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ISSUE SUMMARY

Agriculture, Water, and California's Drought of 1987-92

Background, Responses, Lessons

By
Kenneth W. Umbach Ph.D.

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1029 J Street, Room 500
Sacramento, California 95814
(916) 322-0600

Digest

From 1987 to 1992, California suffered a severe, prolonged drought. Because agriculture uses three-quarters or more of "developed" water in the state, agriculture's means of coping with drought are of special concern. Reservoirs helped to maintain relatively normal supplies to agriculture during the first few years of the drought. After 1989, water deliveries from the Central Valley Project and State Water Project were sharply curtailed.

Farmers and water managers adopted several strategies to cope with reduced surface water supplies from the projects and other sources:

- Where possible, they pumped more ground water.

- In some areas, especially as the drought lengthened, they arranged or participated in water exchanges and transfers, including the Drought Water Bank.

- Where necessary, farmers fallowed land or switched crops, sometimes in association with exchanges.

Other responses to water shortages, such as improved irrigation management and methods, are increasingly widespread, but often as a means of improving crop quality and quantity rather than specifically to reduce water use. In the areas most directly affected by the drought those responses appear to have been less important in coping with reduced surface water than pumping, exchanges, and fallowing or crop switching.

Overall farm production in California remained strong during the drought, although farm profits suffered during that period. The severe frost of December 1990-January 1991 was more damaging to production than was the drought.

Climate varies widely from one part of California to another. For some areas, such as the arid Colorado Desert, "drought" is normal, and water supply was relatively unaffected. For others, especially much of the Central Valley and coastal areas, the drought cut water supplies and clearly differed from average years. Areas hardest hit by the drought included Kern County and the western side of the San Joaquin Valley.

This report concludes:

1. Statewide, California's agriculture can remain productive during drought, but local impacts can be much more serious. Focused efforts may be required to cope with the economic, environmental, and social impacts of drought in the most affected areas.

2. California is more vulnerable to drought now than it was in 1987. Although surface storage is better now than it was at the end of the drought, ground water levels have had little opportunity to recover from six dry years. The cushion in 1994 is much thinner than it was in 1987. New environmental demands on water--for Delta water quality and for protection of fish and other aquatic species--further stress water supplies. Renewal of the 1987- 92 drought could multiply needs for a coordinated response, especially in the most vulnerable areas, and may require relaxation of environmental restrictions on water deliveries.

3. Ground water and its management are increasingly important. Risks of land subsidence, increased costs of pumping, and ground water contamination all point to the need to manage ground water as a scarce resource.

4. No single response to drought is sufficient. Responses to the drought ranged from increased ground water pumping to water exchanges and transfers, conservation-related irrigation improvements, and crop and acreage adjustments. None alone would have been enough to cope with a long and severe drought. The threat of renewed drought may require expanded water management and conservation efforts, and perhaps development of additional water supplies.

5. Irrigation improvements are important, but not a panacea. Water savings through irrigation improvements and crop selection cannot be expanded indefinitely. Eventually, reductions in agricultural water use can come about only by reducing irrigated acreage.

The paper includes an extensive annotated bibliography.

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INTRODUCTION

Governor Wilson declared California's drought of 1987-92 over in February 1993 as a result of heavy fall and winter rains and an excellent snowpack. *If* California now returns to relatively normal precipitation for a few years, reservoir storage can return to normal and ground water supplies that have been drawn down over the last six years can recover. This process would bring a complete end to the drought. Experience after the brief but severe 1976-77 drought shows that substantial recovery is possible in a few years under good conditions.[1] However, precipitation and snowpack trends through March 1994 suggest that water year 1994 will be dry, diminishing prospects for the return to more favorable conditions that the 1993 rains seemed to promise.[2]

Californians can reasonably expect another drought of a year or more within several years, irrespective of the outcome of water year 1994. While the next drought is unlikely to rival that of 1987-92,[3] it will nonetheless challenge California as the state grapples with population growth and environmental concerns.

In view of the demand on water supplies made by California's agricultural sector, estimated at 77 to 80 percent of the "developed" water used in the state,[4] it is especially important to review the responses farmers could and did use to conserve water and continue to grow and harvest crops during the drought. Equally important are the institutional responses of water districts and state and federal agencies.

Published sources (and a few unpublished papers) consulted for this paper are listed in the bibliography. The footnotes sometimes use abbreviated citations. See the bibliography for full citations and for additional notes on many of the sources

[1]California Department of Water Resources, San Joaquin District, *Ground Water Trends in the San Joaquin Valley*, p. 1.

[2]The "water year" runs from October 1 to September 30. For example, water year 1994 began October 1, 1993, and will end September 30, 1994. The Department of Water Resources' "Water Conditions in California" Report 1, February 1, 1994, asserts, "Rain and snow amounts so far this season are similar to those of the recent six-year drought. There is still hope that the remaining 40 percent of the season will bring improvement but the historical odds indicate that water year 1994 will be dry. Carryover storage from last year will help to ease the impact." (Page 1.)

[3]See Maurice Roos, "The Hydrology of the 1987-1992 California Drought."

[4]Various sources, including California Department of Water Resources publications, cite figures in this range. Some sources cite a figure as high as 85 percent, although the proportion seems to have decreased over the past two decades. DWR's November 1993 draft *California Water Plan Update* indicates a lower statewide figure for "applied water demand," at 45.5 percent ("average" for 1990, calculated from data in Table 12-4). Agriculture's proportion of water use varies from one part of the state to another. The August 1990 *Ground Water Trends* report states that "applied agricultural water use comprises 93 percent of the total [San Joaquin] valleywide demand" (p. 1).

The experience of the recent drought may help California craft a timely response at the next sign of drought and address the continuing demands of California's tight water supplies. The purpose of this paper, then, is to summarize the 1987-92 drought in the context of agriculture and water in California, to examine the types of response that farmers and institutions could and did use, and to draw lessons from that experience.

The paper encompasses:

- Part I: A description of California agriculture--major crops, growing areas, and estimated impact on California's economy
- Part II: An overview of California's water supply
- Part III: California agriculture's responses to the 1987-92 drought
- Part IV: Conclusions: lessons for the next drought
- Appendix with selected statistics
- Bibliography

This paper provides broad background about water and agriculture in California. It also outlines what farmers and water managers *could* and *did* do to use less water, use water more efficiently, find alternate sources, and otherwise deal with water shortage. The paper is not intended to say what farmers or managers *should* have done, but rather to provide information to help support analysis of the options.

Much of the territory covered in this paper is complicated, to say the least. The literature on the topics discussed is enormous. A computer search found more than 1,000 titles relating just to the topic of irrigation--published or acquired *in only the last ten years*, and *excluding* periodical articles. (There might have been many more. The computer stopped counting at 1,000.) Despite the unavoidable omissions and simplifications, the author hopes that this paper will be a helpful guide to how agriculture can and did cope with drought in California. The annotated bibliography will serve as a starting point for those who want additional information.

Acknowledgements

Thanks are due to many people who provided information or reviewed earlier drafts of this paper. Special thanks go to Ray Borton, then of the Department of Food and Agriculture, who shared a wealth of information and explained many aspects of agriculture and agricultural statistics. He also reviewed a draft of the paper and suggested much-needed revisions and clarifications. Frank Limacher, also formerly of the Department of Food and Agriculture, provided meticulous and helpful comments on a draft of the paper. Dennis O'Connor and Joe Fitz, of the California Research Bureau, suggested numerous corrections and clarifications.

Special thanks also to the good people of the California State Library, especially in the Circulation and Government Publications sections, and to Karen Crete, of the California Research Bureau, for innumerable assistance in obtaining documents. Note should also be made of Buzz Breedlove, of the California Research Bureau, whose impassive critiques have made this a much better paper--and certainly a much longer one--than it would otherwise have been.

Others who provided information, resource documents, or comments include Ronald Hull, Imperial Irrigation District; Rob Leake and Tracy Slavin, Westlands Water District; Danyal Kasapligil, Monterey County Water Resources Agency; Tom Goehring, Kings River Conservation District; David Harbison, Coachella Valley Water District; Kurt Schulbach, Monterey County Farm Advisor; Phil Nixon, Lost Hills Water District; Lee Waddle, Ventura County Resource Conservation District; Brian Hockett, Pond-Shafter-Wasco Resource Conservation District; Buzz Felleke, Kings County Agricultural Commissioner's Office; Jackie Bressler, Kern County Agriculture Department; Holly Sheradin, California Department of Water Resources; Richard Rohrer and Ricardo Amón, California Energy Commission; Dan Florey, Department of Water Resources; Socorro Dávila-Garcia and Baldev S. Chima, Employment Development Department; R. Brad Shinn, California Farm Water Coalition; Steve Haugen, Kings River Conservation District; Carl Hauge, Department of Water Resources; Bob Kemis; Office of Statewide Health Planning and Development; Carl DeWing, Department of Food and Agriculture; Patrick Porgans, independent consultant (Sacramento); Dean Misczynski, Transition Director, California Research Bureau. Responsibility for errors and omissions remaining in the paper has been ungrudgingly assumed by my six cats, who will agree to anything for a can of tuna.

My apologies--and thanks--to anyone else who has assisted but is not listed above. All assistance was very much appreciated.

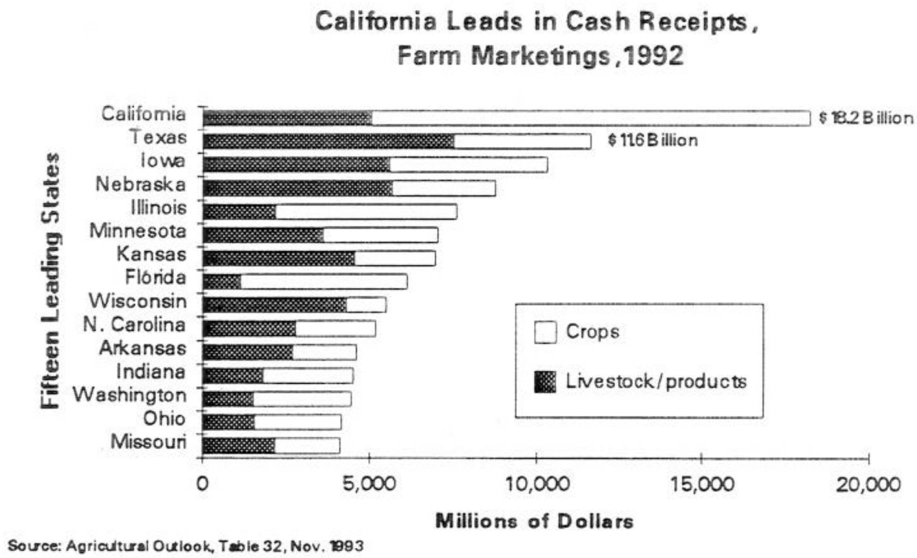
PART I:
AGRICULTURE IN CALIFORNIA

This part presents a summary of California's agriculture: its national importance, variety of products, geographical range, and other characteristics.

California's Agriculture Leads the Nation

California is *the* leading agricultural state in the United States.[5] For 1992, the state's cash receipts from farm marketings, at $18.2 billion, led all states. The nearest competitors for that year were Texas ($11.6 billion) and Iowa ($10.3 billion). These figures include crops as well as livestock and livestock products.

CHART 1



California's 1990 *crop* value of $10.6 billion was more than 13 percent of the entire crop value in the nation, according to U.S. Department of Agriculture figures.[6] Only two other states (Illinois and Iowa) reached even half of California's crop value in that year. California achieved this productivity with only 1.6 percent of the harvested acreage in the nation and about 4 percent of the nation's farms. California's ratio of crop value to

[5]Figures in this paragraph are from Table 32--Cash Receipts From Farm Marketings, by State, *Agricultural Outlook* (U.S.D.A.), November 1993.

[6]The figures in this paragraph are taken or calculated from *Statistical Abstract of the United States 1992*, Table No. 1114, Crops--Acreage and Value, by State: 1988 to 1991.

harvested acreage for 1990, $2,220 per acre, was one of the highest in the nation. Only Florida, at $2,570 per acre, had a higher ratio. The national average for 1990 was $261 per acre.

Fresno County alone produces more agricultural value than about half of the states.

California's agricultural productivity is not just important to California itself. California supplies more than half of all the fruits and vegetables produced in the United States.[7] The state's productivity is vital to the nation and contributes significantly to the world's supply of food and fiber.

California's Agriculture is Diverse[8]

The diversity of California's farm output--made possible by the state's size, climate, and diversity of growing conditions--is as notable as its overall agricultural productivity. California leads the nation in the production of scores of crop and livestock commodities, including alfalfa seed, boysenberries, eggs, kumquats, peaches, raisins, processing tomatoes, and wine grapes. It leads the nation in numerous specialty crops, some of which are grown only in California, as well as in more widely grown crops.

California's agriculture is not concentrated in a few products. For 1992, only milk and cream provided more than a tenth of the state's gross farm income. The only other commodities exceeding 4 percent for that year were grapes (8.9 percent), cattle and calves (7.6 percent), nursery products (6.4 percent), and cotton lint[9] (5.0 percent). The 11th through 20th ranked crops each accounted for 1 to 3 percent of the total.

Chart 2 illustrates the diversity of state's leading agricultural products. According to the California Department of Food and Agriculture's annual statistical report for 1992, California produces about 250 crops, of which 66 are specifically covered in the report. The 20 products named in the chart account for three-quarters of California's agricultural production.

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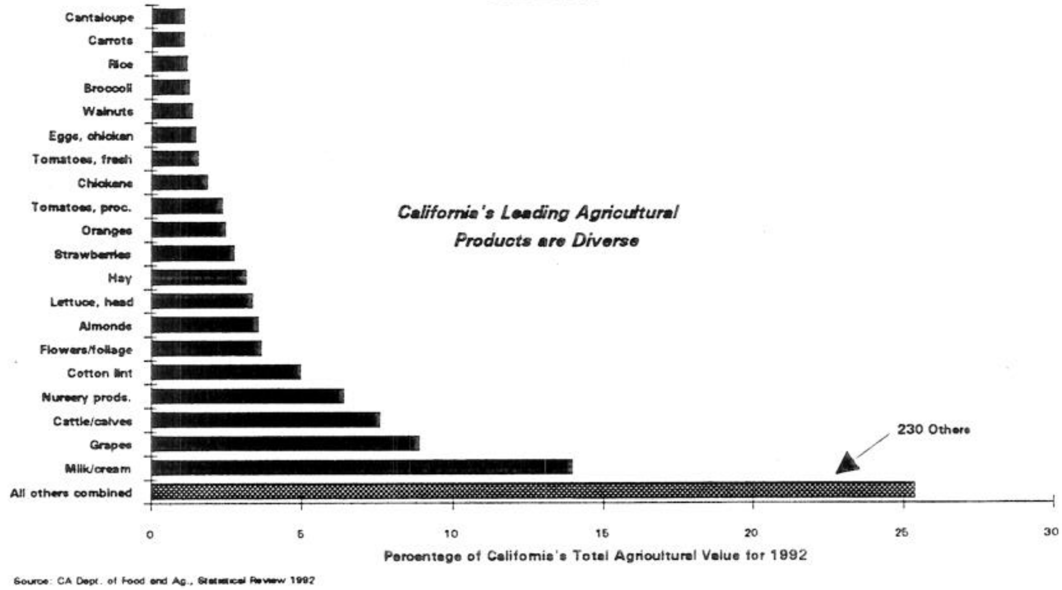
[7]Ray Borton, California Department of Food and Agriculture, personal communication.

[8]Figures in this section are drawn from California Department of Food and Agriculture, *California Agriculture Statistical Review 1992*, published in July 1993.

[9]"Lint" is the fiber used to make cloth--what we usually think of as "cotton." Cotton plants also produce seed, itself a significant commodity. For that reason agricultural statistics specify "cotton lint" to distinguish it from "cotton seed."

CHART 2



Some of California's agricultural products are consumed largely *in* California. Nursery and landscape products (spurred by home construction) are among these. Many other products serve not only the needs of California but also the needs of much of the nation, as well as foreign markets. For example, California produces 90 percent of the nation's broccoli, 72 percent of its lettuce, 91 percent of its processing tomatoes, 94 percent of its apricots, and 99 to 100 percent of its dates, almonds, figs, kiwifruit, olives, clingstone peaches, dried prunes, walnuts, and pistachios.[10]

Agriculture is Important to Many Counties

In 1992, six counties each had over a billion dollars in agricultural production, excluding timber. Eight more each had from half a billion to a billion dollars of production. Nineteen others each had over $100 million dollars of production.

Top producing counties range from Fresno, Tulare, Kern, Stanislaus, Merced, San Joaquin, and Kings in the Central Valley, to Monterey, San Diego, and Santa Barbara along the coast, and to Riverside, Imperial, and San Bernardino in southeastern California. Even such urbanized counties as Los Angeles and Orange have substantial agricultural production ($197 million and $251 million, respectively, for 1992).

Chart 3 shows the value of agricultural production for counties with over $200 million production for 1992.[11] Central, coastal, and southern California counties all appear among the top ten.

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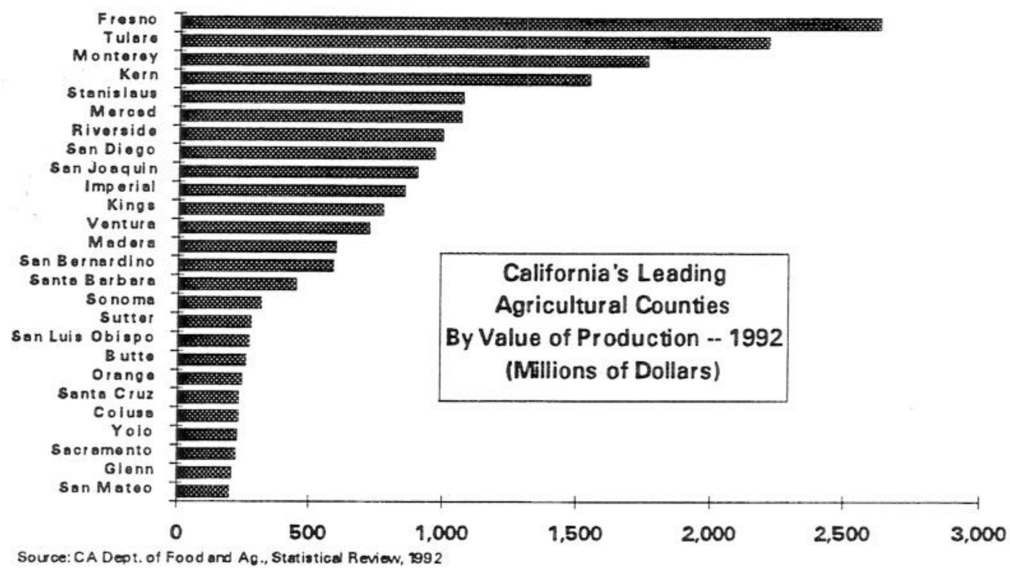
[10]These figures exclude imports of these products.

[11]Data from California Department of Food and Agriculture, *California Agriculture Statistical Review, 1992*, p. 15. Timber is excluded from the figures. CDFA's source is the county Agricultural Commissioners' Reports.

CHART 3



Climates, soil conditions, and water supplies vary widely from county to county, and even sometimes within the same county or even the same farm. Farmers select crops and methods to meet local conditions and to take advantage of changing markets and consumer preferences.

Agriculture Contributes to California's Economy

Not only is agriculture in California important for its role in supplying food and fiber to the state and nation, it forms a significant part of California's economy.

In 1989, California agriculture accounted for 2.6 percent of gross state product and 2.9 percent of total employment.[12] If both direct and indirect economic activity are included, the importance of agriculture to the state is much greater. In a recent analysis, University of California researchers Harold O. Carter and George Goldman found that 9.42 percent of California's personal income, 9.05 percent of its value added, and 9.78 percent its jobs--nearly one in ten--stem directly or indirectly from agriculture.[13] These figures reflect the "multiplier effect," that is, the impact of agriculture's direct employment and production on other sectors of the economy.[14]

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[12]Data from California Department of Finance, *California Statistical Abstract, 1992*, tables D-5, C-3, and C-8.

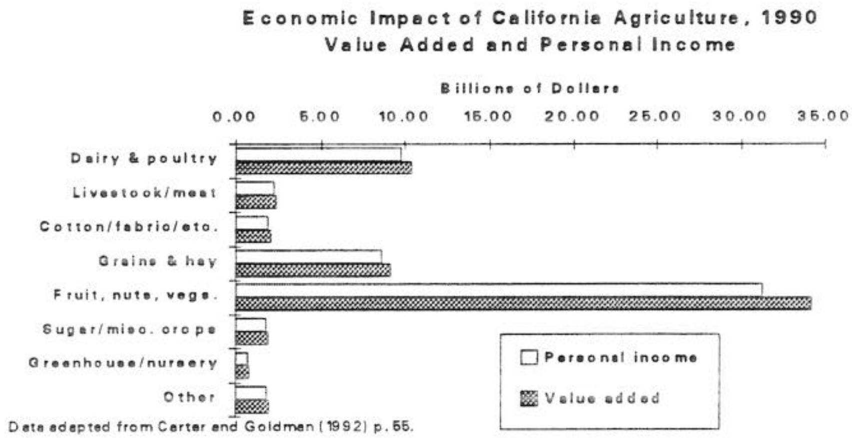
[13]*The Measure of California Agriculture: Its Impact on the State Economy* (Berkeley: University of California Divison of Agriculture and Natural Resources, 1992). Harold Carter is director of the Agricultural Issues Center, University of California, Davis; George Goldman is an economist with the Department of Agricultural and Resource Economics, University of California, Berkeley.

[14]Carter and Goldman (1993), pp. 53-55. The figures were calculated with a U.S. Forest Service computer modeling system called IMPLAN.

Direct agricultural employment in California, as elsewhere in the nation, has decreased as a result of improved production techniques and labor-saving methods. Nonetheless, state Carter and Goldman, "while direct employment from agriculture might be falling off, jobs indirectly related to agriculture continue to be a strong source of employment for many Californians."[15] Carter and Goldman found for 1990 that 1.35 million of the state's 13.85 million jobs could be traced directly or indirectly to agriculture.

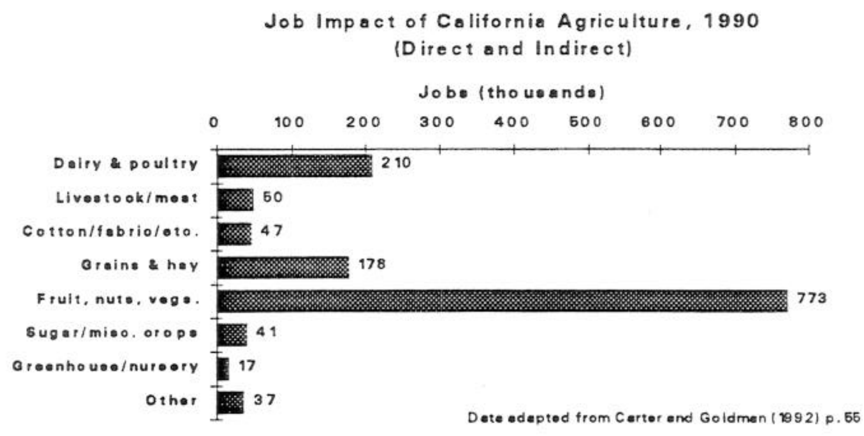
Chart 4 shows the relative importance of various agricultural commodity groups, on the basis of Carter and Goldman's data and computer model calculations for 1990.

CHART 4



Job data show a similar pattern.

CHART 5



In short, although agriculture does not dominate California's economic and employment

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[15] Carter and Goldman, *Measure*, p. 55.

base, it is an important component.

Irrigation is Essential to Farming in California

There are two types of farming, based on water source. The two types of farming face different issues and have different kinds of resources during drought.

- *Dry farming* depends on precipitation and on ground water reachable by the roots of crops. Dry farming (mostly pasture, grazing, and some wheat and other grains) suffers immediately during a drought, as crops wither or fail. During drought, cattle that depend on non-irrigated pasture or grazing land must be shipped elsewhere, slaughtered, or provided with feed shipped in or obtained from irrigated land.

- *Irrigated farming* supplements precipitation and root-accessible ground water through irrigation with water from reservoirs and rivers and with ground water pumped from wells. In years of normal precipitation, irrigation still provides most of the water required by irrigated crops, especially during summer and fall growing seasons.

Most of California's crops are irrigated. In California's most fertile areas, precipitation directly meets only a small part of crop water needs. Although California also has non-irrigated pasture and rangeland, that land does not produce the high-value crops that are the backbone of California agriculture. Without irrigation, California could not support the kinds or extent of farming that it does.

PART II: WATER IN CALIFORNIA

This part looks at regional variations, measurement, and storage of water in California.[16]

California's Water Sources and Supplies Vary Widely

California is large and geographically varied. No one pattern fits the entire state, especially with respect to water.

CHART 6

MAJOR HYDROLOGIC REGIONS

Also called HYDROLOGIC STUDY AREAS

[16]This is a selective overview. For more complete information, see the sources cited in the notes and listed in the bibliography.

To facilitate study and analysis of California's water situation, water analysts divide the state into ten "hydrologic study areas" (HSAs), also known as "hydrologic regions."[17] Each HSA encompasses a group of specified drainage basins and has broadly homogeneous precipitation and ground water characteristics. The Department of Water Resources maintains precipitation and other water-supply data for each HSA.

Table 1 summarizes the hydrologic study areas and the annual average precipitation and runoff[18] of each.

TABLE 1
CALIFORNIA'S HYDROLOGIC REGIONS

Region	Description	Average Annual Precipitation	Average Annual Runoff
North Coast (NC)	Predominantly mountainous (North Coast and Klamath ranges).	51.0 inches	28.6 million acre feet (MAF)
San Francisco Bay (SF)	Predominantly urbanized area around San Francisco Bay.	25.8 inches	1.6 MAF
Sacramento Basin (SB or SR[19])	Encompasses Sacramento River valley and western Sierras. The valley counties are agriculturally productive.	36.0 inches	22.4 MAF
North Lahontan (NL)	Mountainous strip of northeastern California.	22.1 inches	1.8 MAF.
San Joaquin (SJ)	Some of the most productive agricultural counties.	27.3 inches	7.9 MAF
Tulare Lake (TL)	Named for the dry lake which once captured the runoff in the region. Encompasses leading agricultural counties.	15.4 inches	3.3 MAF

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[17]For descriptions and analyses of the areas, see Department of Water Resources Bulletin No. 118, *California's Ground Water* (1975). Also see Volume 2 of California Department of Water Resources, *California Water Plan Update*, November 1993, draft Bulletin 160-93.

[18]Precipitation and runoff figures are from California Department of Water Resources, *California Water Plan Update*, November 1993, p. 49. The Colorado Desert area is identified there as Colorado River (CR).

[19]The Sacramento HSA is identified as "SR" in the Department of Water Resources report "Hydrological Facts 1987-1992" and as "SB" in Bulletins 132 (state water project report series) and 118 (ground water report series).

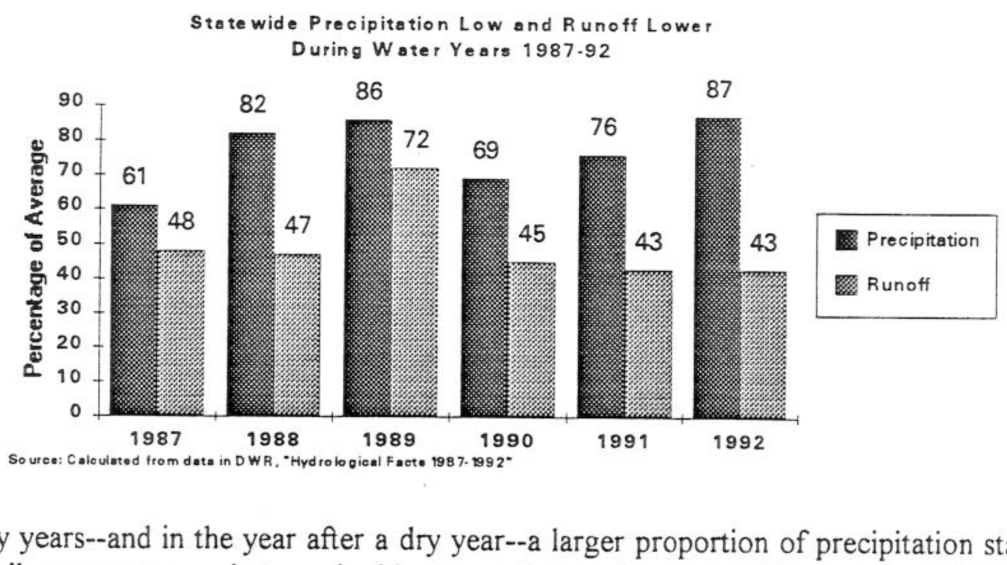
Central Coast (CC)	Seawater intrusion threatens groundwater supplies in parts of this region. Monterey County is among the leaders in California agriculture. The area is heavily dependent on ground water.	19.8 inches	2.5 MAF
South Coast (SC)	Encompasses both urbanized and agricultural areas.	18.4 inches	1.2 MAF
South Lahontan (SL)	Largely desert.	7.9 inches	1.3 MAF
Colorado Desert (CD)	Desert areas whose agriculture is supported by water from the Colorado River.	5.5 inches	0.2 MAF

Precipitation and Runoff

Precipitation includes rain, snow, and other forms of water from clouds. Runoff is the water that runs into lakes and streams rather than soaking into the ground. The Department of Water Resources publishes information on precipitation and runoff for each hydrologic study area in its annual Bulletin 132: *Management of the California State Water Project,* and other documents.

The statewide view of the drought is clear (Chart 7). Precipitation was below average, and except for 1989 (aided by late rains) statewide runoff was less than half of average.

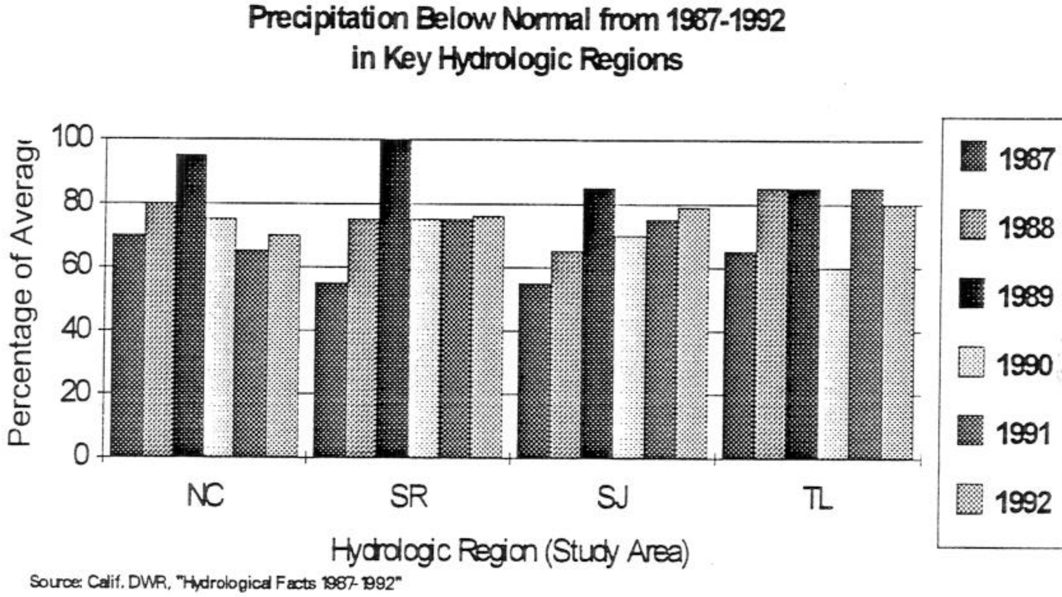
CHART 7



In dry years--and in the year after a dry year--a larger proportion of precipitation stays in the soil, evaporates, or is transpired by vegetation, so less runs off into streams, lakes, and reservoirs. For that reason, precipitation figures understate the severity of drought. Runoff is more critical to water supply, and it is therefore a better measure. On average from 1987 to 1992, statewide precipitation was 79 percent of normal, but runoff was only 46 percent of normal.[20]

Chart 8 shows precipitation levels (as percent of average) for the North Coast, Sacramento, San Joaquin, and Tulare Lake hydrologic regions for water years 1987 to 1992.[21]

CHART 8



Runoff as a percentage of average is shown below for the same period and regions (Chart 9). In general, runoff was less than half of normal. Heavy March and April rains in 1989 provided some relief, as shown in the area charts and in the statewide chart. (Heavy rains over a short period result in more runoff than the same amount of rain spread over a long period because the amount of water the soil can hold is limited.)

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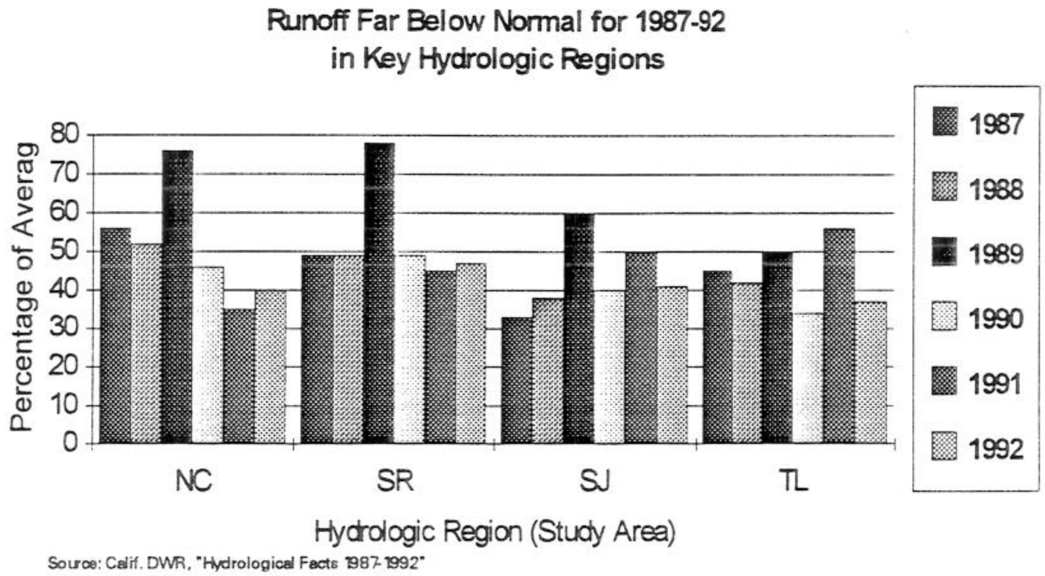
[20]These figures represent averages of percentages for all HSAs for water years 1987-92. Because some HSAs receive very little precipitation in normal years, the average is higher than the true statewide level of precipitation.

[21]The "water year" runs from October 1 to September 30. For example, water year 1992 began October 1, 1991, and ended September 30, 1992.

CHART 9



Reservoir Storage

Smoothing out year-to-year supply fluctuations is one of the purposes of California's system of reservoirs and aqueducts. Another primary purpose is, of course, to move water from where it is relatively abundant to where it is scarce.[22] Because of the water system's surface reservoir storage capacity, water deliveries can continue at a relatively normal level even after drought is well underway. Deliveries did continue with little interruption from 1987 to 1989.

According to the department's published figures, the total capacity of 155 major reservoirs tracked by the Department of Water Resources is 37,648,000 acre-feet. (An acre-foot is the amount of water that would cover one acre to a depth of one foot. It is equivalent to 43,560 cubic feet, or 325,850 gallons, and is about the amount used by a family of five during one year.) The historical average storage in the 155 reservoirs is 22,518,000 acre-feet.

Table 2 summarizes storage in 155 major California reservoirs as of the end of the water year (September 30), 1986-1992.[23] Storage dropped sharply in the first year of the drought, and again in the second. Water year 1989 saw some improvement, followed by a resumption of the decline in storage.

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[22]See Department of Water Resources Bulletin 160-87, *California Water: Looking to the Future*, and Bulletin 132, *Management of the California State Water Project*. DWR updates Bulletin 160 every few years (the latest at this writing is the 1987 edition, although a draft update was released on December 1, 1993, as draft Bulletin 160-93), and issues Bulletin 132 annually. Several other sources listed in the bibliography of this paper describe California's water projects and their history.

[23]Department of Water Resources, "Hydrological Facts 1987-1992."

TABLE 2
WATER STORAGE, MAJOR RESERVOIRS, 1986-1992

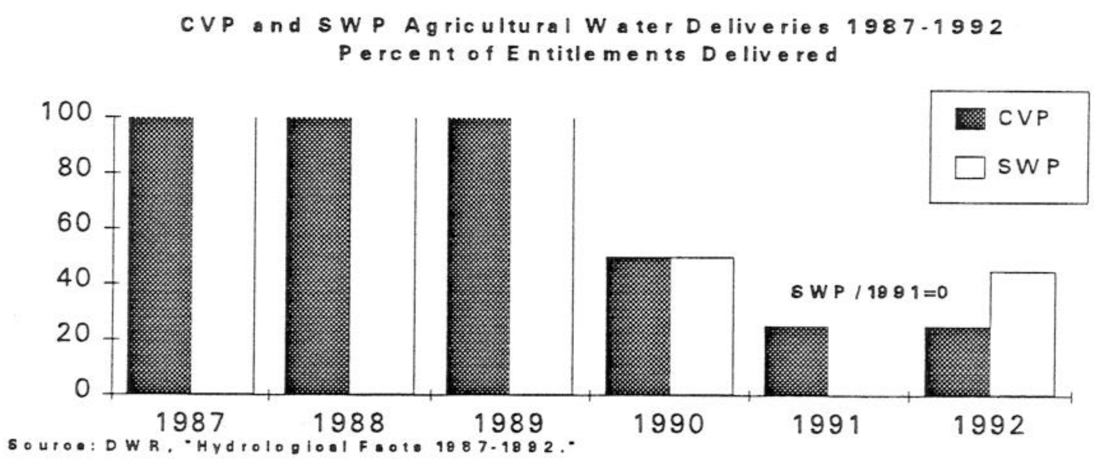
Year	Stored Water (million AF)	% of Normal Storage	Diff. from Prev. Year (million AF)	Accumulated Loss (million AF)
1986	26.8	119	----	----
1987	18.9	84	-7.9	-7.9
1988	14.8	66	-4.1	-12.0
1989	16.7	74	+1.9	-10.1
1990	13.6	60	-3.1	-13.2
1991	13.8	61	+0.2	-13.0
1992	12.7	56	-1.1	-14.1

Source: Department of Water Resources, "Hydrological Facts 1987-1992."

Although they do not dominate the state's water supply, CVP and SWP resources are an important part. Those projects account on average for 7.5 million acre-feet (CVP) and 2.8 million acre-feet (SWP), out of total statewide supply of 63.7 million acre-feet. CVP and SWP together provide about 29 percent of water supplies for the San Joaquin River region and about 47 percent of supplies for the Tulare Lake region. The west side of the San Joaquin Valley is heavily dependent on project water.[24]

Agricultural water deliveries continued at 100 percent of entitlement levels from both the Central Valley Project (CVP) and State Water Project (SWP) for the first three years of the drought, and then dropped sharply (Chart 10).

CHART 10



[24]California Department of Water Resources, draft *California Water Plan Update*, Volume 2, pp. 167, 163, and 198. The figures are for "average conditions" for 1990.

Ground Water

Surface water storage in reservoirs is one buffer against the effects of drought. Another buffer is ground water, a resource that was of great importance as the drought lengthened.

What is Ground Water?

The Agriculture Dictionary[25] defines "groundwater"[26] as:

> Water within the earth that supplies wells and springs. Specifically, water in the zone of saturation, where all openings in soils and rocks are filled with water, the upper surface of which forms the water table.

A California Department of Water Resources report on *California's Ground Water* more concisely defines it as "water stored underground in permeable rock or soil formations." Ground water is contrasted with the "surface water" in lakes, streams, and reservoirs.

According to the DWR report, "about 40 percent of California is underlain by ground water basins." The total capacity of those basins is enormous (some 1.3 billion acre-feet, enough to cover the entire state to a depth of nearly 13 feet). Water quality problems and cost and difficulty of pumping from great depths make the *usable* capacity much smaller, about 143 million acre feet.[27] That usable capacity is about 3.8 times as large as the storage capacity of the 155 major reservoirs described above.

Ground water basins (aquifers) can furnish water that is later replenished through deep percolation.[28] A clay barrier under much of California greatly restricts replenishment of the deep "confined" aquifer by this means. Percolation may be able to reach an "unconfined" aquifer above the barrier, however. In some areas "perched" water tables may sit above another barrier over part of the unconfined aquifer.[29] Perched water tables sometimes rise to within two or three feet of the ground surface. This condition restricts the root zone and increases salinity, thus interfering with plant growth and making management of drainage especially difficult.

Where replenishment is possible, the ground water basin may be drawn upon in dry years and replenished in wet ones, providing a cushion against drought. This practice is called "conjunctive use."

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[25]Ray V. Herren and Roy L. Donahue.

[26]Some writers make the term two words, and others make it one. This paper makes it two words, ground water, but quotes others' usage exactly.

[27]Data from California Department of Water Resources, *California's Ground Water*, p. 3.

[28]In some cases water may be also be put back into the aquifer via injection wells.

[29]See DWR, *California's Ground Water*, p. 18, for an illustration of these concepts. Chapter II of that report (pp. 6-25) is a concise overview of and introduction to ground water.

In some areas, including large parts of the Central Valley, the land subsides when water is pumped from the aquifer. Subsidence results when the spaces between soil or sand particles move closer after removal of water. The spaces that had been available for storage of water disappear and the capacity of the ground water basin shrinks permanently. The land surface has fallen by nearly 30 feet in some areas of the San Joaquin Valley.[30]

Ground Water and California Agriculture[31]

Use of ground water is common in California:

> During normal water years, a significant portion of California's agricultural water supplies are pumped from underground sources--between 20 and 40 percent in the state as a whole and more than 50 percent in the San Joaquin Valley (Department of Water Resources (DWR), Groundwater Trends in the San Joaquin Valley, 1990). In critically dry years, groundwater is pumped at significantly higher rates. In 1991, an estimated 20 million acre feet (MAF) of groundwater were extracted throughout the state for use by agriculture as compared with 16.6 MAF in pre-drought year 1985. Approximately 70 percent of irrigation water for the San Joaquin Valley was supplied by groundwater in 1991, or 13.2 MAF.[32]

Carl Hauge, Chief Hydrogeologist of the Department of Water Resources, has estimated that almost 40 percent of California's water supply is ground water in a normal year, and significantly more in drought years.[33]

During years of normal or above normal precipitation, in most parts of the state ground water reserves stay steady or increase as surface water percolates into the aquifer. During dry years pumping depletes ground water.

Drainage and Salinity

California's water situation, including access to ground water, is complicated by widespread salinity and impaired drainage.[34]

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[30] American Farmland Trust, *Risks, Challenges & Opportunities*, p. 49.

[31] For additional information, see Department of Water Resources, *California Water Plan Update*, Volume 1, November 1993 (Draft, released December 1, 1993), pp. 85-114.

[32] Marsh and Archibald (1992), p. 5.

[33] Carl Hauge, "The Importance of Ground Water in California," p. 15.

[34] See the series of reports titled *Resources at Risk* (listed in the bibliography) sponsored by the University of California Agricultural Issues Center and the Water Resources Center. Those reports are listed in the bibliography under Ray Coppock.

Widespread salts in Central Valley soils are the result of the relatively recent (in geological terms) immersion of all of California's Central Valley by the Pacific Ocean. Sand, clay, and gravel eroded from the Sierra Nevada and the Coast Range, gradually displacing the salt water. Where heavy clay deposits occurred relatively recently, and are therefore near the surface, salts are also trapped between the valley surface and that clay layer (called the Corcoran Clay). Irrigation dilutes these salts, which then flow with the excess water in surface runoff or in subsurface flows along the clay layer.[35]

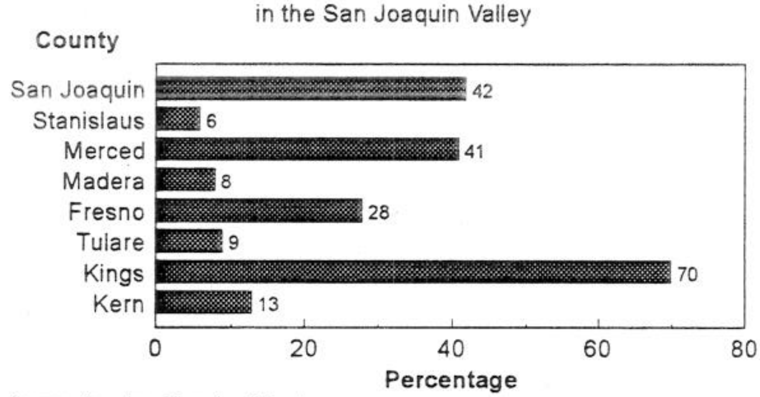
Soil and ground water conditions vary greatly across the state. The widespread salinity of the Central Valley does not extend to Riverside or Imperial County, for example. Conditions vary within the Central Valley, and even within counties. The east side of the valley generally has adequate access to good quality ground water. The west side, on the other hand, has underlying perched saline (salt contaminated) water tables that pose problems for both water availability and drainage management.

Chart 11 shows the percentage of irrigated cropland overlying perched saline water tables in San Joaquin Valley counties.[36]

CHART 11

Perched Saline Water Tables

in the San Joaquin Valley



Source: American Farmland Trust
Risks, Challenges & Opportunities

The soil itself may be (or become) saline, especially above perched saline water tables. Chart 12 summarizes the geographical extent of soil salinity in the San Joaquin Valley.[37] (The chart does not address the *severity* of salinity. Most of the land is still productive for appropriate crops.)

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[35]Most of this summary was provided by Frank Limacher, personal communication. Also see Ray Coppock, *Resources at Risk: Agricultural Drainage in the San Joaquin Valley*, pp. 1-3.

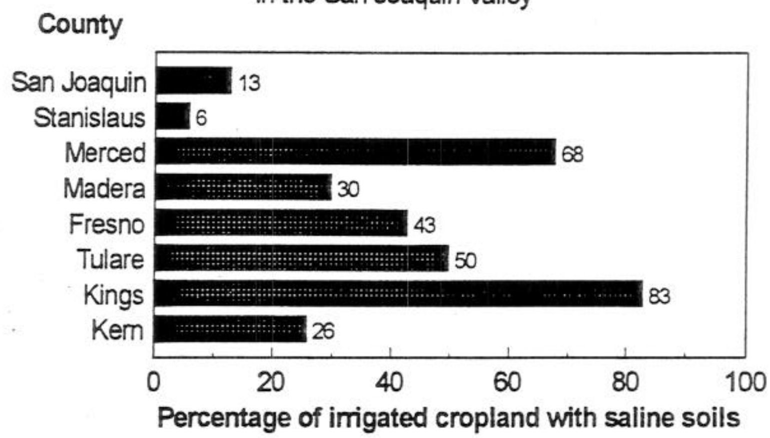
[36]The chart in *Risks, Challenges & Opportunities* from which these percentages were taken in turn cites USDA Soil Conservation Service, Davis, CA, May 15, 1984, as the source.

[37]The chart in *Risks, Challenges & Opportunities* from which these percentages were taken in turn cites USDA Soil Conservation Service, Davis, CA, May 15, 1984, as the source.

CHART 12

Saline Soils

in the San Joaquin Valley



Source: American Farmland Trust
Risks, Challenges & Opportunities

The San Joaquin Valley is not the only part of California affected by salinity. Intrusion of sea water into the aquifer along the coast contributes to salinity that affects or threatens agricultural and municipal water supplies.

Soil salinity limits crop choices to those that are sufficiently salt tolerant. Salt-tolerant crops include, for example, asparagus, barley, sugar beets, and cotton. Salt-sensitive crops include almonds, apricots, carrots, grapes, citrus, and strawberries. Crops can also fall in a middle range. For example, red beets and sorghum are "moderately tolerant," while broccoli and potatoes are "moderately sensitive."[38] If severe enough, salinity makes the land unusable for growing crops.

In summary, California's ground water conditions vary widely and can substantially affect farming. Farmers need to understand the ground water conditions under their acreage and to adapt their techniques to meet those conditions.

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[38]See University of California Irrigation Program, UC Davis, "Crop Salt Tolerance," especially Table 1, in University of California Cooperative Extension (sponsor), *Sixth Annual Drip Irrigation Symposium*.

PART III: RESPONSES TO CALIFORNIA'S 1987-92 DROUGHT

This part summarizes the ways in which California agriculture *could*, and typically *did*, respond to drought from 1987 to 1992.

Irrigated agriculture can reduce the impact of drought in many ways. Some of these ways find additional water. Some redistribute what is available. Some conserve water through improved application efficiency, reduced water use, or both.

- In brief, the primary response to California's recent drought--where feasible and where the drought years differed from "normal" years--was to pump more ground water.

- The second was water exchanges and transfers, including the Drought Water Bank.

- The third was fallowing (and some crop switching), sometimes associated with exchanges. Fallowing is the practice of partly preparing the soil for planting, but leaving the soil unplanted and unfarmed.

Other responses were used to a greater or lesser extent, depending on local conditions. Some responses, such as improved irrigation management and methods, are increasingly widespread, but often as a means of improving crop quality and quantity rather than specifically to reduce water use. In the areas most directly affected by the drought those responses appear to have been less important in coping with reduced surface water than pumping, exchanges, and fallowing or crop switching.

What Determines Crop Water Requirements?

The water applied to crops is used in several ways. The most basic is to supply the water actually transpired (breathed out, so to speak) by the plants as they grow. This is transpiration, often abbreviated as T. Next is evaporation of water from the soil (evaporation, abbreviated as E), but not directly used or transpired by the plants. The two together are called evapotranspiration, ET.

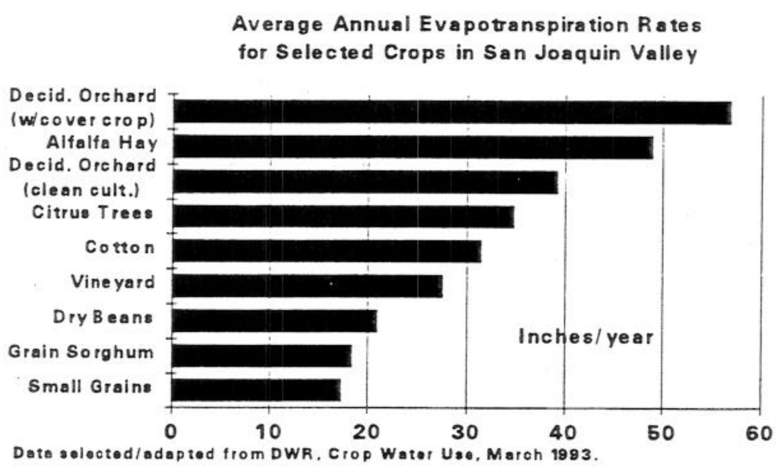
Transpiration is ordinarily the significantly larger of the two components. That is, most of the crop water requirement serves the biological process of plant growth. There is some trade-off between evaporation and transpiration. Irrigation practices that minimize evaporation can lead to warmer soil and air, in turn causing higher transpiration.

Some water stays in the plant itself. This component is comparatively small, and so is often ignored in calculation of crop water requirements. ET is generally used as an approximation of the total direct crop water requirement.

ET requirements reflect both the nature of the crop and the length and timing of the growing season. Cool-weather crops need less water because they face less heat and less sunlight. Crops that quickly achieve good canopy lose less water to evaporation, although they may need more for transpiration. Crops with short seasons, other things being equal, require less water because they are growing (and hence transpiring) for a shorter time. The aerodynamic characteristics of crops affect ET, especially under windy conditions. For example, grass is aerodynamically fine-textured, and therefore more conservative of water during wind than are such aerodynamically coarse-textured crops as corn and sugar beets.

Plant growth and development require sufficient water to meet crop ET. If less water is available to the roots, then the plants die or their productivity shrinks. For example, fruit on underwatered trees is smaller or of poorer quality. Farmers sometimes have good reasons for withholding water at certain times of the growing season. Those reasons reflect specific techniques for maximizing yield, facilitating harvest, or interrupting plant pest or disease cycles. Arbitrary reduction of water ordinarily will reduce crop quantity, quality, or both.

CHART 13



Agricultural scientists calculate and measure evapotranspiration rates. The resulting data allow planning for irrigation requirements and comparison of overall crop water needs. Chart 13 is highly simplified,[39] but gives a general idea of the range of average annual ET rates for some typical San Joaquin Valley crops. The selected crops include deciduous orchard with a cover crop and without, as well as alfalfa hay, citrus trees, cotton, grape vineyard, dry beans, grain sorghum, and small grains (such as wheat, oats, and barley).

[39]DWR's publication *Crop Water Use*, March 1993, provides much more detailed ET rate tables by year and even by week over a period of several years. The data reflect field measurements.

These figures of course represent only part of the water requirements for these crops, as discussed further below.

Under most real farming conditions, farmers cannot match applied water exactly to crop ET requirements. Farmers must ordinarily overirrigate some parts of their fields to assure that the more poorly reached parts receive enough water. Soil type, salinity, atmospheric conditions, field contours, and other factors may lead to percolation below the root zone, runoff, or excessive loss to evaporation despite the most careful design and management of any irrigation technique.[40] As a very broad generalization, irrigation efficiency (ratio of water applied to water used for evapotranspiration and other beneficial purposes) of 75 to 80 percent is considered good to excellent.[41] Higher efficiencies are possible, but may require carefully managed drip or other micro irrigation systems not suited to all field and crop types and sometimes too costly to be economically feasible.[42]

Evapotranspiration rates vary from week to week, depending on atmospheric conditions and growth stage of the crop. The farmer must consider precipitation and these varying ET needs, not just seasonal rates, in planning and managing irrigation. The California Irrigation Management Information System (CIMIS, a joint project of the California Department of Water Resources and the University of California) makes detailed data available to help farmers match applied water closely to current requirements. Circumstances over which the farmer may have no control, such as lack of on-demand availability of water, may limit the farmer's ability to match applied water to current needs.

Water to meet ET requirements is only one aspect (although a large one) of total agricultural water needs. Depending on crop, soil conditions, and other factors, farmers irrigate to leach salts out of the root zone, aid in weed and pest management, replenish moisture in moisture-depleted soil, or protect crops from frost or heat.

Precipitation can meet some of the needs. Rain can replenish moisture in the soil, serve as the "leaching fraction,"[43] or help germinate weed seeds before the crop is planted. But in

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[40]Central Valley Water Use Study Committee, *Irrigation Water Use in the Central Valley of California*, p. 25.

[41]See Gerald Robb and Tracy Slavin, "Attainable Irrigation Efficiency," in Westlands Water District's *Water Conservation Plan*. The authors, who are water management specialists with the district, conclude, "Attainable irrigation efficiency is limited by the distribution uniformity of the system and unavoidable minor losses." (P. C-5.)

[42]Note that excess applied water might be recaptured by a tailwater recovery or recirculation system, percolate to a usable ground water supply, or run off to a stream and be available for use elsewhere. For that reason, irrigation efficiency alone is *not* a measure of how much of the applied water is actually lost to farm, basin, or both.

[43]All irrigation water has some dissolved salts. As water evaporates and as plants draw water from the soil, salts accumulate in the soil. The process of washing the salts to deeper levels of the soil is called leaching. The leaching fraction is not, as some might speculate, that portion of one's adult children still living at home. Rather, it is the fraction of total crop water requirements devoted to washing salts out of

the frequent years when precipitation is ill-timed or insufficient, farmers must irrigate for those purposes.

What is Agricultural Water Conservation?

"Water conservation" can be a confusing term. The U.S. Bureau of Reclamation's *Guidebook for Preparing Water Conservation Plans* illustrates the confusion. It defines "water conservation" as "implementation of best management practices," which it in turn defines as including practices that achieve "significant conservation or conservation related benefits [page 1-3]." In other words, conservation is conservation.

The term's meaning depends in part on who is using it. California's Water Code defines water conservation as,

> the reduction of the amount of water irretrievably lost to saline sinks, moisture-deficient soils, water surface evaporation, or noncrop evapotranspiration in the process of satisfying an existing beneficial use achieved either by improving the technology or method for diverting, transporting, applying, or recovering the water or by implementation of other conservation methods.[44]

That definition takes the "existing beneficial use" as given, and views conservation as reducing the amount of water used for that existing purpose. That definition, as well as the discussion in this section, focuses on on-farm water use, and for that reason takes a narrow view of the topic. However, there is a broader perspective as well. That perspective considers not how efficiently the water is used on the farm, but whether the water should be used for agricultural purposes at all, in contrast to using it for such environmental purposes as protection of Delta water quality, species protection, and so on. In other words, that perspective does not take the "existing beneficial use" for granted. Although that perspective is an important one, it is beyond the scope of the present paper.[45]

From a *farm*-based perspective, applied water is lost or wasted--not conserved--if:

- it exceeds the amount necessary to meet total crop requirements (ET, leaching, weed control, and climate control) **and**

- it is not recovered for on-farm use

In contrast, from a *water-basin-wide* perspective, water is lost only when:

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the root zone to deeper levels. Where the leaching fraction is not met by precipitation it must be provided by properly timed irrigation.

[44]California Water Code, §10902(c), added by Chapter 739, Statutes of 1990 (AB 3616).

[45]For a commentary on federal efforts to reserve delta water for environmental use, see William Kahrl, "The De-Watering of California." Also see Richard Conniff, "California: Desert in Disguise."

- it evaporates or transpires into the atmosphere **or**
- it percolates or runs off into a saline sink, such as the Salton Sea, Pacific Ocean, or a saline water table

In the basin-wide sense, to conserve water is to minimize the amount lost in those ways, although the water so lost may have been beneficially used for plant growth or for washing salts away from the root zone, and not considered lost by the farmer.

Water not lost to the basin as described above does not simply disappear. In one way or another it remains available for reuse--on the same acreage, on neighboring fields, or in more distant areas. The excess water percolates to the water table or runs into a creek, for example. Conserving water by reducing applied water to the minimum necessary for crop growth may be balanced by the reduction in reusable runoff and in deep percolation to an accessible, non-saline water table.[46]

Likewise, conserving water by applying less than the amount needed for crop growth has a real cost in reduced yields and, often, in reduced crop quality. Conserving water by failing to apply sufficient water to meet the leaching requirement (the "leaching fraction") results in increasingly saline soil, crop damage, or the need to change to a more salt-tolerant crop, and to an eventual need to apply additional water to remove the accumulated salts from the root zone or to abandon the acreage.

On-farm water conservation is nonetheless important, both to extend the available surface water as far as it can go and to minimize water-related costs. Cost-conscious and technically astute farmers avoid over-irrigation even when abundant water is available because overwatering requires more fertilizer, may accelerate erosion, increases energy and well-maintenance costs (where the source is wells), and can reduce productivity by drowning roots or encouraging plant diseases.

At the same time, reducing applied water to the minimum that will allow proper crop growth may achieve less than projected water savings. For example, reduced evaporation may lead to increased air temperatures over the fields, in turn increasing plant transpiration.

Depending on soil conditions, crop, ground water conditions, and surface water availability, at times it may be desirable for the farmer to apply excess water specifically to help recharge the ground water. If ground water is not recharged in this or other ways, then the next time surface water is reduced ground water may no longer be accessible, or the pumping lift may be prohibitively large. (Pumping lift is the distance water must be raised from water table to the ground surface.) Ground water recharge, however, is not

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[46]See Davenport and Hagan, *Agricultural Water Conservation in California*, especially pp. 3-9. Also see California Department of Water Resources, *Crop Water Use in California* (1986) pp. 13-15.

necessarily best accomplished through excess irrigation, which may carry agricultural chemical residues to the aquifer.

To some, agricultural water *conservation* simply means *less* agricultural water use. This may require under-irrigating, changing crops, or fallowing acreage. From the viewpoint of the farmer whose fundamental productive asset is land and who seeks to make that land as productive as possible, none of these is a desirable option if it can be avoided.

Farmers can save some water by planting faster-maturing varieties or, in some cases, by switching to less water-intensive crops. But these are not always feasible options, for practical and competitive reasons. Fallowing acreage is a last resort because it takes the farmer's key productive asset (land) out of production. At best, the farmer may be able to fit some fallowing into a crop rotation strategy while concentrating available water on fewer acres of higher value crops.

Further complicating the definition of water conservation is that irrigated acreage can serve other purposes, perhaps of no direct importance to the farmer, but vital to non-farm interests. For example, rice acreage provides habitat for migrating waterfowl, and crops or crop residue can provide an important source of food for a variety of wildlife.[47]

There is one more complication: selecting the best methods for the crop and conditions and managing the methods at the best professional levels can *increase* water use if all or part of the acreage had previously been underirrigated. For example, laser leveling uses a laser to guide a tractor to level a field very uniformly. That can sometimes result in increased application of water by assuring that previously underirrigated portions of fields receive enough water. In that way, conservation of water in the sense of applying exactly the amount needed can sometimes contradict the concept of conservation in the sense of reducing the amount of water applied.

For purposes of this paper, the concept of "water conservation" draws from both of the competing definitions. The term is used here to encompass both feasible reductions in applied water and on-farm and system improvements to increase the proportion of applied

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[47]See, for example, Raymond H. Coppock and Marcia Kreith, eds., *California Water Transfers*, pp. 25-27. Glenn Olson, Western Regional Vice President for the Audubon Society, is quoted there as follows:

> All this [water transfers and related issues] is leading to new alliances. For the National Audubon Society and our colleagues in the environmental movement, I can say that we're working very closely with the California Rice Industry Association.
>
> We have an interest in keeping water on rice fields because those fields can be flooded after the rice is harvested and provide waste grain to the the waterfowl and to the shore birds.
>
> I think the politically formidable alliances that will be put together in the future will see new groupings, like farmers and environmentalists, to make sure that the public understands that there's an environmental benefit to having seven acre feet per acre of water used on a rice field.

water that is used beneficially.[48]

Regional Variations Affect Drought Responses and Impacts

Responses to the drought varied from one part of the state to another because precipitation and water sources vary from part of the state to another. For example:

> **Northern California.** In general, in years of normal precipitation and runoff, northern California has enough water for agriculture and other purposes. In those years, too, a predictable and generally sufficient supply of surface water is available for conveyance to central and southern California. Stored water--both surface and ground--can thus largely meet agricultural and municipal water needs for a year or more of drought (depending on severity). As drought continues, however, ground water becomes increasingly important.
>
> **Southern California.** In contrast, the Coachella and Imperial Valleys--Riverside and Imperial counties--are in *perpetual* drought. (The Imperial Valley was, after all, known as the Colorado Desert until renamed by an enterprising developer early in this century.) Those areas get irrigation water from the Colorado River basin, which has had ample stored water while Northern and Central California reservoir levels have plunged.
>
> **Coastal Regions.** In the Salinas Valley (Monterey County) ground water is essentially the sole irrigation water source in wet and dry years alike. Monterey County's locally funded Nacimiento and San Antonio dams store water for summer release, largely to recharge ground water. The county does not transfer water outside the county and does not receive state or federal project water. The continued pumping during the drought resulted in somewhat reduced ground water supplies, but overdrafting of ground water is a problem for Monterey County with or without drought. Salt water intrusion into the ground water supply has been an issue there for half a century, and cannot be solved by increased precipitation. Ventura County faces similar ground water concerns, as do all agricultural areas near the coast.
>
> **San Joaquin Valley.** San Joaquin Valley farmers rely heavily on ground water, but also receive substantial allocations of state and federal project water. Long-term overdrafting of San Joaquin Valley aquifers and resultant land subsidence are both of concern. Ground water quality varies in the valley, making ground water a relatively unreliable source in some areas, especially on the west side.

The economic impact of the drought likewise varied from one part of the state to another,

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[48]For further information on agricultural water use, see Chapter 7 (Volume 1, pp. 173-204), "Agricultural Water Use," in California Department of Water Resources, California Water Plan Update, November 1993, draft Bulletin 160-93.

although over all its impact on agriculture may have been less than the impact of California's 1990-91 freeze.[49]

The drought's impact--in economic and other terms--extended beyond agriculture. Directly and indirectly the drought affected cities, the manufacturing sector, and of course the environment.[50] However, the agricultural impact of the drought, though widespread, was most severe in Kern County and on the west side of the San Joaquin Valley.[51] Agriculture there had to cope with water scarcity, idled land, reduced yields, and increased costs for water and well drilling. A study by Northwest Economic Associates found that in the San Joaquin Valley, "On-farm revenues [for 1992] fell $171.1 million, water costs rose $258.7 million, and well drilling and well rehabilitation costs rose $79.5 million."[52] Lowered ground water levels and increased salinity will have continuing costs in those areas most affected from 1987 through 1992.

Ground Water Pumping was the First Response

Irrigated agriculture's simplest and fastest response to drought is to pump more ground water. It is feasible to pump more ground water as long as pumping lifts (and hence energy and well-drilling and maintenance costs) do not increase too much, ground water quality remains acceptable, and the crops grown with the water provide sufficient income to pay higher costs. In some areas, the option of increased pumping is seriously limited by ground water conditions, especially seawater intrusion in coastal areas.

California's farmers normally pump ground water for irrigation, not only during drought years. According to the Department of Water Resources, "During normal years, almost 40 percent of California's water supply comes from ground water."[53] The difference in drought years is that farmers (and other water users with wells) pump more ground water and that a greatly reduced level of ground water recharge takes place.

Ground water protected most irrigated farms from immediate consequences of drought as severe as those experienced by dry farming or by urban water users subjected to rationing or usage restrictions. The experience of 1987-92 was in this way comparable to that of the previous drought. University of California researchers Richard Howitt and Marangu

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[49]Zilberman, Haney, and Yoo concluded that, "relatively speaking, the drought appears to have had less negative economic impacts on California Agriculture than the frost of 1990-91, which especially hurt citrus growers." ("Impact of Energy Price Changes on Citrus Growers and California Agriculture," p. 2.)

[50]See, for example, Gleick and Nash (1991), especially pp. 17-58.

[51]George Gardner, Northwest Economic Associates, personal communication, March 16, 1994. Mr. Gardner was unaware of any published studies of the drought's statewide economic impact. Northwest Economic Associates' *Economic Impacts of the 1992 California Drought* pertains specifically to the San Joaquin Valley. The county crop acreage charts in part III of this paper also show varying patterns among counties.

[52]Northwest Economic Associates, *Economic Impacts of the 1992 California Drought*, p. i.

[53]"Water Facts: California Well Standards Questions & Answers," June 1992.

M'Marete concluded, "Experience with the last major drought in 1976-1977 shows that increased groundwater pumping was the critical factor in avoiding substantial economic hardship."[54]

When surface deliveries of agricultural water declined, farmers in areas with accessible ground water of adequate quality increased pumping to replace at least part of the surface water.[55] Not only did farmers increase ground water pumping for their own use, so did water districts for surface delivery to customers. University of California researchers found,

> Statewide, 26 percent of all districts pumped additional groundwater due to the drought . . . . In the San Joaquin Valley and in Southern California, at least 50 percent of the responding districts [those replying to the researchers' survey] pumped additional groundwater from district-owned wells.[56]

The Department of Water Resources tracks ground water levels in many areas.[57] The department's data reveal the extent and impact of pumping in the San Joaquin Valley. In general, pumping depletes ground water during dry years and precipitation replenishes it during wet ones. There is a lag between precipitation and rising ground water levels. For example, the wet year of 1983 resulted in ground water replenishment in many cases in 1984 or later.

Chart 14 shows cumulative ground water storage changes from 1970 to 1991 for the San Joaquin Hydrologic Study Area (Stanislaus, Merced, and Madera counties) and the Tulare Lake HSA (Fresno, Kings, Tulare, and Kern counties).[58] Levels in the Tulare Lake HSA have varied more widely, but dependence on ground water pumping in dry years is clear in

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[54]Howitt and M'Marete, "Value of Groundwater," p. 53.

[55]See David Zilberman, et al., "Lessons from California's Response to the Drought," pp. 9-22.

[56]Zilberman, et al., "Lessons," p. 20. Note that this is a draft paper, so the numbers may be revised before publication.

[57]No agency keeps comprehensive records of ground water pumping in California, but there are local examples of such record-keeping. A recently adopted ordinance in Monterey County will require registration of wells and reporting of ground water extractions beginning in 1994. (*Water Resources Quarterly*, newsletter of the Salinas River Basin Water Resources Management Planning Project, April 1993, p. 4, and Danyal Kasapligil, personal communication). The saltwater intrusion problem in Monterey County led to this requirement. Ventura County adopted such an ordinance, for the same reason, about six years ago.

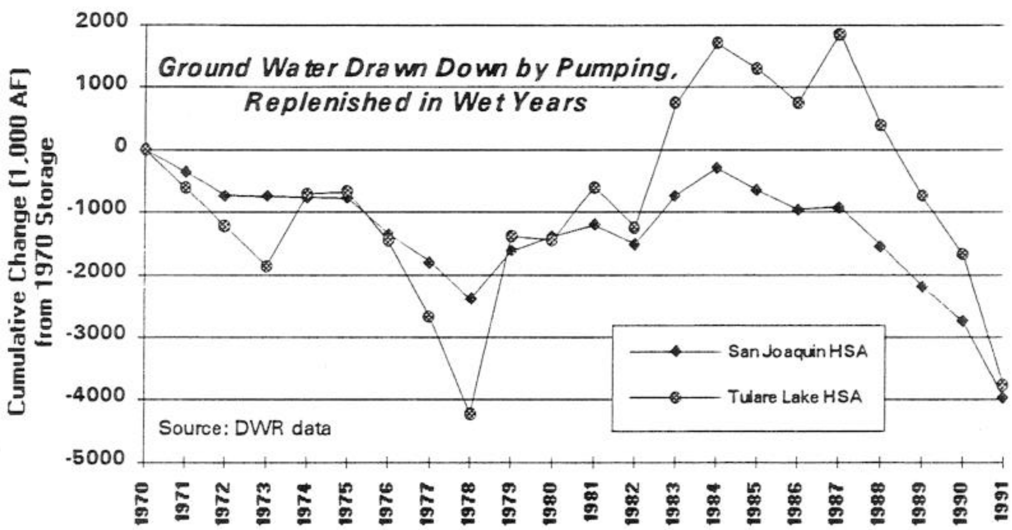
According to a Department of Water Resources staff member, California is one of only two states without statewide ground water management. The other, Texas, has local ground water management in all counties that have ground water resources.

[58]The data source for the ground water storage chart is California Department of Water Resources, San Joaquin District, *Historical Unconfined Ground Water Trends in the San Joaquin Valley*. That report describes the means by which the data were collected and interpreted and the sources of possible error. Readers should consult the report for that information.

both areas.

Chart 14 raises the question of whether a pattern of ground water dependence in dry years and replenishment in wet ones is sustainable over the long run. The figures for Tulare Lake HSA especially show drawing down of ground water during the 1976-77 drought, followed by recovery exceeding the pre-drought level. Does this pattern represent good policy and a pattern that may safely be repeated for other droughts? Or does the dependence on ground water carry unacceptable costs and risks of, for example, subsidence, long-term loss of aquifer capacity, declining ground water quality, or other problems? Although these questions are important, a full analysis of this issue is not available.

CHART 14



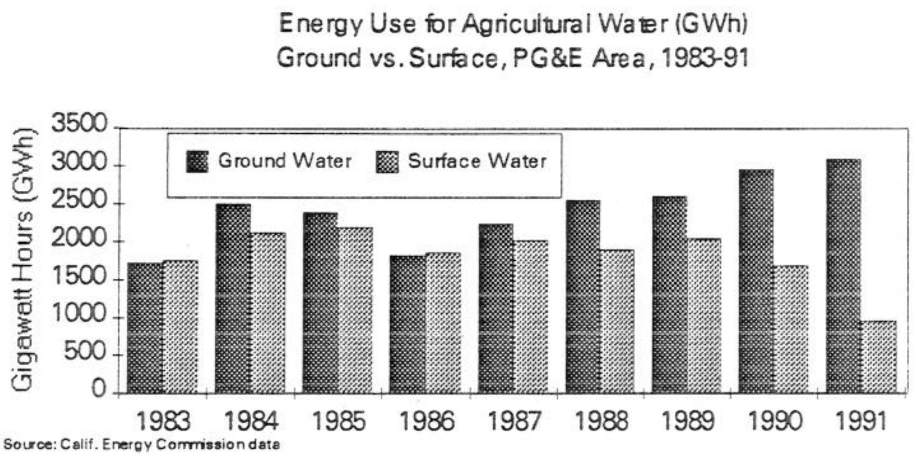
Direct measurements of ground water conditions are not the only source of information on ground water use. An estimated 90 percent of on-farm electricity use is for pumping ground water, according to staff of the California Energy Commission.[59] For that reason, on-farm energy use is a rough measure of energy used for pumping. The charts below illustrate trends in agricultural water use in the areas served by two major utility companies on the basis of electricity use. These data confirm the ground water storage data.

Chart 15, "PG&E Agricultural Water Energy Use 1983 to 1991," is based on data provided by the California Energy Commission (as is the SCE area chart, Chart 16). The chart, reflecting usage in much of central and northern California, shows a pattern of increasing energy use for pumping ground water and generally declining use for moving surface water. The chart shows the expected trend, with more ground water being

[59]Others dispute the 90 percent figure, and suggest that 70 percent would be more accurate. In either event, the figures are only a general indicator, not a precise measure of ground vs. surface water use.

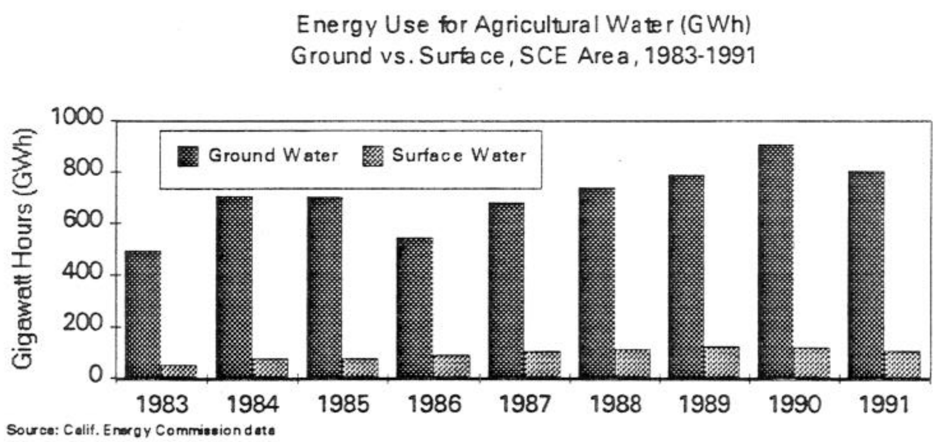
pumped and less surface water available for delivery. Both 1983 and 1986 were wet years, with correspondingly reduced electricity used for surface *and* ground water pumping. As the drought took hold from 1987 on, ground water use increased and surface water use generally decreased, according to the electricity-use figures.

CHART 15



Southern California Edison (SCE) covers much of southern California. Energy used for ground water pumping in that area fell in the wet year of 1986, then rose through 1990. A modest decline in 1991 might have resulted from the severe freeze of December 1990 and January 1991, which damaged many citrus orchards.

CHART 16

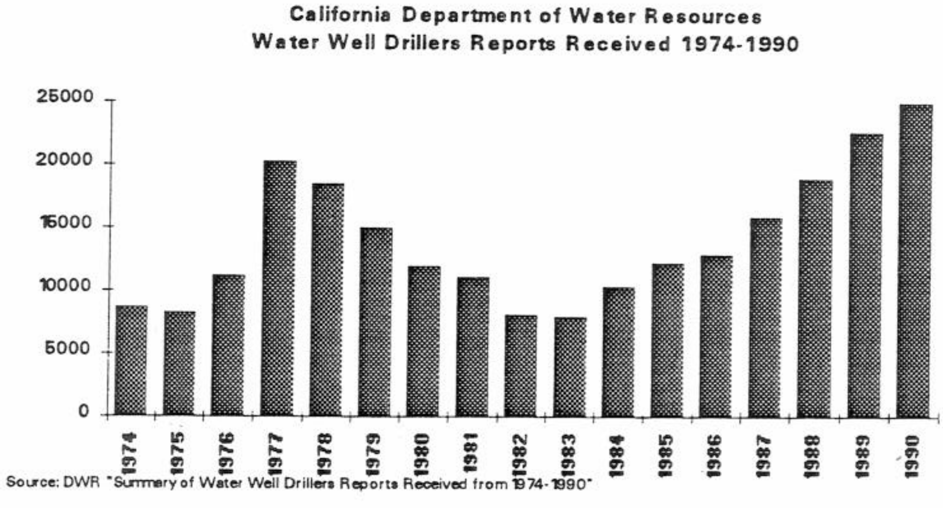


San Diego County (not illustrated) showed a contrasting pattern, with energy use for *both* ground water and surface water declining from 1988 to 1991.

A final indicator of the role of groundwater is the rise in well drilling (agricultural and urban) during drought years. Chart 17 illustrates trends in well drilling from 1974 to

1990.[60]

CHART 17



This pattern is broadly consistent with the patterns of groundwater supplies and agricultural electricity use: less drilling in wet years, more in dry years.[61]

The length and severity of the 1987-92 drought and its impact on ground water have encouraged efforts toward ground water management. For example, Butte County and local water districts are funding a study of ground water supplies that may be an early step toward a ground water management program. However, jurisdictional issues and existing rights and agreements complicate and inhibit ground water management.[62]

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[60]Data from "Summary of Water Well Drillers Reports Received from 1974-1990," July 1991 (leaflet issued by Californa Department of Water Resources). The leaflet cautions, "It is estimated that the number of reports of new wells received by DWR represents about 40-70 percent of the actual number of wells drilled in California." It also notes that the numbers are subject to revision.

[61]Zilberman, et al., found comparable patterns in their survey of irrigation equipment dealers. "Lessons," pp. 21-22 and Chart 1. The pattern shown in the chart is probably also influenced by levels of home construction in areas served by wells and by general economic conditions.

[62]"Irrigation districts try to come in with groundwater plan," *Capital Press*, April 16, 1993, p. 17. Also see various papers in DeVries, ed., *Changing Practices* (1992) and *Coping with Water Scarcity* (1990). For an overview of water rights issues, see David H. Getches, *Water Law*, Chapter Four, "Hybrid Systems and Other Variations." California legislation enacted in 1992 encourages local jurisdictions to manage ground water resources and established a framework for adoption of ground water management plans (A.B. 3030, Chapter 947, Statutes of 1992; California Water Code, §§10750 et seq.). See the November/December 1993 issue of *Western Water* for a recent overview of ground water management activities and the role of A.B. 3030.

Water Managers Set Up Exchanges and Transfers

Local and statewide efforts resulted in some transfers and exchanges of water during the drought. Some of the exchanged or transferred water was used for irrigation, but most went to urban users.

Emergency Drought Water Bank[63]

As a result of especially bleak water supply conditions, Governor Wilson established an emergency drought water bank in February 1991 to help meet the most pressing needs through exchanges and transfers. The Department of Water Resources (DWR) managed the water bank, using redirected staff.[64]

Under the water bank system, DWR bought water from those who could supply it and sold it to those who needed it, with specified conditions and prices at both ends.[65] Howitt, Moore, and Smith summarized the bank's 1991 transactions:

> Over all, the Drought Water Bank entered into a total of 351 contracts to acquire a total of 821,045 af [acre-feet] of water through three types of transactions [fallowing, ground water, and storage]. Through 328 fallowing contracts, which accounted for half the acquired water, the bank paid growers not to irrigate crops. Under nineteen contracts involving ground water, which accounted for one-third of the acquired water, irrigators were paid through their water district (primarily) to substitute ground water supplies for surface water. The remaining 17 percent of the water was acquired through four contracts involving the purchase of stored surface water, the bulk of which (129,200 af) was acquired from the Yuba County Water Agency.[66]

Much of the water transferred through water bank operations went to urban users, but some went to agricultural users in the southern San Joaquin Valley.[67]

Evaluating the impact of the 1991 water bank, Howitt, Moore, and Smith concluded,

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[63]For detailed discussion of the Drought Water Bank, see: Jay R. Lund and Morris Israel, *Recent California Water Transfers*, Chapter 5; California Department of Water Resources, *The 1991 Drought Water Bank*; Richard Howitt, Nancy Moore, and Rodney T. Smith, *A Retrospective on California's 1991 Emergency Drought Water Bank*; Raymond Coppock and Martha Kreith, eds., *California Water Transfers*; and California Department of Water Resources, *State Drought Water Bank: Draft Environmental Impact Report.*

[64]Lund and Israel, p. 48. Lund and Israel also note, "The Drought Emergency Water Bank was to be managed and accounted for separately from the SWP and other State contracts."

[65]To simplify, the 1991 purchase price was $125 per acre foot, and selling price was $175 per acre foot, plus conveyance costs. Prices for the smaller 1992 operation were lower. See the cited sources for details.

[66]Howitt, Moore, and Smith, p. 10.

[67]Howitt, Moore, and Smith, p. 19.

> In sum, the water bank generated substantial benefits for both agriculture generally and for the state as a whole. Even in counties where land fallowing represented the largest proportionate decline in acreage, the over all net effect on county personal income and county total employment was relatively small.[68]

Lund and Israel found,

> Most of those involved in the 1991 Drought Water Bank agree that it was surprisingly successful. In the matter of a few months, the 1991 Drought Water Bank acquired over 820,000 acre-feet of water through transactions with willing sellers. The large-scale water transfer program was implemented in less than 100 days and established important links with local water interests and local governments for future programs. The operational flexibility of both the SWP and CVP allowed conveyance of water through the Delta with minimal additional impacts to fisheries. That flexibility, excessive March rains, and the Water Bank enabled the State to meet all critical needs for water in its fifth year of drought.[69]

A smaller scale water bank operated in 1992. The 1992 version did not allow land fallowing contracts. That change helped to meet some objections to the 1991 water bank. However, "If demands [in 1992] had been higher, it is unclear whether DWR could have secured enough water to satisfy all critical needs without fallowing agricultural lands."[70] A number of other operational changes between the 1991 and 1992 versions of the water bank reflected experience gained in 1991.

Local Exchanges and Transfers.[71]

In addition to the DWR-operated Emergency Drought Water Bank, there have been numerous other water transfers and exchanges in California. Lund and Israel summarize routine transfers within the Central Valley Project:

> In the past decade alone, over 1,200 transfers totaling roughly 3 MAF [million acre-feet] have been effected. Individually these transfers have ranged from a few acre-feet to over 100,000 acre-feet. The primary purpose of these transfers is to accommodate fluctuations in water needs during the year due to changes in cropping patterns and weather.[72]

Such transfers must meet restrictions imposed by the Bureau of Reclamation, which

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[68]Howitt, Moore, and Smith, p. 20.

[69]Lund and Israel, p. 57.

[70]Lund and Israel, p. 63.

[71]See Lund and Israel, Chapter 6, "Other Water Transfers and Exchanges."

[72]Lund and Israel, p. 69.

operates the Central Valley Project.

Other transfers serving municipal as well as agricultural purposes have included, for example:[73]

- Solano Irrigation District and Solano County Water Agency--1991 purchase of 15,000 AF of water from farmers in exchange for fallowing about 5,000 acres. Nine thousand AF went to Benicia, 2,000 AF to Fairfield, and 2,400 AF to Vacaville, with the remainder carried over in storage. (One acre-foot is about the amount typically required annually by a family of five.)

- San Francisco Water Department--1990 purchases from Placer County (15,000 AF) and Modesto Irrigation District (12,000 AF). However, about half (Placer) to two-thirds (Modesto) of this water was lost to carriage water requirements and water quality problems.

- Westlands Water District and Kern County Water Agency--1989 purchase/-exchange agreement involving up to 55,000 AF "to help the WWD through a dry year," which "is to be repaid within ten years from WWD's CVP contracts."

- Yuba County Water Agency--sales to other users of about 290,000 AF (excluding "carriage water") over 1987-90.

Although many transfers have had technical problems (and some attempted transfers have failed to overcome the problems), the drought encouraged widespread experimentation.

Some Farmers Switched Crops

Farmers can save water by shifting to crops that need less water. Some Central Valley farmers have switched acreage from grains to garbanzo beans. The latter, planted as a winter crop, take advantage of rainfall, and therefore require less irrigation. For the same reason, some sugar beet growers are planting earlier and harvesting earlier in order to make best use of winter rain. In that case, only the timing is changed, not the crop.[74]

Factors besides water requirements affect farmers' crop selections. For that reason it is difficult to draw reliable conclusions from acreage statistics. Crop prices change from

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[73]These examples are selected and greatly simplified from Lund and Israel, pp. 72-74 and Appendix A. The transfers discussed by Lund and Israel were of varying sizes; some were single-year and others were multi-year arrangements; some entailed significant losses in transit ("carriage losses"). All of these arrangements were small in comparison to the Drought Water Bank. See Lund and Israel for details. The Kern County Water Agency *Water Supply Report 1991* describes several local transfers and exchanges (pp. 9-11). Also note the arrangement between Southern California Metropolitan Water District and the Imperial Irrigation District. MWD is financing water-conserving system improvements in the IID area, in exchange for the conserved water.

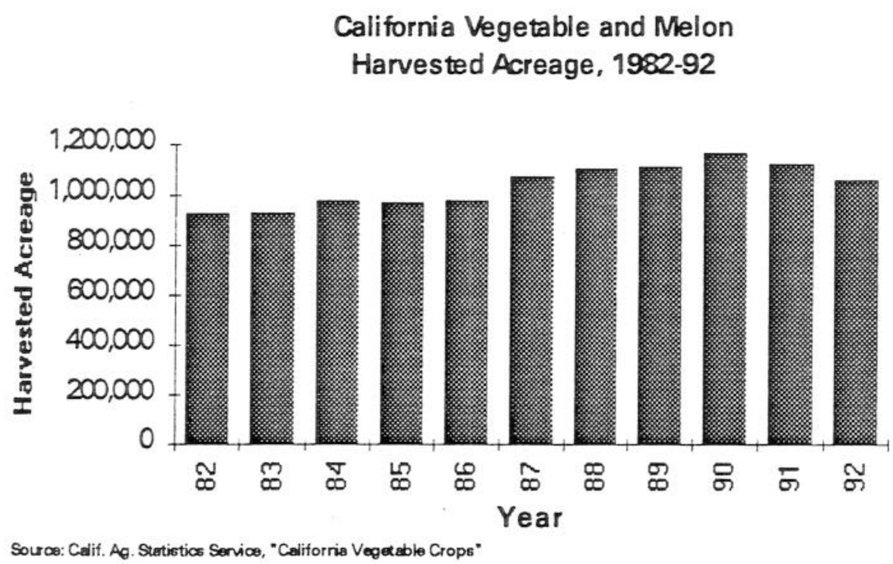
[74]Tracy Slavin, Westlands Water District, personal communication.

year to year, or even from month to month. Farmers may change their cropping patterns to take advantage of rising prices or may decide not to harvest a crop with a falling price in order to cut losses, and not necessarily as a result of water scarcity. Likewise, plant diseases or insect infestations may lead to sudden changes in planted or harvested acreage.

Changing crops may not be easy or simple. Soils and local climates differ. Some are far better for certain crops than for others. Farmers' contractual obligations, available equipment, level and types of expertise, and other factors can limit options or delay changes in cropping patterns. Available data and anecdotal evidence do suggest that some farmers have switched crops to compensate for reduced water availability or higher water costs or to cope with soil salinity.

Chart 18, "California Vegetable and Melon Harvested Acreage, 1982-92," shows increasing vegetable and melon acreage from 1986 to 1990, compensating in part for declining field crop acreage (see next section). The vegetable and melon acreage decline in 1992 largely resulted from reduced demand and prices for processing tomatoes. Processors reduced contracts after three years of increasing acreage and production.[75] A whitefly infestation in Imperial and Riverside counties also affected melon acreage.

CHART 18



Kings County farmers have reduced cotton acreage and increased garbanzo bean and safflower acreage because the latter require less water, according to staff of the Kings County Agricultural Commissioner. However, other factors, such as increased safflower prices and rain-delayed planting, affected farmers' cropping strategies.

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[75]Ray Borton, California Department of Food and Agriculture, personal communication. Also see California Agricultural Statistics Service, *California Vegetable Crops*, 1983-92, p. 3.

Crop switching goes in both directions, both toward and away from water-intensive crops. The Westlands Water District *Water Conservation Plan*, July 1992, notes, "Westlands' trend in cropping patterns continues to be away from relatively low-water use grains to shallow-rooted, more water-intensive vegetables."[76] Vegetables, although water-intensive, are high-value crops that can help farmers cope with cost pressures.

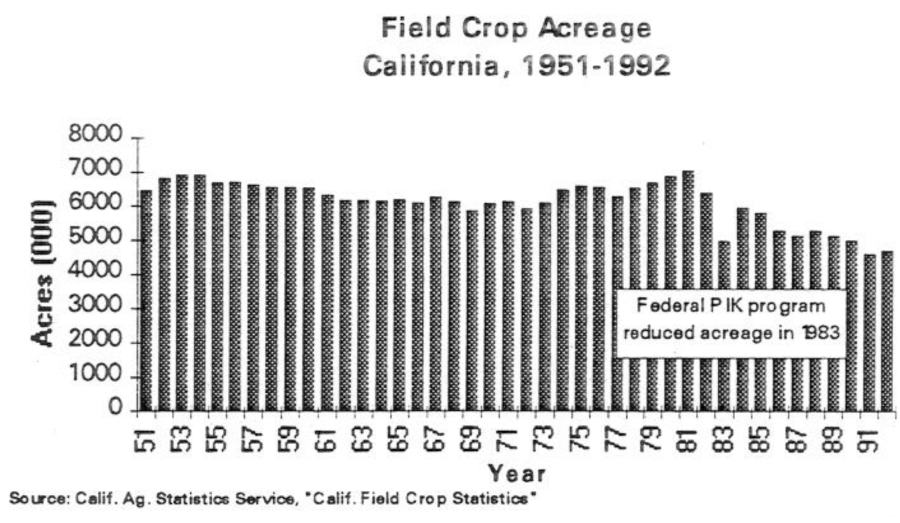
Some Acreage Was Fallowed

Tree and vine crops entail large and relatively long-term investments, so tree and vine acreage cannot readily be fallowed without significant economic costs to the farmer.[77] In contrast, field crops provide more flexibility because they do not require such a long-term commitment. (For this reason, some of the water transfers described above redirected water from field crops to tree crops.)

Statewide Data Show Decline in Field Crop Acreage

As Chart 19 shows, field crop acreage declined statewide during the drought.[78]

CHART 19



[76] *Water Conservation Plan*, Page xix.

[77] California Agricultural Statistics Service (CASS) data show fruit and nut acreage of 2.10 million acres for 1992, of which 1.95 million were bearing and 0.14 million acres were non-bearing. Acreage appears to have remained fairly steady from 1986 through 1993, although with some changes in the allocation of acreage among crops. See CASS, *California Fruit and Nut Acreage, 1992*, pp. ii and 1.

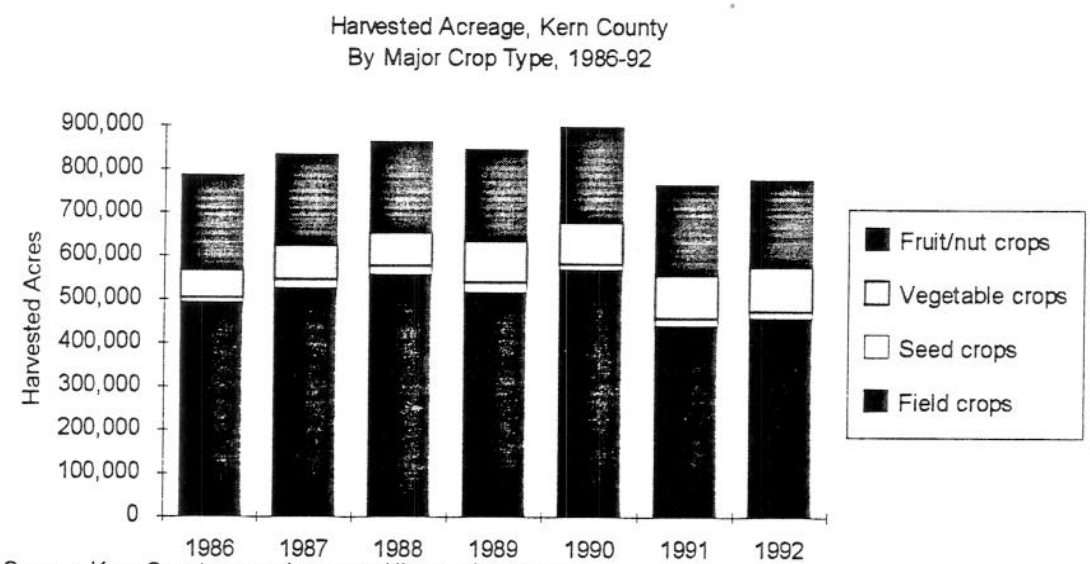
[78] Field crops encompassed in *California Field Crop Statistics* report include hay (alfalfa and other), corn, wheat, barley, oats, soybeans, cotton, sugar beets, rice, and more. It should be noted that there may be more variability in *irrigated* acreage than is reflected in the field crop acreage. Data include some harvested acreage that is not irrigated. The amount of this acreage varies from year to year depending on water availability and costs and on crop prices.

This pattern would be an expected response to scarcer, more costly water. Vegetable and melon acreage increases shown above compensated for only part of the field crop acreage reductions. Slightly improved conditions in 1992 are reflected in an upturn in acreage. The low 1983 figure was the result of the federal payment in kind (PIK) program, which gave farmers commodities in exchange for fallowing acreage. The program significantly affected cotton and feed grain acreage. A wet spring, making fields too wet to plant, may also have caused some acreage reductions that year.

Local Data Show Variations Among Counties

Acreage changes during the drought were not consistent from county to county. Some county data suggest significant fallowing, and others suggest little or none.[79]

CHART 20



Source: Kern County annual crop and livestock reports

Kern County data (Chart 20) show irregularly declining field crop acreage and some growth in vegetable acreage. Better conditions in 1992 allowed some recovery. The reason for the increased acreage for 1990 is not entirely clear,[80] but the 1991 drop is what would have been expected, especially in view of poor ground water conditions. The west side of the county had significant reductions in cotton acreage. Northwest Economic Associates' survey found 73,107 acres of cotton not planted, 1,066 acres abandoned

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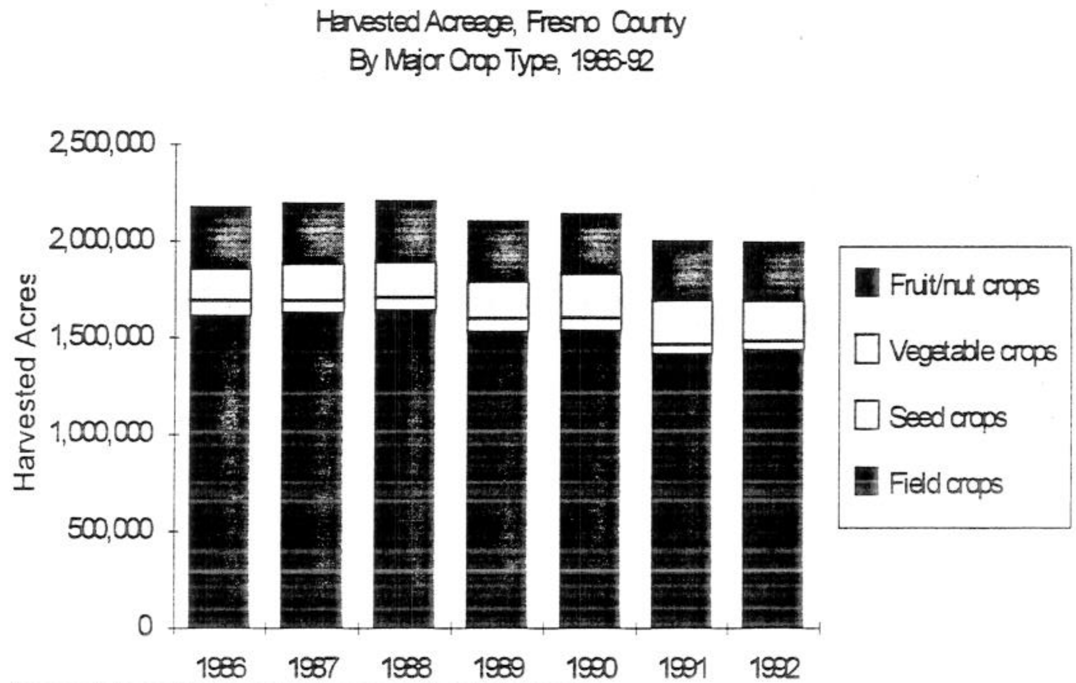
[79]The county charts reflect crop and livestock reports issued by the respective county agricultural commissioners. The data on which the charts are based may be found in the Appendix to this paper.

[80]Increased prices for cotton in 1989 and 1990 could have played a role. Cotton prices declined in 1991 and 1992.

(planted but not harvested), and 19,583 with reduced yields in Kern County for 1991.[81]

CHART 21



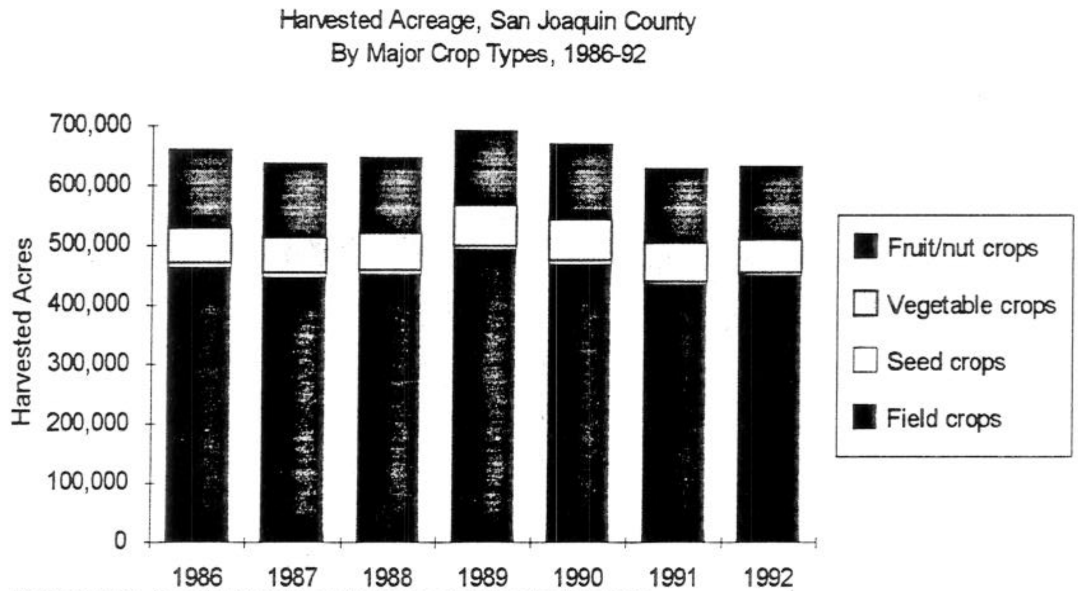
Source: Fresno County annual crop and livestock reports

In Fresno County (Chart 21), field crop acreage declined after 1988. Fruit/nut and vegetable acreage held relatively steady and seed crop[82] acreage declined in 1991 and 1992. As in Kern County, there was a slight acreage increase from 1989 to 1990.

[81]Northwest Economic Associates, *Economic Impacts*, p. 16.

[82]Seed crops are those grown to produce seed for future crops.

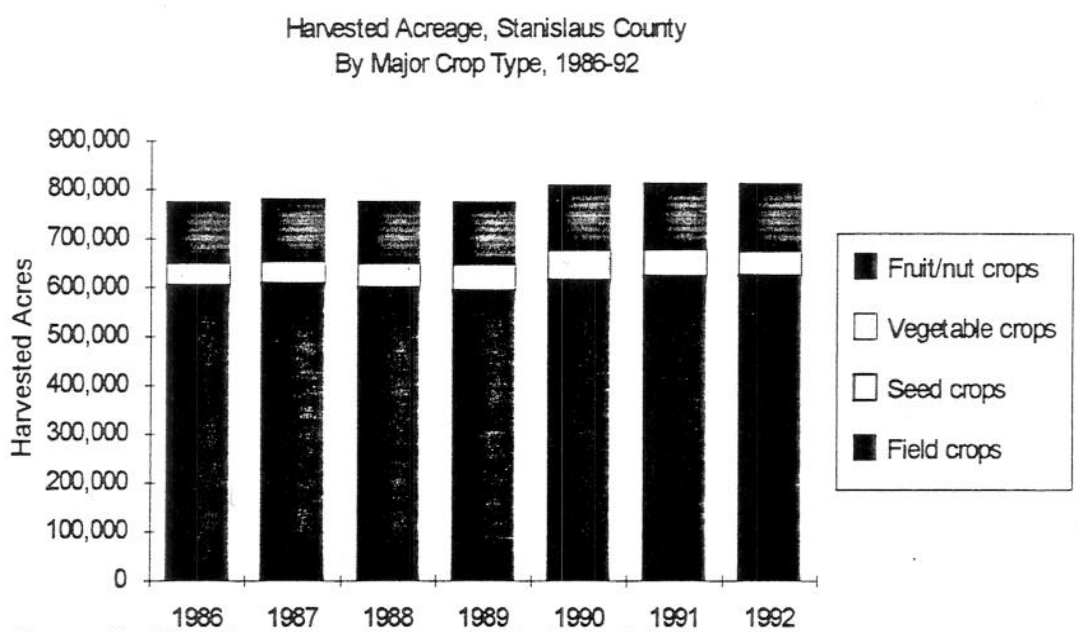
CHART 22



Source: San Joaquin County annual crop and livestock reports

San Joaquin County (Chart 22) had a moderate decline in field crop acreage from 1989 to 1991 after a rise from 1986 to 1989. Better conditions in 1992 allowed a slight upturn.

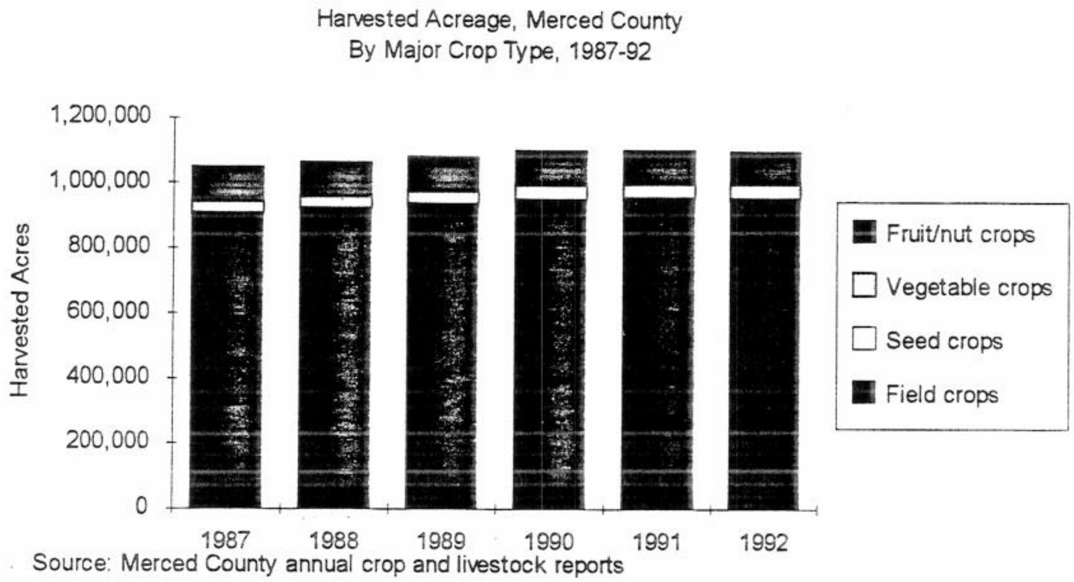
CHART 23



Source: Stanislaus County annual crop and livestock reports

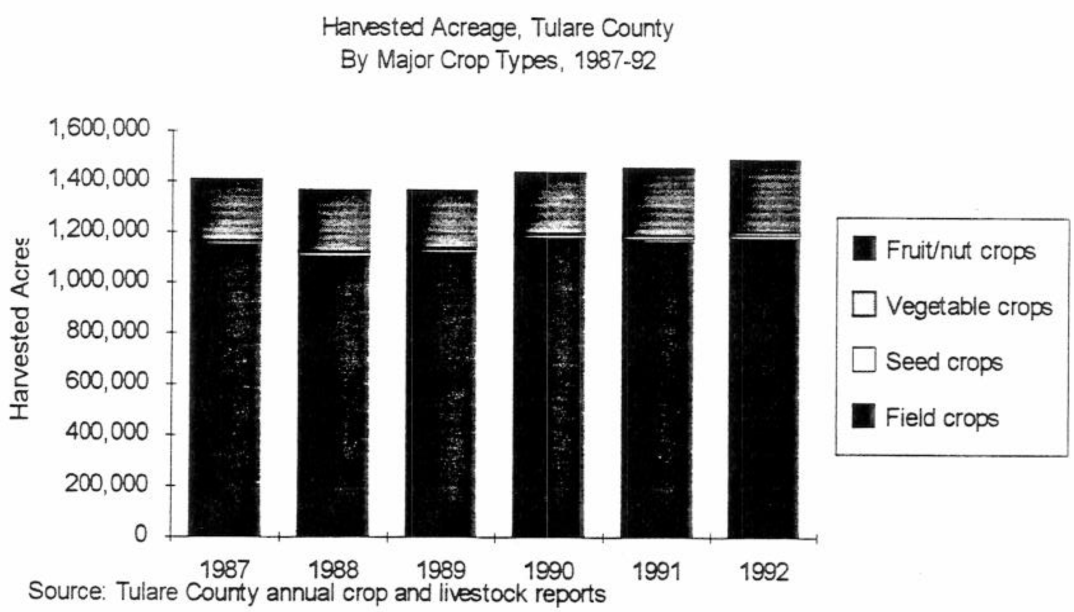
In Stanislaus County (Chart 23), acreage remained stable or slightly increased. This suggests a degree of insulation from the impact of the drought.

CHART 24



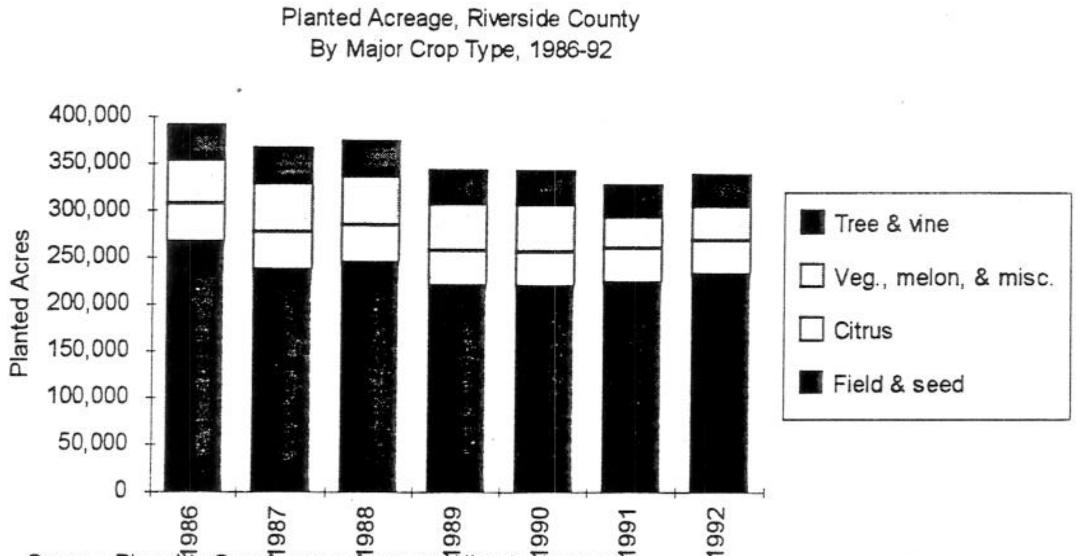
Merced County's acreage remained steady, with slight increases for 1990 and 1991 (Chart 24). This suggests that Merced County had a more reliable water supply than some other areas, possibly because of better ground water conditions.

CHART 25



Tulare County's pattern, shown in Chart 25, is comparable to that of Merced County.

CHART 26



Source: Riverside County annual crop and livestock reports

Riverside County data, shown in Chart 26, show generally declining acreages during the drought, but urbanization accounts for some of the decline. The 1991 "vegetable/melon/miscellaneous" figures may have been affected by the freeze of December 1990 and January 1991. A whitefly infestation affecting Riverside and Imperial counties also led to reduced acreage, especially for melons.[83] Riverside data are for "planted" acreage, not "harvested" acreage, so the data are not necessarily strictly comparable to those of other counties.

Irrigators Improved Methods and Management

Irrigation methods fall under a few broad categories:

> Four basic types of irrigation systems are in use: surface, sprinkler, drip and subsurface. **Surface systems** mainly consist of wild flood, border, basin, and furrow methods. **Sprinkler systems** consist of hand-moved aluminum pipe or plastic hose, solid set, and mechanically moved. **Drip systems** may be below or above ground. **Subsurface systems** allow a high water table to rise in the root zone.[84]

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[83]Frank Limacher, formerly with the California Department of Food and Agriculture, personal communication.

[84]California Department of Water Resources, *Crop Water Use in California* (1986), pp. 8-9. Bold not in original. For a thorough, if older, survey of irrigation methods and issues, see Josef D. Zimmerman, *Irrigation* (N.Y.: John Wiley and Sons, 1966). For those who wonder, the "wild flood" method applies water at the highest point of the field and allows it to run over the field according to its contours.

Many Factors Affect Irrigation Choices

A wide range of conditions limit the farmer's choice of irrigation methods. These include:

- soil type and conditions
- field contours
- crops grown, their value, and their water requirements
- climate
- capital and operational costs of irrigation equipment
- water and energy costs
- fertilization and pest control requirements
- water quality
- expected future use of the acreage
- cultivation (tillage) requirements
- land tenure (ownership vs. lease)

Sometimes the farmer may have a choice of irrigation methods, and sometimes not, depending on the specific conditions he or she faces. The farmer can alter some of the conditions listed above (by leveling fields or changing crops, for example), but has no control over others, such as climate. Decisions about what steps to take reflect a complex mix of factors unique to each farm. The cost or abundance of water is not necessarily among the most important of those factors.

Management is Critical

Whatever method the farmer chooses, *management* of irrigation methods contributes more to efficient water use than does the specific method used. A poorly managed microsprinkler or drip system can waste water,[85] while a well managed flood or furrow system can be highly efficient, given appropriate soil type, topography, and crop.[86] Sometimes a relatively simple and inexpensive change in an existing system can save water. For example, shortening furrow lengths can improve distribution uniformity, thus reducing runoff and deep percolation. This sort of change is a management issue.

Keys to management include:

- timing and monitoring of applied water to match it to actual crop water needs
- cleaning, repair, and adjustment of irrigation equipment

[85]Donald Pitts discusses this point in "Performance of Micro Irrigation Systems: Field Evaluations." He concluded, "The water conserving claims made regarding micro irrigation are critically dependent on the systems' having a higher level of performance than typically observed by this project. The potential water savings benefits of micro irrigation are likely not being fully realized." (P. 42.) The performance problems discovered by Pitts stemmed from irrigation management shortcomings.

[86]See "Uniform, Efficient Irrigation Possible with Furrows, Kings River Irrigation District "Irrigation News," reprinted in the Fresno County Farm Bureau's *Agriculture Today*, November 15, 1993, p. 12.

- coordination of irrigation with leaching, fertilizing, and weed/pest control requirements
- minimizing of unnecessary deep percolation and of uncollected runoff, and
- corrections to soil and field conditions to facilitate most effective and efficient water use

Improvements in irrigation are not the responsibility of the farmer alone. Industry can improve the design of irrigation devices, such as sprinkler heads, flow meters, and drip tubing, through testing and engineering.[87] The greatest potential benefits from design improvements may lie in reducing maintenance needs so that the long-term costs associated with efficient systems are lower.

Over the long term, as farmers replace or upgrade equipment (even where they retain the same *type* of system), improvements of this sort will gradually improve average performance of installed irrigation systems. Improvements in the average could be even greater where better technology makes it economically feasible for farmers to switch to water-conserving irrigation systems.

Rarely is the choice of irrigation methods based simply on whether a particular method can reduce applied water. In fact, depending on the farmer's water rights and the price of water, the farmer might reject a particular water-conserving technology because of its capital, energy, maintenance, or operational costs. For example:

- Pressurized irrigation systems require energy for pumping and careful maintenance.
- Drip and micro-sprinkler systems require expensive filtration equipment to prevent clogging of the lines and openings.
- Drip tape that is designed for relatively short-term use (a year or two) poses a disposal problem. Burning the old tape may violate air pollution laws, and the disposal in landfills "is nearly cost prohibitive."[88] More permanent types of drip tape or buried drip lines are more expensive, and may not be cost-effective unless water costs are very high or large productivity improvements result from their use.

Farmers are Improving their Methods and Management

Despite the costs and difficulties, water supply limitations and increasing water costs are leading California farmers to improve their management of irrigation and adopt water-saving irrigation methods and technology.[89] For example:

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[87]See, for example, David Zoldoske, "The Future of Irrigation is Buried," pp. 11-12. Zoldoske is assistant director of the Center for Irrigation Technology, California State University, Fresno.

[88]David Zoldoske, "The Future of Irrigation is Buried," p. 10.

[89]See David Zilberman, et al., "Lessons from California's Response to the Drought," especially pp. 22-24. Also note that financial assistance for irrigation improvements is available from several sources. The U.S. Department of Agriculture offers cost-sharing programs for gated pipe, lining of ditches, piped distribution systems, tailwater return systems, and so on. P.G.&E. has rebate programs for energy-saving irrigation improvements, which often conserve water as well as energy. (Tracy Slavin, Westlands Water

Tailwater recovery systems. Tailwater is surface runoff from irrigation. Farmers can design their irrigation systems to direct tailwater to other fields (tailwater recovery) or to recirculate it to the originating field (tailwater return). Recapturing tailwater does not necessarily result in basin-wide water savings. That depends on what would otherwise have happened to the water. If it would evaporate (or be transpired by weeds or other unproductive vegetation), flow to a saline body, or percolate to a saline or otherwise unusable water table, it would be lost. If it would flow to another property and be used there, flow into a reservoir or stream from which it could be recaptured, or percolate to an accessible non-saline water table it would not be lost to the basin. Reuse of tailwater can, however, contribute to on-farm water savings, at some cost in energy and equipment.

Micro irrigation systems. *Irrigation Journal* annually publishes a survey of irrigation in the United States. The 1992 survey found that, "During 1992, nearly 1.5 million acres [nationally] irrigated by surface/gravity methods either were converted to more efficient irrigation systems or were removed from production. At the same time, low-flow irrigation acreage increased by 15 percent and sprinkler acreage grew at a pace of 3 percent."[90] If California farmers are adopting more efficient irrigation methods,[91] that is part of a broader national trend as well as a response to California's drought.

Ventura County farmers, whose ground water supply is threatened by seawater intrusion, have adopted substantial changes in irrigation technology to conserve water. According to staff of the local mobile irrigation laboratory, the intrusion threat is forcing Ventura farmers to use water as cautiously as desert farmers, although local conditions limit what farmers can do. Much of Ventura County's farmland is leased to farmers. That fact (along with frequent crop changes) limits use of water-conserving buried drip lines, although an increasing number of farmers are using drip tape.

District, personal communication.) The California Energy Commission has a "Farm Energy Assistance Program" to help fund improvements. (See David Oltman, "Savings and Loan.")

[90]*Irrigation Journal*, January/February 1993, p. 19.

[91]The *Irrigation Journal* data do not appear to be strictly comparable from year to year because of changes in categories. However, the 1992 data suggest a recent increase in use of micro irrigation in California. Zilberman, et al., found widespread adoption of drip and sprinkler irrigation by California farmers and a corresponding reduction in use of border and furrow methods. The Department of Water Resources published a report of a 1991 irrigation methods survey (in its *Agricultural Water Use Biennial Report, May 1993*). While the data do not appear to be completely reliable, the researchers concluded that the survey showed increased use of drip and sprinkler methods and decline in surface irrigation methods in the areas surveyed between previous surveys (1972 and 1980) and the 1991 survey. Kings River Irrigation District found an increase in acreage irrigated by micro irrigation methods from 1.9 percent (1980) to 16.7 percent (1991) in Fresno, Kings, and Tulare Counties. ("Irrigation News," reprinted in the Fresno County Farm Bureau's *Agriculture Today*, November 15, 1993, p. 12.)

Despite its reputation as a water-conserving technology, micro irrigation does *not* automatically reduce water use. A Kern County farm advisor noted that proper use of micro irrigation (more frequent application of smaller amounts of water) can reduce plant stress, closely match evapotranspiration requirements, and actually use *more* water than traditional systems. Typically, micro irrigation modestly decreases water applications, but it is not "the silver bullet to irrigation water savings." Its more important contribution may be to improve crop yield and quality.[92]

The Center for Irrigation Technology found San Joaquin Valley farmers to be moving toward drip irrigation for row crops, but added, "While the prospect of conserving water is among the considerations, the improved quality of the crop, and yield increases are the driving forces behind the conversions."[93] Improvements in yield and quality can help farmers cope with tight water supplies and increased costs.

CIMIS data. California Irrigation Management Information System (CIMIS) data on precipitation and evapotranspiration rates are easily available to farmers and irrigation consultants. CIMIS data also cover crop water use and requirements in a variety of soil types. The service is widely used and is often cited in irrigation-related publications. There is, however, potential for much greater use of the system.

Monitoring soil moisture. Tensiometers (soil moisture monitoring devices) can enable farmers to match applied water closely to actual crop water requirements. Monitoring can sometimes allow the farmer to skip the customary preirrigation of fields, for a net reduction in applied water during the season.

Other On-Farm Techniques

Other techniques that have been tested or used include:

Regulated deficit irrigation. Agricultural researchers have tested water-conservation techniques for specific crops through withholding or reducing applied water during certain parts of the growing season. RDI could have the potential for significant water savings.[94]

Temporary reduction of applied water to survival level. Some permanent crops--trees and vines--can survive a season or longer on greatly reduced applied water while not producing a crop. The same technique can be applied to alfalfa

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[92]Blake Sanden, "Production Increase Main Drip Attraction."

[93]*Center for Irrigation Technology Newsletter,* Winter 91-92, p. 1.

[94]Eric McMullin, "Hard Lessons."

hay, which can survive for extended periods without irrigation. As a last resort, a farmer may choose to use limited water to keep permanent crops alive while foregoing production until water becomes more abundant.

Transplanting seedlings. For some crops, it may under some circumstances be cost-effective and water-conserving to transplant seedlings rather than growing the crops from direct seeding in the field. This technique can eliminate the need for several germination irrigations, but has not been proven to have water-conserving value on a large scale.

Use of drought-tolerant or water-conserving varieties. Some crop varieties can cope better with water stress than others. When other considerations allow, farmers can choose varieties that tolerate reduced water. For example, according to a Westlands Water District staff member, some cotton farmers are turning to older varieties of cotton while water supplies are uncertain. The older varieties can tolerate water stress, while newer ones cannot.

Use of water-conserving soil amendments. These are materials added to the soil to increase water-holding capacity, improve infiltration of water into the soil, and reduce runoff. They can help to reduce water loss to runoff and deep percolation. Organic matter can improve the soil's water holding capacity. Non-organic polymers designed to hold water have been tested, but are not proven to be effective, at least on a large scale.[95]

Application of antitranspirant foliar sprays. These are chemicals sprayed on leaves to reduce plant transpiration, thus reducing the crop's water requirement. This is not a method that appears at this time to have proven potential for significant and economically feasible water savings, but experiments are underway with methanol solutions.[96]

Water Agencies Emphasize Conservation

Water districts and other water-management agencies are seeking to conserve water and to encourage and enable farmers to use water more efficiently.[97] The U.S. Bureau of

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[95]Polymers are discussed briefly in Robert Hof and Eric Shine, "Drought is the Mother of Invention," p. 2, and Richard Conniff, "California: Desert in Disguise," p. 48. Also see Alton Pryor, "Super Sponges." However, Danyal Kasapligil, Mobile Team Leader with the Monterey County Water Resources Agency, considers the value of polymer soil amendments highly questionable.

[96]See M. Le Strange and Milt McGiffen, "Can Wood Alcohol Double Plant Yield?" *California-Arizona Farm Press*, September 18, 1993, p. 25. However, *Capital Press* (an agriculture and forestry weekly newspaper) reported in its January 7, 1994, issue that researchers in 14 states found no meaningful benefits from application of methanol to crops. ("Researchers: Methanol a bust," p. 4.)

[97]Section 100 of the California Water Code declares, "The right to water or to the use or flow of water in or from any natural stream or watercourse in this State is and shall be limited to such water as shall be reasonably required for the beneficial use to be served, and such right does not and shall not extend to the

Reclamation, which manages the Central Valley Project, "requires districts under contract for federal water to '. . . develop a water conservation plan which shall contain definite goals, appropriate water conservation measures, and a time schedule for meeting water conservation objectives.'"[98] The Bureau's Mid-Pacific Regional Office, in consultation with the Department of Water Resources, has published a *Guidebook for Preparing Water Conservation Plans* to help those who must develop district plans.

At the local level, the Monterey County Water Resources Agency requires agricultural water users in the Salinas Valley to submit conservation plans detailing acreage, wells, methods, and irrigation management improvements. This requirement will both provide detailed information on irrigated acreage (information that previously could only be estimated) and strengthen grower awareness of the importance of conservation. A new ordinance requires meters on wells by 1994 because "you can't manage water if you can't measure it."[99]

Help in Selecting and Managing Irrigation Methods

Water agencies provide several types of assistance to irrigators:

Mobile Irrigation Laboratories. The California Department of Water Resources sponsors mobile irrigation laboratories, in cooperation with other agencies. Mobile laboratory staff members help farmers evaluate their irrigation systems and evaluate the costs and effectiveness of potential improvements. The DWR brochure on the program lists mobile labs in the counties of Kern, Merced, Monterey, San Diego, Santa Barbara, Riverside, and Ventura.

Evapotranspiration Data. The Department of Water Resources and other agencies sponsor the California Irrigation Management Information System (CIMIS). CIMIS distributes, via computer system and cooperating newspapers and agencies, detailed information on evapotranspiration and rainfall. This information enables farmers to match water application rates very closely to actual crop water use (if water is available when needed). Private vendors have developed personal computer programs that facilitate access to and use of CIMIS data. According to a DWR staff member, 500 additional users signed up to access

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waste or unreasonable use or unreasonable method of use or unreasonable method of diversion of water." The State Constitution itself prohibits waste of water. Section 275 of the Water Code authorizes the Department of Water Resources and the Water Quality Control Board to "take all appropriate proceedings or actions before executive, legislative, or judicial agencies to prevent waste, unreasonable use, unreasonable method of use, or unreasonable method of diversion of water in this state." For an overview of "beneficial use," see David H. Getches, *Water Law*, pp. 97-100.

[98]Westlands Water District, *Water Conservation Plan 1992*, p. 47, citing Section 210 of the Reclamation Reform Act of 1982.

[99]Danyal Kasapligil, Mobile Irrigation Lab Team Leader, Monterey County Water Resources Agency, Personal Communication.

CIMIS in 1992, and more radio stations, newspapers, and other media are providing CIMIS data. More than 50 water management workshops (incorporating information on the use of CIMIS) have been held in recent years.[100]

Local Assistance Programs. Local water and conservation districts, often with state and federal assistance, are helping farmers to evaluate their water needs and to select and use water-conserving methods. For example:

- Westlands Water District provides extensive water-conservation information and assistance. District publications include the *Water Conservation and Drainage Reduction Programs, 1987-1988* (1989) and *Water Conservation and Management Handbook* (1985).

- Cachuma Resource Conservation District sponsored a workshop on micro irrigation.[101] The workshop encompassed presentations by experts and product demonstrations.

- Kings River Conservation District publishes and widely distributes a bimonthly newsletter to inform farmers about water conservation techniques. The district conducts workshops on AGWATER, a computer program that helps farmers plan efficient irrigation. District staff have conducted tours of Fresno County farms that use drip irrigation systems.[102] The district is also publishing "irrigation almanacs" to assist growers in "estimating the optimum time to irrigate."[103]

- The Westside Resource Conservation District (with funding from the Department of Water Resources) has helped farmers pay the fees of approved irrigation consultants to evaluate their irrigation needs and recommend system improvements.[104]

Other Programs

Other district-level programs and initiatives include:

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[100]Holly Sheradin, Department of Water Resources, personal communication, .

[101]Cachuma Resource Conservation District, *Proceedings*.

[102]The district was not uniformly enthusiastic: "Participants [in the tour] were told that subsurface drip systems may be useful in some situtations, but that they are prohibitively expensive in many cases. Dramatic increases in crop yield have been reported on fields converted to subsurface drip. It is possible that the same yield response is obtainable with improved water management with existing irrigation systems." Kings River Conservation District Annual Report, 1991-92, p. 16.

[103]Kings River Conservation District *Annual Report 1991-1992*, pp. 17-18.

[104]Westlands Water District, *Water Conservation Plan*, pp. 51-52.

Lining delivery canals to reduce seepage. Imperial Irrigation District, for example, is lining canals in cooperation with the Southern California Metropolitan Water District. MWD is paying for the system improvements, and in exchange receives the conserved water.

Seeding clouds to increase precipitation. According to the Department of Water Resources, "By the spring of 1991, the number of [cloud seeding] programs operating in California had increased to 20. Now projects started during the current drought include Lake Berryessa, Calaveras, Tuolumne, Monterey, San Luis Obispo, San Gabriel, and San Diego." DWR cites broad estimates of "2 to 15 percent increase in annual precipitation, depending on the number of storms treated."[105] The Salinas River Basin Water Resources Management Planning Project reported on local cloud seeding efforts:

> Overall conclusions indicate a rainfall increase of from 12 percent to 16 percent during the total five months of the [1991]-1992 seeding program. This equates to a . . . reservoir increase of between 17,000 acre-feet and 22,600 acre-feet.[106]

Ground water recharge projects. In some areas, conjunctive use of ground water is local policy. Ground water recharge projects supplement the natural recharge that results from precipitation and streamflow.

For example, when surface water is available, the Arvin-Edison Water Storage District, in Kern County, spreads excess water to percolate into its aquifer. In dry years it pumps water back out.[107] In cooperation with the Metropolitan Water District, Arvin-Edison has developed a program to store excess project water not needed by MWD during wet years. During dry years the district will pump the stored water so that additional water may flow past Kern County to MWD.[108]

In the Salinas Valley, the Monterey County Water Resources Agency developed an "enhanced groundwater recharge (EGR) demonstration project":

> The concept is quite simple: the [mazework of sand and gravel] berms [in the low-flow channel of the Salinas River] cause the summer dam release flows to cover a broader area of the riverbed than the typical narrow

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[105]California Department of Water Resources, *California's Continuing Drought*, p. 45.

[106]*Water Resources Quarterly* (the Project's newsletter), October 1992, p. 10.

[107]The district's annual report for 1991 charts the percolation and extraction under this "water percolation program" for 1966 to 1991.

[108]For details, see EIP Associates, *Arvin-Edison/Metropolitan Water Storage and Exchange Program: Draft Environmental Impact Report/Statement*, January 1992. For a summary, see the district's *Water Resources Management Program*.

> meander. When this occurs in areas of high percolation rates like the riverbed above the Gonzales Bridge, increased deep percolation occurs.[109]

Orange County, another area affected by seawater intrusion, has operated a ground water replenishment program since 1956. The district assesses a replenishment fee against ground water pumpers.[110]

Monitoring ground water extractions. A few jurisdictions in California monitor ground water extractions. For example, the Fox Canyon Groundwater Management Agency (Ventura County) requires well metering. After initial resistance, Ventura County growers reportedly now strongly support well metering, according to local resource conservation district staff. The Monterey County Water Resources Agency has adopted similar requirements, for the same reason: the threat of seawater intrusion into the aquifer. Orange County monitors extractions for its replenishment program, also the result of seawater intrusion.

Conclusion

To summarize this broad overview, attempts to cope with the drought appear at all levels, from individual farmers to large-scale water project management. California's ground water resources provided a large--but not inexhaustible--cushion during drought. Individual farmers and water districts relied at least in part on ground water to replace precipitation and surface water deliveries. Water managers arranged or enabled water exchanges and transfers on large and small scales, and some farmers have changed crops or fallowed acreage to help cope with shortages. At the same time, a network of researchers, advisors, and consultants worked--and continue to work--with farmers to help bring better irrigation management to the fields. Their contribution helps to conserve water and to make irrigation water more productive.

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[109] *Water Resources Quarterly*, October 1992, p. 9. The project was to have been installed and tested in 1993, but delays in getting permits have delayed implementation until 1994, according to water agency staff.

[110] See William R. Mills, "Orange County Ground Water Management," in DeVries, ed., *Changing Practices* (1992), pp. 133-138. Mills is general manager of the Orange County Water District.

PART IV: LESSONS FOR THE NEXT DROUGHT

This part summarizes conclusions from the preceding review of agriculture and the 1987-92 drought.

The drought affected the state unevenly. Because of the different sources of water and different climate and ground water conditions, there can be no single, uniform, statewide view of "the" impact of the drought.

California's Central Valley was directly affected by the lack of precipitation and by decreasing ground and surface water for irrigation. The drought constituted a change from normal conditions. In contrast, desert agriculture, as in Imperial County, is always in drought (in terms of precipitation), while coastal areas face perennial ground water challenges and have limited access to surface water.

California's Agriculture Can Remain Productive During Drought, but Local Areas may Suffer Disproportionately

California agriculture's strength stems from its wide variety, geographic spread, excellent soil and climate conditions (drought notwithstanding), strong institutional support, and skilled management. These factors remain valid and important even during drought. Despite six years of drought--and other challenges to agriculture during the same time--California's agriculture as a whole has remained productive and profitable. Chart 27 shows statewide total farm production expenses and net farm income for 1986 to 1991. Farm income appears to have been damaged more by the 1990-91 freeze than by the drought.[111]

Despite the seemingly moderate *statewide* impact of the drought on agriculture, local impacts were more severe in some areas. These include Kern County and the west side of the San Joaquin Valley (encompassing parts of several counties).

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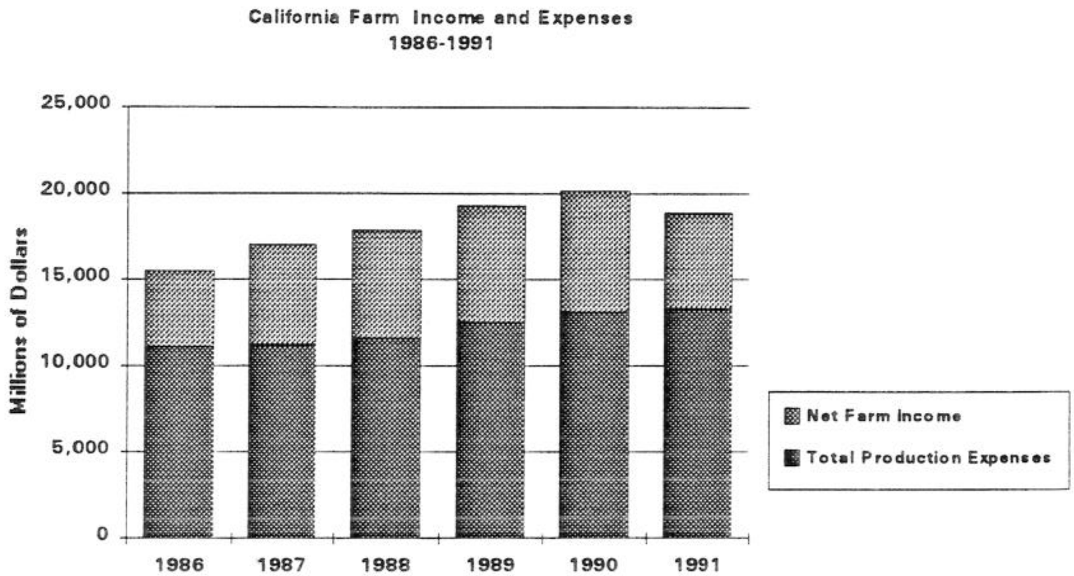
[111] Data provided by California Department of Finance, which cites the Economic Research Service as its source. (*California Statistical Abstract*, Table G-10.) Note that the chart does not address income and profitability of non-farm agriculture-related businesses that may have been affected by the drought. These include farm equipment dealers and agricultural chemical suppliers.

CHART 27



Source: Calif. Dept. of Finance, Statistical Abstract 1992, Table G-1

California's Vulnerability to Drought has Grown

California began the 1987-92 drought in reasonably good condition. Ground water levels had recovered since the preceding drought, and surface storage was good. The resources of stored surface and underground water provided an initial cushion. Although surface storage is better now than it was at the end of the drought, ground water levels have had little opportunity to recover from six dry years. The cushion in 1994 is much thinner than it was in 1987.

Lowered water tables and aggravation of salinity problems in the most strongly affected areas place those areas in an especially weak condition to face renewed drought. Farmers who exhausted financial reserves while coping with one drought are ill-prepared to survive another without an opportunity to recover. This risk exists whether drought is the result of reduced precipitation and runoff or the result of regulatory decisions for Delta water quality and for protection of fish and other aquatic species that reduce water deliveries.

Renewal of the 1987-92 drought could multiply needs for a coordinated response, especially in the most vulnerable areas. Potential impacts extend beyond issues of water availability and distribution. They also encompass economic adjustments necessary to cope with drought's impacts.

The Legislature may wish to create a mechanism to coordinate all available avenues for coping with direct and indirect impacts of future droughts. Such a mechanism might be a broad-range coordinating council that encompasses the state's economic and social assistance programs as well as water management.

The Legislature and federal officials may want to take the comparatively high vulnerability of agriculture in some areas of the state to reductions in water supplies into account in designing programs to protect the Delta and endangered species.

Ground Water and Its Management are Increasingly Important

Ground water has long been vital to California agriculture. A main purpose of the Central Valley Project, and to a lesser extent the smaller State Water Project, was to reduce agriculture's dependence on--and overdrafting of--ground water by providing a reliable source of surface water for irrigation. But even in years of normal or above normal precipitation and runoff and in spite of project water, farmers depend on ground water to meet much of their irrigation needs. During dry years ground water use increases, from the normal 40 percent of agricultural applied water to 60 percent. Water table levels then plunge.

Not only is water table depth an issue, so is water quality, which is affected by lateral movement of water, drainage problems, and brackishness at lower depths. One aquifer can underlie not only many *properties*, but many *water districts*. For that reason, many competing ground water users are affected by pumping, recharge, and water quality issues.

Sea water intrusion in coastal areas has been the strongest motivation for ground water management. Areas facing this threat are in the forefront of ground water issues, even regulating wells. Precedents set in Orange, Ventura, and Monterey counties, all of which have adopted well metering requirements, could eventually spread to inland counties whose ground water is threatened by salinity, plummeting water tables, and subsidence. At a minimum, the precedents established in coastal counties may show that there is more to be gained than feared from metering and other ground water controls.[112] The importance of ground water management is demonstrated by the 1992 enactment of A.B. 3030 (Chapter 947, Water Code §§10750 et seq.). That legislation established a framework for ground water management planning.

The Legislature may wish to evaluate whether special legislation could be developed to encourage ground water management in the San Joaquin Valley, in view of that area's unique geological and hydrological conditions.

[112]It has been suggested that ground water management might have prevented the complete dessication of the Owens Valley. See Marc Reisner's discussion of the Owens Valley in *Cadillac Desert*, especially at pp. 104-5. "By the 1970's," he notes, " . . . the aquifer was so drawn-down that desert plants which can normally survive on the meagerest capillary action of groundwater began to die, and the valley went beyond desert and took on the appearance of the Bonneville Salt Flats." Chapter Two of *Cadillac Desert* details the history behind that development.

No <u>Single</u> Response to Drought is Sufficient

Both at local and statewide levels, farmers and water managers must use a range of tools to prepare for drought and to cope with it when it comes. The impact of drought can be mitigated by careful planning, finding supplemental water (primarily ground water), reducing applied water in the most economically feasible ways, and reallocating water supplies on the basis of need and value.

The Emergency Drought Water Bank, local transfers and exchanges, assistance in improving irrigation methods and management, and improvements in irrigation water delivery methods all helped to stretch available water supplies. While some hardship was unavoidable, especially where ground water could not meet the need left by reduced surface supplies, the net impact of the drought on agricultural production was less than proportional to the drought's length and severity, in part because of state and district management.

The California Irrigation Management Information System (CIMIS), by disseminating information and providing consultation on water-conserving methods and technology, can contribute to water conservation. Although use of CIMIS has increased, it appears likely that its use could be greatly increased.

The Legislature may want to determine whether more effective promotion is needed for CIMIS.

Likewise, the Legislature may want to establish or expand programs to promote farmers' adoption of energy-conserving and water-conserving irrigation technology.

Finally, given the importance of planning for drought, the Legislature may want to evaluate recent improvements in drought and water-supply forecasting methods and whether funding should be provided for research toward improving forecasting methods.

Irrigation Improvements are Important, but not a Panacea

To use water more efficiently is not necessarily to use less water. A farmer who adjusts water use to meet crop water needs and leaching requirements as exactly as possible might use more water than before, not less. Correction of under-irrigation on parts of fields may partially or completely offset water savings from reducing over-irrigation on other parts. However, improved irrigation efficiency can result in better crop yields--both quantity and quality. Sometimes farmers can simultaneously reduce water use and improve yields through better irrigation methods, management, or both.

Even in water-short years, no technology or management can significantly reduce the evapotranspiration demands of planted crops nor the amount of water required for appropriate and necessary cultural practices. At best, farmers may achieve modest percentage reductions in water used for specified crops and acreage. Such reductions cannot be expanded indefinitely.

Once a farmer has reached the highest achievable application efficiency, reductions in agricultural water use must come from reducing irrigated acreage (or, where feasible, changing to less water-intensive crops). The net impact of acreage reductions on crop production will be reduced, and may be relatively small in the aggregate, if farmers take marginal acreage out of production and use their available water to best advantage on their more productive acreage.[113]

In view of the proportionally modest opportunities for reduced water use that are achievable through irrigation improvements and crop pattern manipulations alone, the Legislature may want to evaluate whether the state should adopt an agricultural land-retirement program to reduce water demand by removing marginal agricultural land from production.[114] Such a program might be accompanied by conversion-assistance programs broadly comparable to defense conversion programs that address military base closures.

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[113]The impact of such acreage reductions will, of course, be large for individual farms on predominantly marginal acreage. This is an issue that any program for retirement of marginal land would have to address.

[114]The federal Central Valley Project Improvement Act, Title 34, Section 3408(h), P.L. 102-575, authorized a land retirement program. The San Joaquin Drainage Relief Act, S.B. 1669 (Chapter 959, Statutes of 1992--§§14900 et seq., California Water Code), authorized a land retirement program to help cope with drainage problems. Both programs are under review and development at this writing. (Background and public comments are summarized in U.S. Department of the Interior, Bureau of Reclamation (Sacramento office), "Central Valley Project Improvement Act/San Joaquin Drainage Relief Act: Land Retirement Program Update," March 1994.)

APPENDIX: SELECTED STATISTICS

This appendix presents statistics behind some of the graphs in "Agriculture, Water, and California's Drought of 1987-92: Background, Responses, Lessons."

The following county data are from the respective county agricultural commissioners' annual crop and livestock reports.

Selected County Agricultural Statistics

FRESNO COUNTY HARVESTED ACREAGE

	1986	1987	1988	1989	1990	1991	1992
Field crops	1,612,300	1,629,500	1,642,800	1,530,400	1,538,140	1,417,190	1,437,970
Seed crops	79,135	62,170	67,180	73,310	66,310	51,240	48,120
Vegetable crops	166,503	191,249	185,108	187,935	228,980	228,860	205,060
Fruit/nut crops	320,803	316,587	317,231	315,986	315,921	309,228	310,041
TOTAL (these crops)	2,178,741	2,199,506	2,212,319	2,107,631	2,149,351	2,006,518	2,001,191

KERN COUNTY HARVESTED ACREAGE

	1986	1987	1988	1989	1990	1991	1992
Field crops	492,539	525,180	556,083	516,834	568,955	440,303	458,723
Seed crops	9,740	19,301	20,241	22,199	11,407	16,641	14,546
Vegetable crops	65,378	78,944	77,188	95,422	97,847	99,832	102,626
Fruit/nut crops	219,719	210,397	210,283	211,980	221,067	209,757	202,264
TOTAL (these crops)	787,376	833,822	863,795	846,435	899,276	766,533	778,159

MERCED COUNTY HARVESTED ACREAGE

	1987	1988	1989	1990	1991	1992
Field crops	904,178	919,156	933,208	947,630	952,523	951,206
Seed crops	4,125	3,683	4,564	3,863	4,555	4,889
Vegetable crops	34,180	36,187	38,346	42,700	42,565	42,079
Fruit/nut crops	107,532	105,895	107,033	109,065	104,588	101,674
TOTAL (these crops)	1,050,015	1,064,921	1,083,151	1,103,258	1,104,231	1,099,848

RIVERSIDE COUNTY PLANTED ACREAGE

	1986	1987	1988	1989	1990	1991	1992
Field & seed	267,446	237,446	245,138	220,934	219,729	224,319	233,391
Citrus	40,720	40,010	40,075	37,180	36,697	36,244	35,840
Veg., melon, & misc.	46,416	52,114	51,559	49,637	50,864	33,273	36,572
Tree & vine	37,053	37,658	38,366	36,483	35,782	34,969	33,785
TOTAL (these crops)	391,635	367,228	375,138	344,234	343,072	328,805	339,588

SAN JOAQUIN COUNTY HARVESTED ACREAGE

	1986	1987	1988	1989	1990	1991	1992
Field crops	463,000	446,000	452,000	494,000	469,000	435,000	451,000
Seed crops	6,850	7,630	7,000	6,170	7,320	4,920	4,230
Vegetable crops	59,300	60,000	62,600	68,000	69,400	66,400	56,200
Fruit/nut crops	132,000	125,000	126,000	126,000	126,000	124,000	123,000
TOTAL (these crops)	661,150	638,630	647,600	694,170	671,720	630,320	634,430

STANISLAUS COUNTY HARVESTED ACREAGE

	1986	1987	1988	1989	1990	1991	1992
Field crops	602,443	606,702	599,346	592,488	613,000	622,000	624,000
Seed crops	3,800	3,680	2,361	2,841	3,770	2,600	1,750
Vegetable crops	43,629	43,614	47,334	51,836	59,100	52,700	48,300
Fruit/nut crops	126,113	127,844	127,619	128,137	134,000	137,000	139,000
TOTAL (these crops)	775,985	781,840	776,660	775,302	809,870	814,300	813,050

TULARE COUNTY HARVESTED ACREAGE

	1987	1988	1989	1990	1991	1992
Field crops	1,150,820	1,104,940	1,121,000	1,178,839	1,164,700	1,176,200
Seed crops	7,097	9,691	7,932	8,895	6,443	10,864
Vegetable crops	7,157	9,015	8,156	8,929	16,087	14,132
Fruit/nut crops	245,177	242,818	230,213	241,948	269,982	289,780
TOTAL (these crops)	1,410,251	1,366,464	1,367,301	1,438,611	1,457,212	1,490,976

Selected Statewide Agricultural Statistics

The following field crop acreage information is from California Agricultural Statistics Service, *California Field Crops Statistics, 1983-92*. The vegetable and melon information is from California Agricultural Statistics Service, *California Vegetable Crops: Acreage, Production, and Value -- 1983-92*.

California Harvested Field Crop Acreage 1951-92

Year	Acres (000)
51	6451
52	6827
53	6923
54	6921
55	6689
56	6702
57	6630
58	6557
59	6551
60	6531
61	6319
62	6168
63	6166
64	6147
65	6202
66	6101
67	6263
68	6142
69	5865
70	6076
71	6133
72	5923
73	6104
74	6482
75	6602
76	6548
77	6284
78	6537
79	6694
80	6877
81	7025
82	6375
83	4971
84	5947
85	5788
86	5290
87	5123
88	5289
89	5124
90	4992
91	4595
92	4693 (prelim.)

California Harvested Veg./Melon Acreage 1982-92

Year	Acres
82	925,737
83	927,656
84	978,101
85	969,798
86	978,218
87	1,075,485
88	1,104,899
89	1,114,261
90	1,168,595
91	1,123,932
92	1,059,888

Selected Hydrologic Data.

Precipitation as Percentage of Normal, by Hydrologic Region

	1987	1988	1989	1990	1991	1992
NC	70	80	95	75	65	70
SF	55	75	85	65	75	89
SC	55	100	65	55	95	138
CC	60	85	65	55	95	110
SR	55	75	100	75	75	76
SJ	55	65	85	70	75	79
TL	65	85	85	60	85	80
NL	50	60	110	65	80	66
SL	50	130	50	55	80	115
CD	90	135	40	80	95	190

Source: Department of Water Resources, "Hydrological Facts 1987-1992"

Water Year Runoff as Percentage of Normal, by Hydrologic Region

	1987	1988	1989	1990	1991	1992
NC	56	52	76	46	35	40
SF	25	26	45	23	48	35
SC	32	40	28	16	58	112
CC	19	20	19	9	43	53
SR	49	49	78	49	45	47
SJ	33	38	60	40	50	41
TL	45	42	50	34	56	37
NL	42	33	78	45	45	35
SL	66	56	58	42	49	47
CD*	93	58	41	39	62	51

*CD runoff is inflow to Lake Powell

Source: Department of Water Resources, "Hydrological Facts 1987-1992"

Selected Energy Use Data

Energy Use for Agricultural Water--Gigawatt Hours 1983-91

PG&E	1983	1984	1985	1986	1987	1988	1989	1990	1991
Ground Water	1721.5	2502.6	2390.4	1827.1	2239.4	2553.2	2604.2	2951.5	3087.6
Surface Water	1754.9	2124.7	2189.8	1861.7	2020.6	1905.2	2045.2	1684.1	957.8
TOTAL	3476.4	4627.3	4580.2	3688.8	4260.0	4458.4	4649.4	4635.6	4045.4

SCE	1983	1984	1985	1986	1987	1988	1989	1990	1991
Ground Water	492.8	702.9	700.3	541.8	678.2	735.6	786.3	905.8	802.4
Surface Water	51.8	74.6	74.7	88.7	103.2	110.5	124.4	119.6	105.8
TOTAL	544.6	777.5	775.0	630.5	781.4	846.1	910.7	1025.4	908.2

SDG&E	1983	1984	1985	1986	1987	1988	1989	1990	1991
Ground Water	45.7	57.1	49.1	54.7	59.7	64.6	62.4	57.3	55.7
Surface Water	18.5	25.6	22.3	16.4	12.0	12.7	11.8	5.9	5.0
TOTAL	64.2	82.7	71.4	71.1	71.7	77.3	74.2	63.2	60.7

Data provided by California Energy Commission.

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