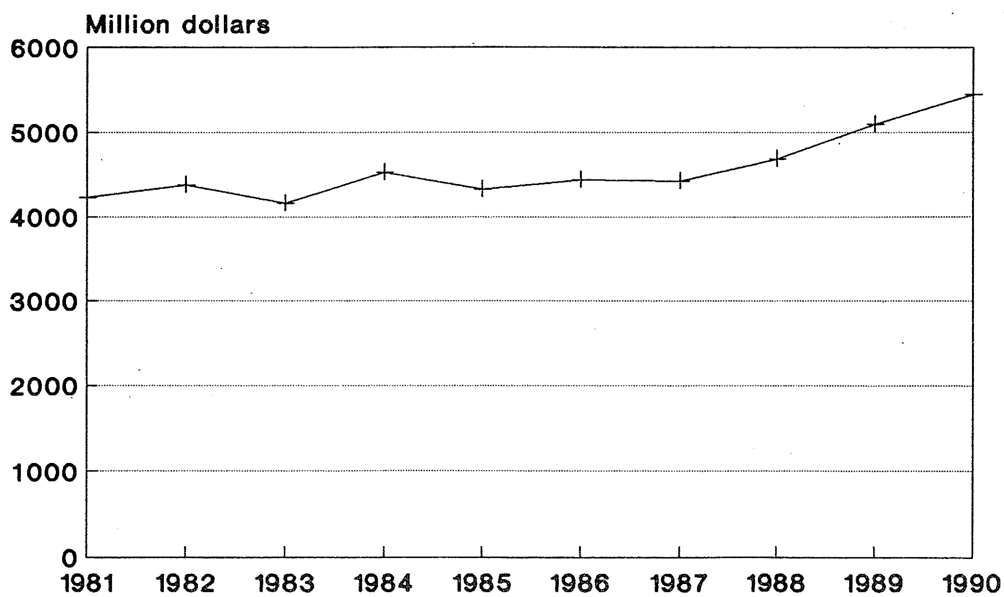
According to a source within the California Department of Forestry and Fire Protection, the drought has exacerbated existing trends of overgrazing in the State. In the long run, the drought provides an opportunity to change the way livestock management is done, to permit improvements in the quality of riparian lands and water quality, and to

Table 13: Federal Livestock Feed Program Expenditures Since 1987

Year	Funds Paid (dollars)
1987	$2,180,610
1988	$8,918,146
1989	$6,969,886
1990	$17,610,185

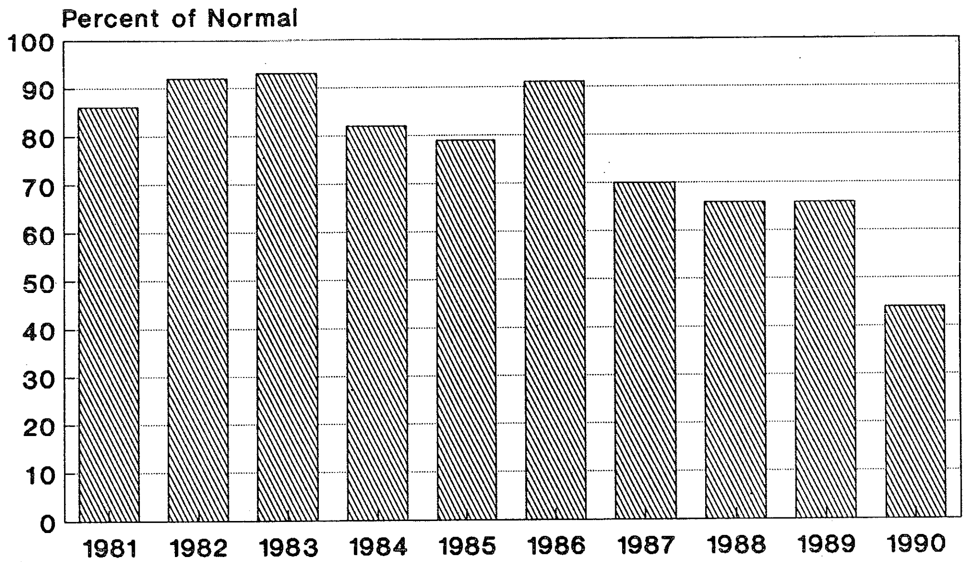
Note: See text for explanation.
Source: Data from Livestock Feed Program Reports-California. U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service. J. Jeffries, pers. comm.

Figure 15
Cash Receipts from Marketing of Livestock, Poultry, and Honey, 1981-90



Source: CASS, 1991c.

Figure 16
California Range Conditions, 1981-90



Severe Drought: <50; Very Poor: 50-64
Poor to Fair: 65-79; Good: 80+
Source: CASS, 1991c.

learn how to improve flexibility and to manage smaller herd sizes. There remains some question, however, about whether Federal and State agencies responsible for managing grazing and maintaining the quality of rangelands have perceived this opportunity and will act on it.

Energy

Hydroelectricity, one of the most important sources of electricity for the State of California, has two major advantages over other forms of electrical generation: it is inexpensive, and it can be turned on and off extremely quickly, making it very valuable for "load-following" -- meeting the fluctuating loads of electric utilities. Because of these advantages, hydro is a generating source of choice and the amount of hydroelectricity produced in any year is directly related to the amount of water available in storage.

For the last four years of drought, hydroelectric generation in the State has dropped dramatically. During a normal water year, California's hydroelectric output provides approximately 20 percent of the State's total electrical energy supply, and nearly one-third of the electricity produced by California utilities. From 1987 through 1990, hydroelectric generation dropped to about 12 percent of total generation (and to about 18 percent of in-state generation). This lost hydro has been made up primarily by burning more natural gas and by increasing purchases from out-of-state sources. Because the cost of generating electricity with natural gas is higher than the cost of producing hydropower, the drought leads to a direct increase in electricity costs to California's ratepayers.

Using estimates from the California Energy Commission and California utilities of the amount of hydroelectricity generated both in an average year and during the drought, it is possible to calculate the extra natural gas and oil burned. At an average additional marginal cost to ratepayers of $0.03 per kilowatt hour, the first four years of drought have cost California ratepayers an extra $2.4 billion. Table 14 summarizes the additional cost to ratepayers of drought-induced reductions in hydroelectric production. This includes only those additional costs of generation from in-state facilities and excludes additional costs from out-of-state purchases. Hydroelectricity production in 1991 will also be well below average and the additional costs to ratepayers are likely to be comparable to 1990 costs -- most likely exceeding $500 million statewide. Some California utilities are especially dependent on hydroelectricity, including the Pacific Gas and Electric Company, the State's largest investor-owned utility. For 1991 alone, PG&E estimates that the purchase of fossil fuels to make up for lost hydroelectricity due to the drought will cost its ratepayers over $300 million -- an increase of about 5 percent (G. Reuger, Pacific Gas and Electric Company, pers. comm.).

In addition to these direct economic costs for California ratepayers, there are environmental costs associated with additional fossil-fuel use, including increased air pollution and the emission of greenhouse gases. While it is difficult to accurately assess all of these impacts, we estimate that the additional natural gas and oil burned to make up the hydroelectric deficit has increased California's electric utility emissions of carbon dioxide -- a major greenhouse gas -- by over 25 percent from levels emitted during a normal water year. Table 14 shows the extra carbon dioxide emitted for the years 1987

Table 14: Costs to California Ratepayers of Lost Hydroelectric Generation; Additional Carbon Dioxide Emission (a)

	1987	1988	1989	1990	1991 (b)
Cost to Ratepayers of Additional Fossil Fuel Use (million $)	570	640	460	660	600
Additional CO_2 (million tons)	10.7	14.3	10.9	13.8	na
Additional CO_2 (percent)	21	30	23	34	na

Notes:

(a) To make up lost hydroelectricity generation, California utilities burn additional natural gas and oil. These calculations are based on comparison with an average hydro year.

(b) 1991 figures are estimates.

through 1990. Other unquantified but important effects include decreased air and water quality and an increased reliance on imported supplies of fossil fuel.

Energy used in agricultural ground-water pumping has also increased because of the drought. This increase takes two forms: greater overall pumping for ground water because of decreased surface-water supplies; and an increased cost of pumping as ground-water resources became depleted and pumping heights increased. Table 3 shows rapidly declining ground-water levels in the San Joaquin Valley during the last few years of drought, but no overall estimates of the extra cost of groundwater pumping are yet available.

Forestry and Fire

The five years of the drought have had an enormous impact on the forests of California. There has been a pronounced die-back of trees, particularly in the Sierra Nevada, a weakening of their general conditions, which makes them susceptible to a host of pests and pathogens, and a great increase in dry fuel available for sustaining forest fires. In southern California, a chronic die-back in *Ceanothus* chaparral has caused mortality of as much as 60 percent on coastal mountains in Santa Barbara, Ventura, Los Angeles, Riverside, and northern San Diego counties (California Department of Forestry and Fire Protection, 1991a). Where the die-back has been extensive, severe fire conditions exist. An opportunistic fungal pathogen, suspected as the causal agent, has been identified in several chaparral species, and the most severe die-back has been observed in regions with chronic air pollution problems. This suggests that air pollution may lessen the ability of a plant to resist attacks by pathogens (California Department of Forestry and Fire Protection, 1991a). In the Sierra Nevada, a record number of insect-killed trees were reported as of spring 1991 (R. Hruvies, pers. comm.). The majority of dying trees are lower-valued species, like white fir.

The California Department of Forestry estimates that 12 billion board feet of merchantable timber has been lost on State lands; over 5 billion of that in 1990 alone. The U.S. Forest Service estimates that 10 percent of the trees in 18 National Forests have been killed by the drought and related insect infestations (CDWR Weekly Update, 5/24/91). The U.S. Forest Service manages approximately 6.5 million acres in California for commercial lumber. In August of 1990, as part of an annual survey of trees greater than 12 inches in diameter, the Forest Service documented 2.6 billion board feet of dead timber attibutable to the drought. Surveys conducted in August of 1988 and 1989 documented roughly 1 billion board feet of dead timber in each year (K. Denton, USFS, pers. comm.).

Salvage recovery of dead timber may reduce economic impacts, although some trees cannot be harvested before they deteriorate and become uneconomical to fell and log. fO the 2.6 billion board feet of dead trees in U.S. National Forests as of August 1990, the Forest Service estimates that as much as 1.6 billion will be salvaged -- about 800 million board feet each in 1990 and 1991. By comparison, timber volumes salvaged along the Eastern seaboard following Hurricane Hugo were about half of this amount.

In normal years in California, approximately 90 percent of trees sold and cut on U.S. Forest Service lands are considered "green", or live trees, and 10 percent are "salvage", or dead trees. In the last four years this ratio has been completely reversed in some areas of the State, largely due to the drought and related insect damage (E. Whitmore, U.S. Forest Service, pers. comm.). On National Forest land, more than half of the 1990 and 1991 timber sales will be dead trees. Figure 17 shows "green" and "salvage" timber sales from U.S. National Forests in California since 1980. The significant shift in 1988 is the result of the massive fire year in 1987 and the subsequent harvest of fire-damaged trees. The 1989 and 1990 increases in salvage sales reflects the growing influence of the drought. Data for 1991 will not be available until late fall.

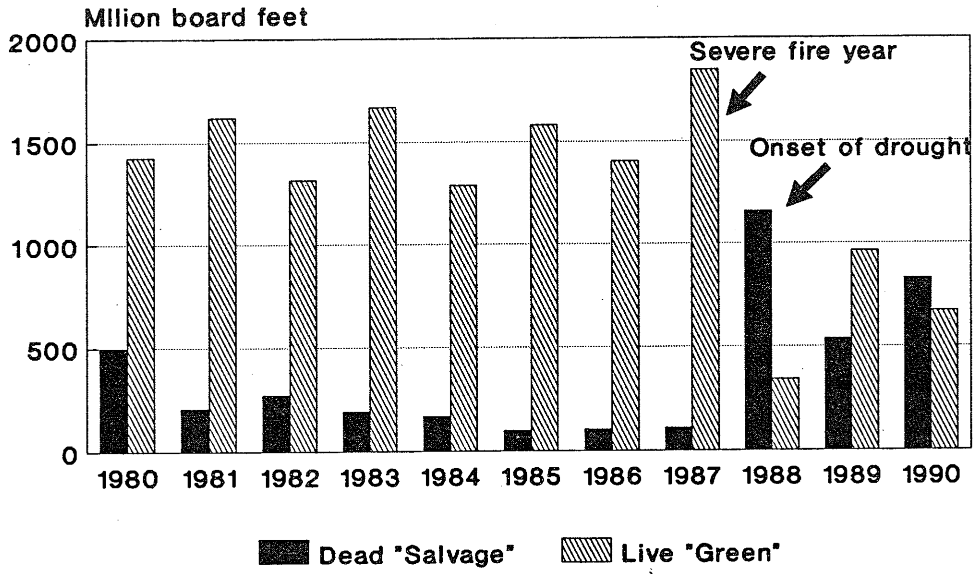
During years when salvage volumes are high, extensions are granted for the harvest of live trees under contract. Thus overall harvest volumes are expected to stay about the same or to increase slightly statewide. Most restrictions on tree harvests, such as the numbers and types of trees removed, and the methods required to remove them, are suspended for salvage harvests. This is a substantial benefit to the lumbering industry (S. Petrin, Timber Association of California, pers. comm.), which otherwise might suffer reduced sales.

Another direct effect of the drought on California's forests is the greater risk of forest fires. The risk of wildfires varies with the availability of dry timber and fuel and the frequency of "starts" -- ignition events. 1987, 1988, and 1990 were among the worst fire seasons the State experienced due in part to the dry conditions and in part to a large number of starts. For the U.S. Forest Service, 1987 and 1988 both had an unusually large number of fires and relatively large acreage burns (see Table 15). 1990 witnessed the first closing of Yosemite National Park in history due to fire. Note that the total acreage burned also reflects the levels of effort to suppress fires.

The drought has led to greater expenditures for fire protection, fire control staffing, and operational expenses. Both State and Federal expenditures for fire suppression and fighting have risen considerably since 1986, permitting faster and stronger responses, which have helped reduce the severity of some of the fires that occur. Table 16 and Figure 18 show total State and Federal emergency fund expenditures for wildfire control. These expenditures are over and above the regular costs of maintaining fire fighting equipment and personnel.

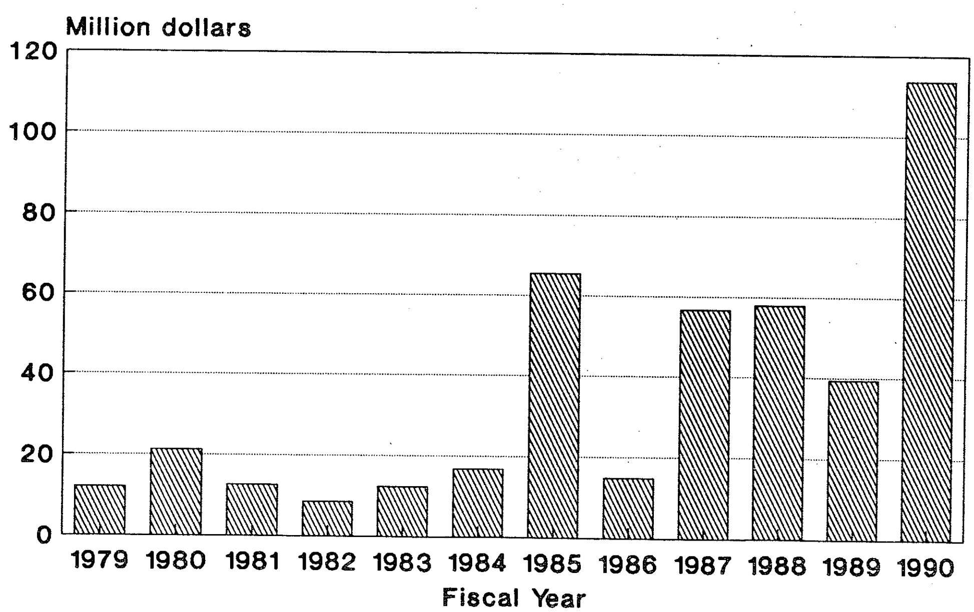
As of spring 1991, the California Department of Forestry and Fire Protection (CDF), which is responsible for the largest area of forest (about 34 million acres) in California, was maintaining increased "dispatch levels" -- the level of early effort devoted to stopping wildland fires from spreading. Emergency fire costs (above and beyond the regular $200 million cost of maintaining the initial fire attack force equipment and personnel) in 1990 were over $80 million, more than twice the average.

Figure 17
California National Forest
"Green" and "Salvage" Timber Sales



Source: W. Simonson, USFS, pers. comm.

Figure 18
State and Federal Emergency Fund
Expenditures for Wildfire Control



Source: CDF, pers. comm.

Table 15: Total Acreage Burned in the State of California, 1981 to 1990

Year	Acreage Burned
1981	322,000
1982	160,000
1983	128,000
1984	251,000
1985	595,000
1986	119,000
1987	873,000
1988	345,000
1989	173,000
1990	349,000

Source: K. Terrill, CDF, pers. comm. 1991.

Table 16: State and Federal Emergency Fund Expenditures for Wildfire Control (1000 $)

Fiscal Year	General Fund	Federal Funds	Total Expenditures
1979–1980	11,978	0	11,978
1980–1981	21,178	0	21,178
1981–1982	12,582	0	12,582
1982–1983	8,619	0	8,619
1983–1984	12,358	0	12,358
1984–1985	16,847	0	16,847
1985–1986	65,510	0	65,510
1986–1987	12,347	2,452	14,799
1987–1988	25,288	31,481	56,769
1988–1989	48,983	9,000	57,983
1989–1990	28,500	10,845	39,345
1990–1991	83,750	30,000	113,750

Source: J. Spero, CDF, pers. comm. 1991.

Recreation and Tourism

Recreation and tourism is the largest single industry in California and is reflected in dozens of ways: camping, hiking, and visits to National and State Parks, tourism to the theme parks, beaches, and sights of southern California, skiing in the Sierra Nevada, boating on the State's numerous reservoirs and natural lakes, and countless other activities. The amount of money spent in California on these activities in 1989 was estimated to be nearly $50 billion; over 700,000 jobs are associated with tourism and recreation.

The drought has certainly had an effect on these activities, but it is often extremely difficult to quantify these impacts and to separate them out from other factors, such as the current severe economic recession, when overall personal expenditures are declining. Nevertheless, there have been some clear impacts on certain aspects of California's recreation industry: the ski industry has been hit by bad snow conditions in the mountains; houseboating on reservoirs has been hurt by low conditions of the reservoirs; and fishing for salmon and striped bass has been severely affected by rapidly declining populations of these fish (see **Ecological Impacts**).

The ski resort business in California is a $300 million-a-year industry. Bob Roberts of the California Ski Industry estimates that "skier visits" to the 41 ski resorts in the State of California dropped to 4.1 million in winter 1990-91 from 6.1 million the year before and from 7.1 million in the good season of 1988-89. The Mammoth Resort in southern California recorded approximately 400,000 skier visits in 1990-91, compared to about 1 million during winter 1989-90. Industry estimates are that each visit produces approximately $45 to a resort, excluding all secondary economic effects such as equipment purchases, travel costs, and associated expenditures. Using this rough estimate, the ski-resort industry lost about $85 million during the 1990-91 winter alone. In addition, the industry employs 7,000 to 10,000 people during a normal season; during the 1990-91 industry employment was about half this amount (B. Roberts, California Ski Industry, pers. comm.).

A growing number of resorts in California have installed expensive "snow-making" equipment that permits them to open earlier in the year and to stay open during periods of low snowfall. These resorts did considerably better than the others. Snow Summit, for example, had a record year this year, following installation of snow-making equipment.

The value of annual expenditures associated with warm weather recreation on Shasta and Trinity Reservoirs and in the Sacramento and Trinity Rivers has been estimated at $117 million during normal years (Table 17). Fourteen houseboat/vacation resorts on Shasta and Trinity Reservoirs are threatened by declining lake levels; one has reportedly gone out of business due to the drought (T. Sletteland, pers. comm.). Estimates of losses on other reservoirs or rivers in the State are not yet available.

Recreation on State Water Project facilities has also begun to decrease due to the drought. Figure 19 shows the change in recreation days per year for the last 13 years. After reaching a peak of 7.2 million recreation days in 1987, the first year of the drought,

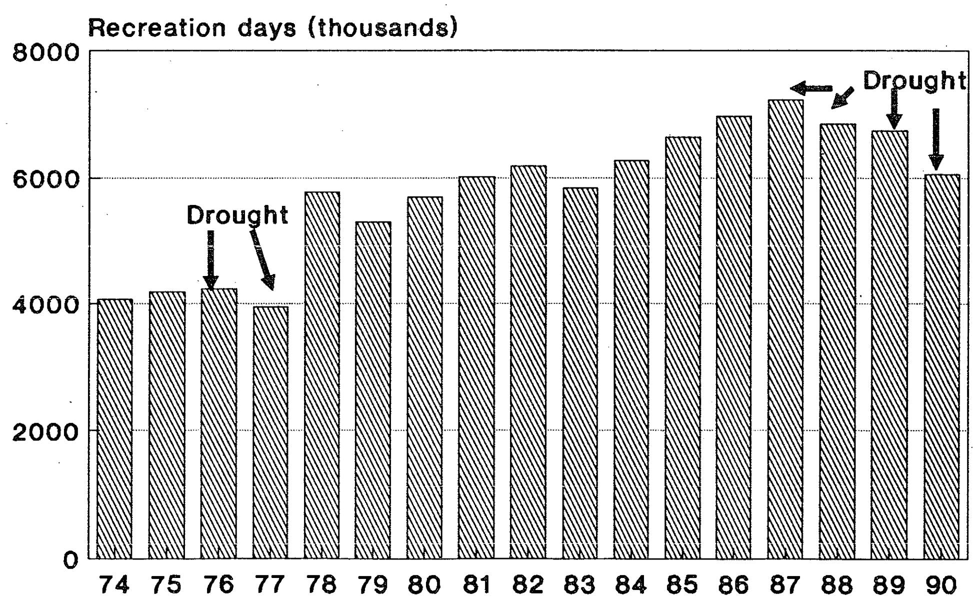
Table 17: Annual Expenditures for Boating and Fishing in Shasta and Trinity Counties.

	(million dollars)
Shasta Lake (boating)	75
Trinity Lake (boating)	25
Sacramento River (fishing)	10
Trinity River (fishing)	7

Notes: Sacramento River fishing consists of both salmon ($4 million) and trout ($6 million). Trinity River fishing is all anadramous fish.

Source: July 31, 1990 letter from the Shasta-Cascade Wonderland Association (Tryg Sletteland) to the Shasta County Board of Supervisors; T. Sletteland, pers. comm.

Figure 19
Recreation at California State Water Project Facilities



Source: CDWR, 1991c

the figures have dropped to the levels of the early 1980s -- about 6 million recreation-days per year. While the recession may have played a role in this drop, the drop began before the recession and the reductions in the last several years primarily reflect lower reservoir levels and less attractive reservoir conditions for recreational boating.

Other aspects of the recreation industry have proven to be remarkably robust. Total visits to the California State Parks system has not been affected by the drought, though there was concern prior to the heavy March rains that Central Valley reservoirs would be too low to permit normal use. Table 18 shows the numbers of visitor-days spent at California park facilities from 1984 through 1990. According to officials at the California Department of Parks and Recreation, the quality of the weather on the three major vacation weekends tends to have a much greater effect on total visits to the parks than has the drought. No State park closures were reported due to the drought.

Two U.S. Forest Service campsites in the Tahoe National Forest have been closed due to outbreaks of bubonic plague in the resident squirrel populations. These outbreaks are the result of higher flea populations that are partially attributable to the drought. Other sites in Sequoia National Forest may be closed later in 1991 for the same reason (G. Plisco, U.S. Forest Service, pers. comm.).

In mid-summer 1990, 500,000 acres of the Stanislaus National Forest were closed to recreation due to high fire danger, and other fire-restriction closures are under consideration for 1991 (G. Plisco, U.S. Forest Service, pers. comm.).

The effects of the drought on recreation in other parts of the State are extremely difficult to measure, in part because of the complicating effect of the recession and in part because no consistent statistics are kept. There is, however, some anecdotal evidence from different regions. The City of Santa Barbara, for example, estimated that they lost $30 million in tourism in 1990 due to publicity about the drought and bad fires (Reinhold, 1991). Some other data may become available later in 1991.

Municipalities

In 1990, five counties declared emergency drought conditions: Santa Barbara, San Luis Obispo, Kings, Madera, and San Benito. By early spring 1991, five additional counties had been added: Mendocino, Glenn, Sutter, Colusa, and Tulare.

Several regions have begun to require water-efficient equipment in new construction. In spring 1991, Marin County required all new hook-ups to have ultra low flush toilets and put significant restrictions on new services. Marin County plans to spend $16 million over two years to extend a pipeline to expand use of reclamation water. The Metropolitan Water District of Los Angeles has announced plans to spend approximately $30 million per year for water conservation programs. They are also spending $228 million to line irrigation canals and improve aqueduct control systems in return for 100,000 acre-feet per year from Imperial Valley irrigation projects, and another $150 million to line the All-American Canal, which is expected to provide 75,000 to 100,000 acre-feet of water per year.

Table 18: California State Park System Recreation Visits: 1984 to 1990

Year	Visitor–Days
1984	65,885,000
1985	66,072,000
1986	69,254,000
1987	72,846,000
1988	72,486,000
1989	78,093,000
1990	77,776,000

Notes: Fiscal Year (July to June)

Source: L. Paynter, CDPR, pers. comm.

Residential conservation programs have been widely implemented. Los Angeles approved a 31 percent reduction, which was reduced after the March 1991 rains to 15 percent. 25 percent reductions were enacted by the San Francisco, Marin, and Santa Clara Water Agencies. The East Bay Municipal Utilities District implemented a reduction of 15 percent. The Santa Barbara County Water Agency has implemented a 45 percent reduction. While some districts eased rationing after the heavy March rains, many municipalities are maintaining some restrictions. In most cases, these programs have proven highly effective. Santa Clara County asked for a 25 percent voluntary reduction and achieved 20 percent in 1989 and 1990. Per capita use dropped 24 percent. Kern County set a voluntary goal of 25 percent and achieved a 15 percent savings during the winter months. Water use in Santa Cruz is 21 percent below the last pre-drought year.

In the Sacramento-San Joaquin Delta, the drought has affected water quality by decreasing fresh-water flows and permitting the increased intrusion of salt water. At the Contra Costa Water District, chloride levels are expected to reach 250 mg/l by the end of the summer of 1991. This causes the formation of additional trihalomethanes (THMs), a known carcinogen. In order to reduce THM levels, the District has been spending an additional $200,000 per year for water treatment. Other impacts of high salinity include (1) a reduced aesthetic quality of the water; and (2) increased public health concerns due to the links between high sodium levels and blood pressure (E. Cummings, Contra Costa Water District, pers. comm.).

Industry and Manufacturing

California has an economy worth over $700 billion annually. For a few industries most sensitive to water availability, the drought has had a measurable impact and some industries have implemented major water conservation programs. Worries about severe impacts in 1991 were mostly defused by the heavy March rains, but if the drought continues for one more year, more severe industrial impacts could begin to appear.

There are many industries in California, other than agriculture and recreation, that are dependent on reliable water supplies, including refining, food processing, semiconductor manufacturing, and services. The impacts of the drought for these industries varies with their dependence on water, the availability of alternative supplies, and their ability to improve water-use efficiency. Most water-intensive industries are not expected to face any declines in production due to water cutbacks in 1991. Some businesses will see an increase in demand due to the drought, including certain landscapers, manufacturers of water-saving devices, efficient car washes, and plumbers (Yamane et al., 1991).

Industrial growth in California has been extremely strong in the last decade. At the same time, there has been a substantial reduction in the amount of water required for production. Seven of California's major industrial sectors, including fruits and vegetable processing, paperboard and box production, refining, concrete, communications, and motor vehicle production, have reduced their water use by 3 to 10 percent annually despite significant increases in production in all of these sectors (Spectrum Economics, 1991). In industries where water use has increased, the rate of growth of water use was always below the rate of growth of production (for those industries adequately surveyed), suggesting substantial improvements in water-use efficiency (W. Wade, pers. comm.).

Most industrial water users have shown enormous resilience in the face of shortages. For example, in 1988, the East Bay Municipal Utilities District (EBMUD) requested industrial users to cut back water use by 9 percent. Actual reductions among the industrial users in this district averaged 29 percent.

There is some concern about future water shortages for the industrial sector. Continued growth in California's economy will require additional water, which will have to come from conservation measures or from purchases from other sectors. While at present water is not considered a serious constraint, there is a growing perception that limitations on supply may be a long-term problem. In reality, the value of water, and hence the price that industry is willing to pay for reliable supply is likely to be sufficiently high to ensure that, in the long run, industry will be able to obtain sufficient water for manufacturing. Short-term shortages, though more likely, have not yet caused economic hardship. A brief discussion of specific industrial sectors is presented below.

Petroleum Refining

Petroleum refiners are among the largest industrial users of water in California. In the early 1980s, petroleum refineries used nearly 230,000 acre-feet annually (CDWR 1982). In recent years, however, refiners have taken steps to substantially reduce their water requirements, and this has helped cushion the effects of the drought. The Chevron Corporation, which runs a major refinery in the Richmond area, has begun a program to reuse large amounts of water for industrial cooling, which by 1993 will save an estimated 5.4 million gallons per day. It anticipates a major, permanent reduction in water needs for its refineries as it completes plans to recycle and reuse refinery process water. The current drought has not yet affected day-to-day operations or profitability.

Food Processing

The food industry is also a large user of water -- over 100,000 acre-feet per year (CDWR 1982). This industry has also made considerable progress in reducing water requirements through recycling, more efficient equipment, and changes in operations. Little or no effect on production due to the drought is anticipated.

Semiconductor Manufacturing

The semiconductor industry uses substantial amounts of water for cleaning silicon wafers, but most have begun to implement water conservation measures that will prevent any production cutbacks in 1991.

National Semiconductor Corporation, in Silicon Valley, has reportedly cut their million gallon per day water consumption by one-third since the drought began. IBM in the Santa Clara Valley has cut total water use by 25 percent since 1987, but still requires 1.5 million gallons a day for cleaning parts, and for cooling machinery and computers.

The company is exploring ways to cut back further without cutting production time (Fagan, 1991).

If the drought continues through another year and industrial cutbacks are increased, costs may rise in this industry or companies may be forced to rely more heavily on out-of-State production facilities (Yamane et al., 1991).

Housing and Construction

Some communities in California have imposed temporary bans on new water hook-ups, effectively preventing new construction. The number of cities imposing such bans is small and primarily limited to areas heavily dependent on imported water. One side effect of such bans is to drive up housing prices, increasing an areas net worth. The net effects of this are mixed -- benefitting some and hurting others. No study has looked at the overall economic effects, and such bans are expected to be temporary. One result has been an increase in the use of water-saving devices during the construction process.

Others

Some industries have benefitted from the drought. Well drillers are experiencing a boom in business not seen since the 1976-77 drought, when backlogs of several months were common and when out-of-state drillers flocked to California.

The credit industry has been paying close attention to the drought in California because of concern that water shortages may affect the costs of industrial production, revenues from water or electricity sales, and the ability of bond holders to repay debt. As of June 1991, no industrial credit ratings had been downgraded, but some early warning indicators of financial performance have appeared (Table 19). For example, in early 1991, some electric utilities were looking at significant energy cost deferrals to make up for lost hydroelectricity generation and added fossil fuel purchases. Several utilities, such as the Turlock Irrigation District, are particularly dependent on hydroelectricity and are thus exposed to significant increases in rates. Similarly there have been some deferrals (but no defaults) on bond payments for the State Water Project by water districts not getting sufficient water in 1991 to permit the production of crops and profits. Ultimately, there is a good chance that larger water districts will absorb smaller ones now deferring payments (J. Costagliola, Standard and Poors Co., pers. comm.).

Table 19: Drought–Affected Bond Issuers in California

Issuer	Rating	Outlook	Debt	Amount (millions)
Los Angeles Dept. of Water & Power	AA	Stable	Water Revenue	$440
Los Angeles Wastewater	A	Stable	Sewer Revenue	$605
Metropolitan Water District of Southern California	AAA	Stable	Gen. Operating	$726
" " "	AA	Stable	Revenue Bonds	$365
Sacramento Municipal Utility District	BBB	Stable	Electrical	$1,200
San Francisco Public Utility Comm.	AA	Stable	Water	$106
City of Santa Barbara	A+	Stable	Water, Sewer	$19
" " "	A	Stable	Water	$10
Santa Clara Valley Water District	A+	Stable	Water	$81
Turlock Irrigation District	A	Negative	Electric	$53

Source: J. Costagliola, 1990. "Drought Reigns in California", Standard and Poor's Credit Week, August 27, 1990.

THE DROUGHT AS AN ANALOGUE OF CLIMATE CHANGE

If the drought is not a manifestation of anthropogenically induced climate change but merely an extreme of the current climate, it may nonetheless serve as an analogue of a future climate that is more severe than that of the present. Extreme events that have occurred in the past can tell us something both about the types of changes that we might expect in the future and, perhaps more importantly, about the ability of society to adapt to extreme climatic events.

Among the impacts expected from global climatic change are an increase in the mean global and regional temperatures and diverse changes in precipitation patterns. The details of the regional impacts of such changes are not known, although General Circulation Models (GCMs) suggest that the northern temperate zones will warm more than the equatorial zones and that precipitation will increase toward the higher latitudes. Mid-latitude precipitation changes are far less certain, with increases and decreases possible in different areas. GCM predictions of temperature along the West Coast of the US suggest that average annual temperature may rise by 2° to 5°C for an equivalent doubling of carbon dioxide (IPCC, 1990). Warmer temperatures, by themselves, will decrease runoff by increasing evapotranspiration; however, because precipitation may either increase or decrease, the overall impact on runoff and water supply is uncertain. Higher temperatures will also increase the demand for water in many sectors.

Global warming would have many other impacts that have not been experienced as a result of the current drought. For instance, warmer temperatures would increase peak electricity demand and could affect yields for many agricultural crops. Higher temperatures could also have dramatic impacts on ecosystems and wildlife by shifting climatic zones and seasonality. Changes in snowfall and snowmelt patterns are also likely, which will have significant effects on the risks of flooding and drought (Gleick, 1989). In addition, sea-level rise will have dramatic impacts on California's coastal economy and ecosystems.

The current drought does not provide any information on the effects of increases in global and regional temperature, but does illustrate the impacts of decreased precipitation and runoff. In a limited sense, it provides us with an indication of what some of the impacts of global warming might be, if global warming were to be associated with decreased runoff. Thus, it is useful to examine the drought in a narrower sense, as an indicator of society's vulnerability to shifts in hydrology and water availability. The impacts of the current drought suggest that the economy can withstand five years of reduced water supply, but that we are running up against severe limits and facing difficult choices. Specifically, ground-water supplies and reservoir storage, which have buffered the impacts in the agricultural sector, are being heavily drawn down, and many wildlife populations are so strained that their ability to recover must be questioned. Thus, if the drought were indicative of long-term changes in the State's water supply, it would suggest fundamental changes in the State's economy and environment.

An important caveat is that the economic impacts of reduced water supply will vary over the short- and long-terms. What we have witnessed to date is the short-run response, in which there is little time for either capital investment or structural change, and, as a result, the costs can be much higher than they would be in the long-run. In the absence of water-saving investments (e.g. recycling systems, low-flow shower heads), industries and consumers are forced either to pay significantly more for water, to forego opportunities (e.g. reduce output), or to endure hardships. The impacts of the current drought have been partially mitigated by changes that were induced by the 1977-78 drought, particularly in the municipal and industrial sectors. Undoubtedly, the current drought will induce still future investments in water conservation, which should reduce long-run impacts.

The same reasoning, however, only partially applies to California agriculture. A sudden decrease in water availability (or increase in water price) can be devastating to a farmer in the short-run. It will mean either lost crops, increased costs, or both. Over the medium-to long-term, farmers may invest in water-saving irrigation technology or make the transition to less water-intensive crops or to higher value crops. But, while in general we expect short-term costs to be much higher, the agricultural sector has been buffered during the current drought by the availability of ground water. Over the last two years, the dominant response to the drought in the agricultural sector has been the replacement of surface water with ground water. Reliance on ground water, however, is a short-term buffer and over time increased pumping costs and decreased water quality will exhaust the resource. Thus, in our opinion, the drought may be more costly to farmers in the future.

Despite the inherent differences between climate change and drought, and between short-run and long-run responses to reduced water supply, the drought provides some important examples of how society in general, and California in particular, will respond to general environmental change. First, statewide policy for much of the drought has been reactive and slow, and has been marked by an unwillingness to recognize that the drought might persist for several years. For the first four years of the drought, reservoir storage was continually drawn down while only limited conservation policies were adopted, in the hope that we would soon see a "normal" precipitation year. It has been only within the last year that major changes were made in reservoir management, that conservation was (temporarily) mandated in several municipalities, and that innovative policies (i.e. the State Water Bank) were implemented. In particular, the concept of a water bank is not new but was slow to be adopted.

The reluctance of policymakers to recognize and respond to California's vulnerability to climate is perhaps more critical with respect to climate change than to the drought. The future is even more uncertain and the risks potentially much greater; yet the experience of the drought suggests that California will not address climatic changes with specific policies until long-after the impacts are being felt. In the meantime, opportunities to reduce long-run costs may be lost.

Second, the most severe impacts of climate change are likely to be local in scale rather than statewide. For example, while the State's agricultural economy is strong enough to withstand the drought, the impacts on local communities have been more severe. Water shortages were not equally distributed among regions or communities, and those harder hit have suffered proportionately greater losses.

Third, more initial impetus and innovation seemed to come from the local rather than the State, regional, or Federal level. Several municipalities implemented effective voluntary conservation programs early on and sought to help the public and industries to reduce their water usage.

Fourth, the drought and environmental change more generally imply contentious tradeoffs among the three main water-using sectors in California: agriculture, municipalities, and the environment. The divisiveness that currently marks this debate in California has been aggravated by the drought and would certainly be evident in the event of long-term climatic changes.

Fifth, it is frequently difficult to disaggregate the effects of drought, or climate change, from other factors. For example, changes in the agricultural sector are being driven by the economy, weather, rising land values, international trade, and Federal set-aside programs, while changes in ecosystems are being driven by pollution, habitat alteration, and introduced species. This problem arises in part from the failure of governments and researchers to gather the information that is needed to properly estimate impacts. Yet the difficulty inherent in determining causal relationships can, and does, detract from the debate over appropriate responses.

Sixth, as a society, we tend to place a high discount rate on the future when faced with a crisis. The problems engendered by the current drought have led to decisions to deplete ground water and to ignore or to downplay the ecological ramifications of the drought. Partly this reflects the fact that it is easier to measure the direct and immediate impacts on the agricultural and industrial sectors, while the impacts on future generations will not become manifest for several years or decades.

Finally, we can say a number of things about the relative costs of the drought versus climate change. The drought has provided us with an opportunity to measure the cost of extreme events assuming a stationary climate. Should climate change cause extreme events to change in proportion to the climatic mean, we will see much more severe variations. Among the most recent projections of the drought's impact on the agricultural sector, is that it will cause revenue to decline by roughly $400 million in 1991. In the energy sector, we estimate that over 5 years, the drought has cost nearly $3 billion, not including the costs of increased air pollution. These costs can be compared to an estimated $1 billion that it would take to protect existing development around San Francisco Bay alone from a 1 meter sea-level rise (Gleick and Maurer, 1990). Given that sea-level rise would threaten the entire coast of California, including greater Los Angeles and San Diego, the overall costs of sea-level rise would be much higher than $1 billion.

Global warming may have additional adverse impacts on agriculture. Of greatest concern is the increase in temperature extremes and the greater frequency of heat stress in the hotter regions of the State. The ecological costs of long-term climate change are also likely to be higher. California's ecological resources are already severely threatened. Moreover, through the elimination of species and the conversion of habitat, we have left little room for species adaptation and migration. If, in addition, ecological resources have to compete with other interests for protection and consideration amidst a looming crisis, their prospects grow dimmer.

Although an imperfect analogue, the drought does illustrate the vulnerability of the economy and the environment of California to variations in climate. The prospect of climate change is that these variations would be even more extreme than those we are currently experiencing. While we have considerable ability to adapt to environmental changes, the short-run costs may be very high. Moreover, our response to the drought suggests that we will tend to discount the future and adopt the easiest measures first. On the other hand, the drought has forced California to re-analyze its water policies and has spurred an important debate about vulnerability, tradeoffs, and priorities. In this sense, the drought may provide the impetus to plan for and to adapt to global warming.

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