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Private and Institutional Adaptation to Water Scarcity During the California Drought, 1987-92

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Abstract

This Staff Paper documents the responses of water users and water managers to the 1987-1992 drought in California, based on surveys of irrigation districts and irrigation equipment dealers in late 1991 and additional anecdotal information. The findings are consistent with predicted behavior as suggested by economic theory.
The main findings are:
(1) The use of water-storage reserves delayed necessary reductions in water deliveries.
(2) Farmers responded to reduced water supplies in various ways, including increased ground-water pumping, adoption of more costly water-conserving irrigation technologies and management practices, and changes in land use by switching to higher value crops or fallowing low-value field-crop acreage.
(3) The continuous drought led to institutional changes at the Federal, State, and water-district levels, such as introduction of incentives for water conservation, establishment of a framework for water trade, and provisions for agreement between water suppliers and water users concerning actions to be taken by each.
The nature and intensity of the response varied by the agro-climatic region within California, since soil and weather conditions affect cropping patterns and the ability of farmers to adapt existing water management practices to drought conditions.

Keywords: Drought, California, adoption, adaptation, irrigation technologies, water districts, ground water

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Summary

Significant changes in environmental conditions generally have important effects on agriculture and other sectors of the economy. Determining impacts on resources and estimating private responses is critical to develop effective policy responses. The California drought of 1987-92 offers examples of private and institutional adaptation to changes in environmental resources.

Drought--or the lack of natural precipitation relative to "normal conditions"--is a recurrent natural phenomenon, both in the United States and abroad. Under near-fully appropriated water-allocation systems in the western United States, sustained droughts are often damaging to agriculture and natural systems. Yet society's response to drought is typically reactive and inadequate, potentially resulting in additional economic and environmental costs. As expanding water demands compete for increasingly limited water supplies, the flexibility of surface-water allocation systems to meet growing water demands will be further restricted. Society needs to develop policy structures to mitigate adverse effects of drought.

This report presents a case study of how irrigated farms, irrigation water districts, and water-allocation institutions in California adapted under increased water scarcity during the 1987-1992 drought. The response of water users and water managers is documented from surveys of irrigation districts, irrigation equipment dealers, and other sources. Hypotheses on predicted behavior under water scarcity, as suggested by economic theory, are evaluated against observed adaptations. It is instructive to understand the nature and extent of adaptation that may occur as water resources become scarce, and what policies might be generalized to other regions subject to periodic drought.

Irrigators in central California rely heavily on surface-water supplies provided by Federal and State water projects. In the early years of the drought, use of water-storage reserves delayed significant reductions in water deliveries. As the drought progressed, irrigation deliveries declined sharply in many areas. Cutbacks in water deliveries often involved changes in both water-allocation schedules and per-unit water charges. Junior water-right holders were the first affected and experienced the most severe cutbacks over time; water allocations fell less rapidly for senior right holders.

Water use patterns in California have undergone modifications as a result of the recent drought. Key sources of farm-level adjustments occurred through water-source substitution, technology adoption, and land use changes. While these trends apply generally to the study area, the nature and intensity of the response varied across agroclimatic subregions, depending on soil conditions, cropping patterns, priority of water-rights, surface-water reserves, and availability and cost of ground water. Technology adjustments are likely to be more permanent while water-source and land-use changes may be more temporary.

Increased ground-water use for irrigated production was an important consequence of the drought. Increased pumping rates from existing wells served to offset shortfalls in surface water supplies. As the drought progressed, new wells were drilled and existing wells

were upgraded, resulting in expanded pumping capacity and an overall increase in the share of irrigation water use supplied by ground water.

Important changes in irrigation technology were observed over the course of the drought. Increasing water scarcity spurred adoption of water-conserving technologies, including low-pressure sprinkler, improved gravity, and micro-irrigation systems. Findings indicate an increase in the use of improved water management practices at the farm level--soil moisture monitoring, water scheduling, system automation, and use of weather-information services. Water-conserving technologies were used primarily in the production of higher-value crops and perennial crops. Regions most severely affected by water cutbacks were likely to adopt improved technologies earlier, with higher rates of adoption over time.

Producers also adapted to drought conditions at the extensive margin with changes in land use. Substitution of low-value crops, such as alfalfa and pasture, for higher value or less water-intensive crops was observed in many areas. While total irrigated acreage remained relatively stable through the drought period, some fallowing of low-value field-crop acreage occurred over time. This was particularly apparent in regions severely affected by water cutbacks, such as the central and southern San Joaquin Valley.

Drought conditions gave rise to various conservation initiatives at the irrigation-district level. As the drought intensified, districts provided conservation incentives to producers through tiered water-pricing schedules and subsidized loan programs for improved on-farm technologies. Irrigation districts also invested in conserving technologies off-farm, including canal upgrades, pipeline installation, and improved water-scheduling practices.

Increased water scarcity also helped pave the way for institutional changes at the State and Federal level. Provisions include introduction of new institutional mechanisms to facilitate water market transfers, legislation to ensure protection of instream flows and environmental amenities, water conservation agreements between urban and agricultural sectors, changes in the price of water charged to irrigation districts (and urban users) under renewed Federal contracts, and expanded technical assistance and loan programs for water-conserving practices.

Private and Institutional Adaptation to Water Scarcity During The California Drought, 1987-1992

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Introduction

Water management and policy analyses are concerned with the impact of policy measures—such as pricing structure and regulations—on private decision variables (e.g., water use levels and technology choice) and public decision variables (e.g., investment in storage and conveyance infrastructure). Economic approaches suggesting the use of incentive systems to achieve water conservation—through improved water management, adoption of water-saving technologies, or changes in cropping patterns—have not been empirically examined on a global basis. Supporting empirical data are rare since very few case studies of sufficient duration and spatial coverage exist to allow for time-series and cross-sectional effects.

Drought is one of the most far-reaching and devastating natural phenomena that mankind has witnessed. Yet response to drought has often been inadequate both at individual and institutional levels. Drought occurs, not because something "happens," but because natural precipitation fails to occur over time, or comes too late or too little. Because of its gradual development, the determination of the drought's duration and severity is often difficult to affix. Although drought is a gradual phenomenon, its impact can be significant. The need to develop policy structures to mitigate adverse effects of drought are of great importance.

Well-documented responses to specific drought events might provide adequate information to hypothesize the likely responses of decisionmakers under future drought conditions. A drought may shock the water sector, inducing behavioral changes for both private and public decision-makers. Drought impact is dynamic, basically influenced by the interactions between supply and demand. The relationship between the supply of water, which can be expressed in physical as well as organizational terms, and the demand for water, which is affected by socioeconomic factors, is clearly not static and may vary considerably over time (Wilhite and Glantz, 1987).

California relies heavily on water-harvesting projects, and therefore is very sensitive to rainfall and drought conditions. California is basically a desert State that transformed itself through water development. In previous decades, California responded to water supply and demand imbalances by investing in water-harvesting and water-control infrastructure that increased supplies. State and Federal projects are the source of most of the surface-water supply in Cali-

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fornia; these projects harvest and store melted snow and rainfall, which is then delivered to end users. The bulk of California's precipitation falls as winter rain or snow. Water is then stored in a series of reservoirs for municipal use, irrigation supply during the growing season, and other purposes. About 60 percent of the State's irrigation water needs come from surface-water storage reservoirs, with the remaining 40 percent coming from ground-water sources.[2] When surface-water supply is short due to limited runoff, users often pump ground water where available and economically feasible. Of the 36.2 million acre feet (AF) of water consumed in California in 1990, the largest share—26.8 million—was consumed by the agricultural sector, with 6.8 million consumed by the urban sector, 1.1 million used for wetlands, and 1.5 million used for recreation and energy production.

Over time, with a well-developed water delivery system, California has become the producer of almost half the fruits and vegetables of the United States. The Central Valley region of California, in particular, has become one of the most productive agricultural regions in the world.[3]

Water scarcity has been managed historically through a comprehensive system that includes water mining, storing, transportation mechanisms, and allocation institutions. The physical water-control system has not been dramatically modified since the 1960's, when the two major water projects—the Central Valley and the State Water Projects—were launched. The physical and institutional systems were sufficient to accommodate localized short-term water scarcity, and very little incentive was provided to Californians to change their water system.

Beginning with the 1987 water year (October 1986), California experienced the driest continuous 5-year period since 1928-1934. Precipitation levels were below normal in all 5 years, including both rainfall and snowmelt runoff (table 1 and fig. 1). Storage levels declined over this time as the prolonged drought caused reservoirs to be drawn down well below average levels.[4] Well-above-normal precipitation in 1993, 1994, and 1995 (143, 120, and 127 percent above average, respectively) signaled the end of prolonged drought conditions in California (DWR, 1995).

Drought impacts varied depending on water availability by region, with the Central Coast depending heavily on ground water, the Imperial and Coachella Valleys relying on water imported from the Colorado River system, and the rest of the State using a combination of reservoir storage and ground water. The southern area of the Central Valley relied heavily on State Water Project (SWP) water. SWP water deliveries were cut drastically in 1991 and 1992 due to extremely low storage levels. As part of the State Emergency Water Plan, the Governor established the State Water Bank to purchase water from available sources in order to transfer it to areas in severe need.

The Central Valley Project (CVP)—the largest Federal water project operated by the Bureau of Reclamation—had to cut back overall agricultural water deliveries by 50 percent in 1991 due to a decline in reservoir storage levels (from 6.3 million AF to 1.6 million AF). Some agricultural water service contractors were scheduled to receive approximately 75 percent of their normal

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[2]Information in this section is based, in part, on Johnson (1991).

[3]Water imports to the *San Joaquin Valley* created severe drainage problems that harmed agricultural production and the environment on the Valley's west side.

[4] In 1992, statewide precipitation averaged 85 percent of normal runoff, and statewide reservoir storage on July 1, 1992, was 17.8 million acre-feet (61 percent of normal). In July 1, 1991, reservoir storage was 19.1 million acre-feet (AF). During the 5-year period, 1987-1991, statewide runoff was 48, 48, 70, 45, and 43 percent of normal, respectively. Storage in major reservoirs of the Central Valley system (as of July 5, 1992) was 10.374 million AF (42 percent of normal). The capacity of these reservoirs is 24.983 million AF (California Department of Water Resources, DWR, 1992).

supplies because they were senior water rights holders.[5] Many water districts serving junior water rights holders received only 25 percent of their normal supplies in 1991, after receiving only 50 percent of their normal supplies in 1990 (table 2).

Very little quantitative documentation exists on the response of agricultural water users and water suppliers to prolonged drought conditions. A comparative study of drought policy in the United States and Australia (Wilhite, 1993) reveals that governments often respond to drought through crisis management rather than pre-planned programs. Young (1994) compiled a set of studies that assessed the likely impacts of and policy responses to severe, long-term drought in the Colorado River Basin. The findings suggest that allocation rules among instream and off-stream uses should be reconsidered, and that improved coordination both within and between States is needed. Easterling and Riebsame (1987) examined drought impacts and adjustments in agriculture and water resource systems, using two case studies from Colorado (1974-1977) and California (1977). A study by the U.S. Army Corp of Engineers (1993) focused mainly on institutional aspects of drought and drought preparedness.

Existing documentation on drought response in California focuses mainly on water balances and institutions developed by urban communities to ration water and by water-supply agencies to provide water to urban and agricultural users (DWR, 1977, 1991a). These reports also provide information on ground-water quantity and quality, and economic consequences for agriculture and urban areas.

Several studies provide information on storage and financial assistance available to the different sectors in California that may be affected by drought (DWR, 1989; DWR, 1991a; State of California, 1991). A more detailed study (Northwest Economic Associates, 1992) documents the 1991 drought in the San Joaquin areas of California.

While the California 1987-92 drought imposed significant costs on the agricultural sector, it has provided us with a long-term statewide case study of how behavioral patterns have changed across all levels of decisionmaking, including State water policymakers, water agencies and reservoir operators, and end users of water. This report identifies important changes and demonstrates how they are consistent with theoretical predictions. We present and analyze findings of a survey (conducted in 1991-1992) on California's response to the drought, focusing on adaptations within the agricultural sector.

The next section develops several hypotheses drawn on existing literature to explain patterns of decisionmakers' behavior during a drought. The third section discusses the data collection methods used. Descriptive findings of the survey of water districts are listed in section 4, and

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[5] Under the appropriative system, people are allowed to divert water for beneficial use (in the past, beneficial use was defined mostly as "agricultural and municipal use"). However, seniority in water rights depended on historical use levels, and the rights to water are preserved as long as they are used. So, basically there are two principles that define prior appopiation: use it or lose it and first come first served (Cuzan, 1983).

"Under the riparian doctrine, each property owner fronting on a lake or stream has a right to the unimpaired use of the waterway (appropriative right), regardless of the location of his property along the waterway and regardless of the time at which the property is acquired or use made of the waterway. Consequently, rights to water are only usufructuary: strictly speaking the right holder may not diminish the flow of water by physically consuming it as this would impair the rights of other riparians" (Burness and Quirk, 1979).

"The literature on the economic motivation for the emergence of the riparian rights doctrine is sparse. In essence, it is a squatter rights system and should be viewed in the context of settlement and growth policy. Historically, in an economy with underutilized water resources and severe constraints on government spending for growth and development, this regime encouraged farmers to settle in previously unsettled areas" (Shah et al., 1993).

results of a survey of irrigation equipment dealers are provided in section 5. Section 6 presents conclusions of the analysis.

Theoretical Considerations: Responses of Different Sectors to the Drought

Various responses to the California drought of 1987-92 were observed at project, district, and farm levels. The major water suppliers—the Federal Government and the State water agencies via the Central Valley Project and the California Water Project—imposed water cuts on the water districts and other users. The empirical investigation in this study does not focus on the response of the State and Federal governments, but rather on responses of water organizations (water districts), irrigation equipment dealers, and individual farmers.

Economic theories may be useful in assessing alternative strategies available to parties affected by drought (fig. 2). Several hypotheses can be generated about the possible response to drought. We considered the behavior of four groups: water storage managers, water users (farmers), water intermediaries (irrigation and water districts), and nonagricultural interests (environmentalists, municipalities, etc.).

Water Storage Managers

Those responsible for the management of water deliveries from large, mostly surface-water inventories include officials in the Bureau of Reclamation responsible for water deliveries from the Central Valley Project (CVP) and individuals in the California State Department of Water in charge of allocating California water-project water. Their behavior is affected by many legal considerations and prior arrangements but, at least in principle, their water allocation choices are based on an implicit (constrained) optimization procedure. Their objective is to maximize net expected discounted benefits of water delivered to users, with the benefit function assumed to be concave.

For small delivery levels, the marginal benefits of delivered water are likely to be very high (when the water is used as drinking water); but marginal benefits are likely to decline and become very low for relatively large water deliveries. At the beginning of a period, an initial water stock is distributed; a random amount of water resulting from rain and snowmelt is then added to this stock. The total of the stock and added water cannot exceed inventory capacity, and any excess water (whenever it exists) is released for use.

The optimal delivery is set at a level where the marginal benefit from delivery in one period is equal to the marginal cost of reduced water inventory levels in the following period. Water deliveries for a given year are decided after rain and snowmelt situations for that year are (more or less) known. The uncertainty is with regard to the future. Policymakers generally avoid decisions that can be expected to cause water inventories to reach reduced levels in the future, especially if these low levels are accompanied by low rain and snowfall and may not allow delivery of water for essential activities. Therefore, it follows that, as the sum of the initial stock plus rainfall and snowmelt inputs decline, the amount delivered for irrigation and other uses becomes smaller.

The optimization problem of the water supplier is confronted each period to determine optimal water allocation. The sum of initial water stock and rainfall/snowmelt contributions is crucial for determining water delivery. If a drought lasts several years, like the recent California drought, this sum declines over time. Thus, water deliveries decline over time. As the drought progresses, the water inventory in the reservoir reaches dangerously low levels and water delivery policies become more severe.

Causal effects involving water storage and water deliveries presented above are rather simplistic. Many factors explaining manager behavior can be considered, including adjustments and expectations regarding rainfall distribution, and changes in benefit functions over time. However, such additions will not alter the prediction that *water deliveries from reservoirs will decline as the drought progresses.*

Water Users

For simplicity, we consider farmers to be representative of water users. The possible responses of water districts, which represent many users, are discussed later in the text. The discussion is rather heuristic since the goal is to obtain and verify general hypotheses. We assumed that farmers may diversify and grow several crops. A farmer's land may be allocated between high-value perennials and high-value vegetable crops and some lower-value field crops such as alfalfa, cotton, and rice. We further assumed that farmers receive water from surface-water sources but may also pump ground water from some ground-water aquifers where available. Surface water is relatively inexpensive compared with ground water, and the conjunctive use model explains the behavior of many farmers in California's Central Valley: they use ground water mostly to augment their surface water. Furthermore, as the ground-water pumping rate increases over time, the aquifer level declines and pumping costs increase. With this background, it is clear that if, as expected during the drought, surface-water deliveries decline, farmers will increase ground-water pumping. Because of open access to aquifers (as presently instituted in California), farmers are unlikely to be concerned about the future availability of ground water, so the main constraints to ground-water pumping are pumping costs, pumping capacity, and ground-water quality. Therefore, we hypothesize that, *during drought, farmers with access to ground water may increase their pumping capacity as well as increase the quantity pumped.* Obviously, during a very long drought, there may be a point at which ground-water pumping will decline as reservoirs are depleted. In the early stages of a drought, however, one may expect increased ground-water pumping as surface-water deliveries decline.

Given the existing water-rights system and geographical differences within California, the impact of the drought may vary across locations and according to water rights. Farmers who have senior rights to water are not likely to be affected much by drought, especially during the early stages when the reservoirs are sufficiently full. *Farmers with junior rights are most likely to be affected by drought. Their water deliveries may be cut substantially, and they are likely to make the most drastic adjustments.* Thus, drought may lead to differing behavioral responses—in terms of technological choices and crop selection—between junior and senior rights owners, under existing institutions governing water allocation.

At the farm level, producer response to drought may involve adjustments in land use, irrigation technology choices, and various water-management practices.

Land use. Farmers can adjust land-use choices relatively quickly, especially the amount of land allocated to field crops and non-perennial vegetables. Therefore, a cut in acreage allocated to field crops may follow a reduction in water availability, and may occur shortly after the drought begins. However, several factors may limit crop substitution under deteriorating water supply conditions. For example, long-term contracts may obligate farmers to continue to provide certain commodities even when water expenses are high. Similarly, farmers are unlikely to risk losing their commodity program base and may continue to grow cotton and other program commodities under unfavorable water conditions.[6] But, overall, *farmers will reduce the acreage of low-value field crops as water availability declines and drought continues.* Acreage of perennial crops and high-value vegetable crops are less likely to be affected by the drought. Also, conversion to dryland production systems may be infeasible in some areas. In more extreme situations, farmers may fallow portions of their cultivated land.

Irrigation technology. Farmers can invest in modern technology, such as drip and sprinkler, or modify existing gravity-flow systems (by using laser beam leveling of the soil, reduced furrow length, or gated pipes). Investment in improved technologies and management increases fixed costs per acre, but increases irrigation efficiency (water utilized by the crop as a fraction of water applied). Technology and management changes are site specific, therefore, irrigation technology choice is related to land-use and cropping pattern choices.

The literature on irrigation technology adoption suggests that adoption of modern technologies is more likely to occur for higher value crops, in locations with higher water prices and lower water-holding capacity soils (e.g., Dinar and Zilberman, 1991). In the case of drought, it is reasonable to hypothesize that *adoption of modern technology is more likely to occur for high-value perennials and vegetable crops, and is more likely to be done by farmers with junior rights[7] and/or by farmers facing very high pumping costs.*

Decisions to install drip or sprinkler irrigation, to modify existing irrigation technology, or to improve water management practices take several months to implement, and farmers often must make these choices before winter when information on next season's rainfall and snowmelt is unavailable. Farmers may, however, know the initial stock of stored water, and may base their technology choices, in part, on this information. During the first year of a drought when initial water stock is still high, there may be few irrigation technology changes. In the following years, when the surface stock level is low, farmers recognize that the probability of receiving surface water is small, providing them with additional incentive to adopt high-investment, water-conserving technologies. Consequently, *adoption of modern irrigation technologies is not expected to increase in the early period of a drought, but it is likely to rise in later years.*[8] Obviously, the adoption of modern irrigation technology is more likely to occur under desirable financial conditions with low interest rates and relatively high commodity prices.

Water management practices. Farmers may respond to drought by reducing water use under existing technologies. For example, they may reduce the amount of water used for pre-irrigation and leaching; they may apply less water than is required to meet full crop consumption requirement (deficit irrigation); and they may reduce water use by improving management (e.g., improved scheduling). It is reasonable to expect that *farmers facing reduced water availability and increased water cost will modify current technology for existing crops to reduce water use.*

One means of increasing water-use efficiency is to adapt irrigation timing and volume to crop needs (improved scheduling). This may require better monitoring and information on crop moisture needs, as well as the use of more information-sensitive management practices and procedures. Various types of soil/plant-moisture monitoring equipment (e.g., tensiometers, computer software) as well as public and private sources of weather information are available for

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[6] This may be less relevant under the 1996 Farm Act.

[7] Here one should also consider the effect of uncertainty associated with water deliveries on investment decisions. A junior-rights holder may hesitate to invest heavily in improved technologies if the water supply is not guaranteed.

[8] The definition of "early period" depends on the relationship between the reserve stock and average annual water flow. If reserves can last for many years, say, 10, then "early period" may be 3 or 4 years. If the stock capacity suffices for normal use over 3 or 4 years, then "early period" may only be 1 year.

irrigation purposes. Throughout California, many irrigation consulting firms offer water planning and scheduling services. *During a drought, farmers are more likely to use irrigation consultants and adopt information-based irrigation management strategies.*

Water Intermediaries

Water intermediaries include institutions such as water districts or canal companies that serve as intermediaries between users, farmers, and water suppliers. In some cases, water districts actually own the water; but, in most cases, the districts purchase water from regional projects and deliver it to farmers. Most agricultural water utilities are nonprofit public agencies controlled by farmers. Other water intermediaries are regulated utilities. For analytical purposes, it is useful to treat water districts as agents who own and operate water conveyance systems and who set prices to defray costs (and in some cases to obtain a normal rate of return).

Much of the expenditures of water districts are short-term, fixed costs (salaries, capital costs, maintenance costs), which are covered by per acre-foot fees paid by users. The nature of these costs may impose some difficulty in immediate adjustment to changing available water-quantity situations. Therefore, a reduction in the volume of water received by water intermediaries may lead them to increase fees charged to water users. *During a drought, user fees and water prices are expected to increase for water districts receiving less water.*

In addition, water districts may reduce water loss in delivery systems and thus increase the percentage of district water that reaches farmers. Therefore, *during drought periods, water districts may invest in lining their canals and upgrading their pipe system.*

Nonagricultural Interests

Municipalities, industries, and environmental amenities (wetlands, fisheries) may suffer severe cuts in water allotments during periods of drought, especially when they involve junior water rights within the queuing system. Municipalities are likely to introduce measures to induce customers to practice water conservation, but as the drought continues, nonagricultural water users with junior water rights are most likely to apply pressure for reform of the existing water rights systems (Rausser and Zusman, 1991). In practice, junior water-rights holders (especially groups promoting environmental amenity activities) are likely to seek more water from agricultural senior rights users. Thus, the behavior of such players may result in some institutional changes. *As the drought progresses, water allocation systems are increasingly likely to be modified to allow transfers to junior rights holders who have high value of marginal productivity for water.*

Data Collection Methods

This section provides an overview of data-collection methods for the main affected parties—irrigators and water districts—and for irrigation equipment dealers who were indirectly affected by changes in demand for water-related equipment.

Water Districts

Data on water districts were collected using a questionnaire to individual water districts throughout the State. A prototype questionnaire was developed and tested on five students for consistency. Changes to the questionnaire were incorporated, and it was tested by three water-district managers prior to its release. Based on suggestions made by these managers, questions were added, deleted, and revised. The final form of the questionnaire is presented in Appendix 1.

Water districts (WD's) were surveyed to gather information about changes in irrigation, cropping patterns, and ground-water usage by farmers in the WD's. Additional information on water distribution arrangements, water exchange facilities, and any changes therein over the last five years of drought were also obtained. The survey was conducted during the summer of 1991. The data collection phase was conducted by four pre-trained graduate students. Interviewer training included background on the water problems in California agriculture, interview techniques, and data-handling procedures. The data collection process comprised three stages: First, telephone interviews were conducted with water district managers or their deputies. The interviewers presented the research objectives, reviewed survey questions 1 through 25, and filled in the survey responses. Then the questionnaires were copied and sent with any unanswered questions to the water districts. Completed questionnaires were returned by the districts, and the data were verified and entered into a Microsoft Excel spread sheet. Data from each questionnaire were tabulated and rechecked for consistency, using the SAS statistical package.

Irrigation Equipment Dealers

Irrigation dealers provide farm services that might enhance or encourage adoption of low-volume irrigation systems. Irrigation dealers can also provide important information on the extent of adoption of low-volume irrigation systems. Sales of certain components of irrigation equipment, such as pumps, may indicate increased ground-water use, which in turn increases demand for sprinkler and drip systems. This is especially important since farmers may overcome surface-water shortages through more extensive use of ground water, which may involve drilling new wells or amending existing ones.

The 53 California dealers identified in a U.S. Irrigation Association list were contacted by phone to assess their ability and willingness to participate in the survey. In all, 45 questionnaires were mailed and 28 dealers returned questionnaires. The questionnaire is presented in Appendix 2. Data from the questionnaire are discussed in section 5.

Findings from the Survey of Water Districts

The results of the water district questionnaires were analyzed by production region of California (table 3). Each production region (fig. 1) contains several counties, and is characterized by similar environmental and weather conditions. To some extent, water institutions are also likely to share similar characteristics in these production regions. It should be mentioned that the water district survey does not cover all counties.

Phone calls were placed to 195 WD's. Phone interviews were conducted with 139 WD's. Under the second phase, the questionnaires were sent to the 139 WD's. Completed questionnaires were received from 116 WD's, upon which the analysis is based. Table 4 provides the distribution of WD's over 12 production regions presented in table 3.

Over 9 million acres, of which 5.9 million are irrigable acres, were served by these 116 water districts. The observations were aggregated into the 12 production regions, and each WD was classified by the county in which its headquarters was located. No observations from the North Coast region were included in the analysis.

Total acres served, main crops, number of landowners, and area with drainage systems are presented in table 5 (questions 3, 5, and 6). The WD's infrastructure of water-delivery systems and storage capacities are presented in table 6 (question 7).

The distribution of services provided by the WD's is presented in table 7 (question 4). Services include provision of surface and ground water for agricultural and urban purposes, recharge of ground water, drainage and flood control, electricity generation, provision of water to parks, and sewage and water reclamation. Services associated with surface water for irrigation are provided in 93 percent of the WD's, and services associated with surface-water supply to urban consumers are provided in 43 percent of the districts. A district can be a supplier of more than one service. Ground-water supply services to agricultural customers are provided in 31 percent, and ground-water supply services to urban customers are provided in 23 percent of the districts. Drainage control and flood control services are provided in 17 to 24 percent of the districts. Electricity generation and sales were reported by 23 percent of the districts. Services associated with water to parks, tailwater return, sewage, and other services were reported by 1 to 6 percent of the WD's. Results by agricultural region are not discussed here but are included in the table.

Distribution of water-allocation methods is presented in table 8 (questions 10, 11, and 13). The majority of the WD's (79 percent) are able to supply water upon demand; 25 percent allocate water to their customers by rotation and 7 percent by using a previously arranged queue. The average lead time for turning water on and off is 25 hours and 14 hours for rotation and queuing, respectively.

Institutional arrangements for water exchange among WD members and effects of drought years on the rate of exchange are presented in table 9 (questions 18, 19, 21, 22, 24, 25). Exchanges of district water are allowed in 49 percent of all districts and in 20 percent and 17 percent of districts in the Mountain and Southern California regions. No exchange is allowed in districts in the San Diego and Riverside regions. In 87 percent of the WD's, exchange of water requires approval from the WD. Inquiry by the WD about the payments involved was reported in 15 percent of the districts, while, in some regions, WD's did not inquire about payments. Forty-nine percent of the WD's reported that water exchange was a regular practice. An average of 10 percent of district water was subject to these exchanges, with values varying from 1 percent in the Central Coast region to 33 percent in the Mountain region. Over 50 percent of the districts reported that a significant increase in the number of exchanges had occurred during the last few years. Of these water districts, 73 percent attributed the increase to the drought; and 100 percent of the WD's in the Sacramento and Kings and Tulare regions attributed the increased exchanges to the drought.

Responses to the continuous drought conditions in the last 5 years are recorded in table 10 (question 8). Actions taken by WD's include both physical and institutional adjustments. Physical responses include pumping additional ground water, lining canal systems to prevent leaking, and replacing open ditches with pressurized pipes. Institutional actions include offering assistance to farmers to change both irrigation scheduling practices and irrigation methods, changes in district water-allocation schedules to users, and changes in water-pricing schemes. An open question allowed respondents to add and explain additional steps not included in the questionnaire. Nearly one-quarter of the WD's pumped additional ground water to augment the reduced supply of surface water. This water was pumped at the WD level; additional ground water can be pumped by individuals. Pumping additional ground water was not reported by WD's in the Imperial or Kern regions and, at the other extreme, was practiced intensively by WD's in the San Joaquin and Southern California regions (54 percent and 53 percent, respectively). Canal lining, reported by 11 percent of the WD's, was not well documented, and missing values exist for WD's in the Central Coast, Sacramento, Mountain, and San Diego regions. The 100 percent and 33 percent values of WD's in the Imperial and Riverside regions is outstanding compared with other northern districts. Pressurized pipes were installed by 12 percent of the WD's, with values ranging from 0 to 25 percent in the different regions. The institutional responses at the water-district level were more common; reported rates for institutional responses vary from 38 to 52 percent of the WD's. A preliminary hypothesis (to be verified in later stages of the research) is that WD's responded initially with less costly measures before making additional investments in infrastructure. They probably first reactivated existing wells, lined canals with cement, replaced open canals with pressurized pipes, and drilled new wells. Some of the open-ended answers not included in the questionnaire are presented in box 1.

The responses of the individual farmers in the WD's are presented in table 11 (question 9). Farmers' responses were distributed differently from those of the water districts. The most common responses at the farm level included pumping additional ground water, either by existing or newly installed wells (in 65 percent of the WD's); installing new sprinkler irrigation equipment (36 percent); installing new drip equipment (33 percent); improving existing furrow irrigation (36 percent); shortening existing furrows (25 percent); and switching crops (33 percent). These numbers are fairly consistent with regional-level values. An open question allowed respondents to add and explain additional steps not included in the questionnaire (box 2).

Table 12 (question 26) provides information about the total acres served by the WD's and the acres fallowed due to the drought conditions. Information was provided only from portions of the WD's that were included in the survey. The number of WD's responding to each item in the table is also recorded. The percentage, for all districts, of land fallowed over time remained almost constant (around 9 percent), with an increase in 1991 to 16 percent. Districts in the Sacramento, San Joaquin, Fresno, Kings and Tulare, Kern, and Imperial regions are associated with relatively high and/or increasing percentages of fallowed land. WD's in the Central Coast, Mountain, Southern California, Riverside, and San Diego regions reported nonsignificant values of fallowed land.

There are several sources of water and several arrangements for water rights in California (table 13, question 30). As was mentioned above, each of these water-rights holders was affected differently by the water cuts resulted from the drought. The various definitions are explained in the footnote to table 13.

In addition to information in table 11 (question 9), respondents were asked to provide both the number of district-level operated wells and the amount of ground water pumped (table 14, question 31).

Findings from the Survey of Dealers

Dealers who sell irrigation and pumping equipment to farmers and provide guidance and information regarding irrigation management were surveyed in order to amend information collected directly from the water districts. Forty-five dealers whose names were obtained from the Irrigation Association of the United States were surveyed, and 28 complete responses were received.

Each dealer surveyed was asked about trends in sales of different types of irrigation technology, pumps, and automation. They were also asked to provide information about the services they offered their clients (do they sell only hardware or do they also provide advice). Finally, they were asked about their assessment of land shares of different irrigation technologies in their region of operation.

The dealers are widely distributed throughout the State. The geographical distribution of the dealers, by county, is presented in table 15.[9]

The majority of the dealers included in the survey generate 50 percent or more of their total revenue from agriculture (table 16). The crop acreage served by irrigation equipment dealers are mostly fruits (including citrus), nuts, and grapes. Few dealers reported field crops such as rice and cotton. This may lead to overestimation of the overall use of modern irrigation technologies since traditional forms of irrigation continue to be relatively important in field crops.

Analysis of the data is presented in three sections. The first section addresses general data describing the nature of the respondents' business, including geographical location, type of business (i.e. marketing, sales, installation of irrigation equipment, etc.), extent of business related to agriculture, and in which region (by county) irrigation equipment is sold. The second section describes Part II of the questionnaire, namely dealers' assessment of the use of different types of irrigation technologies for those crops which are most important in terms of acreage and for which they sell irrigation equipment. Furthermore, dealers have been divided by geographical area; their assessments are described in this section as well. The third section of the dealers' data analysis summarizes data obtained from dealers with regard to pumps, including the volume of sales and the different types of pumps sold in their areas. This section also outlines dealers' assessment of water use and yield effects when traditional forms of irrigation are compared with modern irrigation technologies.

General Description

To differentiate between dealers who serve urban areas and those who serve the agricultural sector, we asked for the percentage of revenues generated by agriculturally related activities. The great majority of dealers responding to the questionnaire generated 50 percent or more of their total revenues from agriculture (column IV, table 16). Responses indicate that even though all dealers generate revenues mostly from the sale of irrigation equipment, they are involved in other irrigation-related activities as well. Approximately 50 percent of the responding dealers provided design of agricultural irrigation systems as a service to their customers. Furthermore, over 60 percent of the respondents provided installation of equipment and/or related activities.

[9]As will be seen later, not all dealers responded to all questions included in the survey. Reasons for this vary. Some of the reasons stated by the dealers were that some of them do not sell or rent pumps or that they sell irrigation equipment for one crop only.

Most respondents did not engage in marketing activities (only three did so). Of lesser importance, other activities included rental of equipment and irrigation-related consulting services.

Dealers were asked if they observed farmers switching crops during 1990, and if so, to assess whether or not changes in crop patterns were due to the drought. Fifty-one percent did not observe changes in crop patterns. Of those who did observe change, 50 percent believed that such changes were the result of the drought. Dealers' responses are presented in bar charts in figures 3 through 14. The reader should recognize that the data used for these bar charts do not necessarily coincide with results for the State or even for the San Joaquin Valley. They represent only the dealers' point of view.

Dealers' assessment of irrigation technology sales. In the second part of the questionnaire, dealers were asked to estimate the extent of use of different types of irrigation equipment for the period 1987-1991 for crops on which the irrigation equipment they sell is used. Crops were divided into four categories: (a) citrus, (b) fruits and nuts, (c) grapes, and (d) vegetables. Dealers were asked to assess use of different irrigation systems as a percent of total acreage. Their responses are summarized in figures 3 to 6.

Before 1989, the use of sprinklers and furrow remained fairly constant for citrus irrigation, with furrow declining very slightly; drip increased from an average of 47 to 53 percent between 1987-1989 (fig. 3). In 1990, however, the use of sprinklers and furrow, especially sprinklers, declined rapidly, while the use of drip irrigation increased to an annual average share of 62 percent of total acreage in 1991. As shown in Castillo et al. (1992, figure 1), drip irrigation was the most widely used type of irrigation for citrus for the period of study (1987-1991), during which its use increased. The use of sprinklers on citrus decreased.[10]

Furrow irrigation was the dominant technology for fruits and nuts before 1990 (fig. 4). Just prior to 1990, however, drip irrigation surpassed furrow and became the leading type of irrigation used on fruits and nuts, increasing from just over 25 percent of annual average acreage in 1987 to almost 45 percent of total acreage in 1991. Use of sprinklers remained fairly constant for the 1987-1991 period. Figure 4 also shows that the use of sprinkler irrigation in 1987 was slightly higher than the use of drip; nevertheless, in 1988, drip use surpassed the use of sprinklers.

As with the other crops, the use of sprinklers and furrow for grapes declined for the period in study (fig. 5). The use of furrow declined from nearly 32 percent in 1987 and 1988 to 27 percent in 1989, 1990 and 1991. The use of sprinkler irrigation declined between 1987 and 1990, when sprinkler comprised 21 percent of total acreage. For 1991, total average acreage use of sprinkler for grapes decreased below 20 percent. Drip use on grapes rose from below 30 percent in 1987 to almost 40 percent in 1991, with a slight decline for the last year (1991).

Furrow remains the most widely used form of irrigation for vegetables (fig. 6), although its importance declined for the 1987-1991 period, particularly after 1990. Dealers reported no use of drip irrigation for vegetables before 1988. However, in 1991 the use of drip for vegetables rose to an annual average of almost 10 percent of total acreage. The use of sprinklers rose for the 1987-1991 period, although furrow is by far the most common form of irrigation for vegetables. It is important to note that, according to the data, vegetables are the only crop category for which the use of sprinklers increased during 1987-1991.

Figures 3 to 6 are consistent with expectations that use of low-volume irrigation systems will increase as the severity of the drought deepens and that farmers rely more on modern forms of irrigation to deliver water to their crops.

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[10]As we will see later, this pattern repeats for all crops during 1987-1991 with the exception of vegetables between 1990 and 1991.

Figures 7 through 11 summarize the data obtained from Part II of the questionnaire organized by geographical area. The data were divided by county into six regions (table 17).[11]

When the dealers are grouped by region, high-value crops are not separated from low-value crops. The figures presented in this section are aggregates for each of the regions outlined above. As will be shown later, the trend outlined for crops in the previous section concurs with the trend in this section and provides a good guideline for the purpose of this study.

Furrow was the most widely used form of irrigation in the north (fig.7). Although its importance diminished between 1987-1991, furrow still accounted for over 30 percent of total acreage during 1991. The use of sprinklers also diminished during 1987-1991. As will be shown, this is a common pattern for all areas.[12] Drip use increased dramatically in the north during 1987-1991. While, in 1987, drip was reportedly being used for just over 7 percent of total average acreage, by 1991 that figure had increased to 26 percent. The use of drip irrigation during 1987-1991 was more evident for all crops other than vegetables. This is consistent with the earlier observation that the use of drip for vegetables is not a common practice among farmers. Reasons for this vary. One likely explanation is that implementation of drip for vegetables is either not profitable or difficult because of the nature of the crop.

Data for the south (fig. 8) should be viewed with some caution since both respondents were located in Tulare County (no dealers from Kings or Kern Counties responded). The trends, however, are consistent with the other regions and crops. Between 1988 and 1989, drip irrigation surpassed furrow as the most widely used form of irrigation, while the use of sprinklers declined over time.

In the North Coast area, drip use surpassed furrow between 1989 and 1990; however, furrow continued to be important and its use increased during 1990-91 (fig. 9).[13]

In the South Coast area, for the entire period, drip was the most widely used irrigation system, increasing from 55 percent of total average acreage to almost 80 percent in 1991 (fig. 10). Furrow continues to play an important role, and its use was 20 percent over the average for total acreage. Sprinkler use dropped after 1989.

The use of drip was substantial in the Riverside area, and the use of furrow and sprinklers declined steadily between 1987-1991, with furrow more widely used than sprinklers (fig. 11).

As mentioned earlier, farmers make their adoption decisions based, at least in part, on future (expected) increases in yields and future (expected) reductions in water use. This information can be obtained from several sources, including extension specialists and irrigation dealers. In Section 1 of the questionnaire, dealers were asked about expected effects on yield and water use if farmers were to adopt modern irrigation technologies for the reported crops. Specifically, dealers assessed yield and water-use effects of a traditional form of irrigation (furrow) compared with modern irrigation technologies such as sprinkler and drip (table 18).

An overview of table 18 shows consistency with the theory described earlier, namely, dealers expect a decrease in water usage and an increase in yield if adoption of modern technologies occurs. Furthermore, if furrow is compared with drip, water savings and yield increases are greater than when furrow is compared with sprinklers. It should be stressed that these are *expected* effects and not actual observed effects.

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[11]For the geographical analysis, only the first crop reported by dealers was taken into consideration.
[12]This was also the case when we organized the data by crop instead of by area.
[13]Another aspect is that all dealers in this area except one reported grapes as their most important crop, the other crop being lettuce, on which the use of furrow is common and extensive.

Table 18 provides additional insights to dealers' expectations. Two dealers reporting pasture as a significant crop referred to impact of improved irrigation technology on pasture yield. Dealer 11 reported the highest expected reduction in water use if furrow were replaced by sprinklers or drip (44 percent and 95 percent, respectively), but reported no expected increase in yield when furrow is compared with drip, and reported a 50-percent yield increase when furrow is compared with sprinklers. Since the term drip may refer also to a moving line or Low Energy Precise Application (LEPA), we do not discard these data. This finding is also consistent with empirical observations regarding the dynamics of the adoption process; namely, if adoption of low-volume irrigation systems does not increase yields, adoption is less likely to occur. A major shortcoming of comparing drip and furrow for a field crop, such as pasture, is that drip is not practiced on pasture due to soil, biological, and other inherent characteristics of the crop. Pasture is a water-intensive field crop, and use of low-volume irrigation systems is minimal in the State.

Dealers' assessment of pump sales. Ground-water use requires capital outlays for pumps and energy. Because of these capital cost requirements, it is reasonable to correlate pump sales with ground-water use.[14] Dealers were asked about pump sales levels for the 1987-1990 period. An index sales ratio was calculated using 1987 as the base year. This ratio shows the level of sales with respect to the previous year for the 1987-1990 period (fig. 12). The steady increase in pump sales is consistent with the earlier assertion that the number of wells operating in the State has also been increasing over time. This may indicate that, as expected and in response to the drought, farmers rely on ground water to make up for the increasing scarcity of surface water. Information on well drills during this period, obtained from a different source (DWR, 1991b), is presented in figure 15.

According to dealers' assessments, the north is the region where furrow is the most widely used form of irrigation (fig. 7). Traditional forms of irrigation (such as furrow) are not associated with ground-water use. As shown in figure 12, the pump-sales index was lower (on the average) for the north region. If the pump-sales index is assumed to be a good indicator of the extent of ground-water use for the 1987-1990 period, then it follows that the use of low-volume irrigation systems should be lower in the north and indeed, this was the case.

The most common form of energy used for pump operation is electricity. For the 1987-1990 period, over 80 percent of pumps sold by irrigation dealers required electricity for their operation. Pumps using diesel for energy accounted for over 10 percent of total sales, with a small increase during the same period (fig. 13). The number of pumps operated with gas was not significant.

Over 70 percent of the dealers who responded to the survey sell automated irrigation equipment. Using the same criteria as for sales of pumps, an index ratio of sales of automated equipment was calculated for the 1987-1990 period (fig. 14). The upward trend is probably correlated with the upward trend in pump sales, since pumps are often a component of automated irrigation equipment. Data obtained in the survey show that, in general, dealers who sell pumps also sell automated irrigation equipment.

Data obtained from other sources support the data obtained from irrigation dealers. Water irrigation districts were surveyed, and the resulting data show increases in ground-water pumping and a greater reliance on low-volume irrigation systems for irrigation needs. Table 19, taken from Zilberman et al. (1992), shows availability of surface water and ground water for the irrigation districts in the sample. Similar results are provided in table 12 in this study. Ground-water

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[14]Of course, farmers who buy pumps for ground-water use for the first time must be differentiated from those replacing existing pumps.

pumping increased gradually, and reliance on ground water was much more substantial during later stages of the drought.

Data provided by DWR (1991b) document the increased rate of well drilling in California as the drought progressed. For example, the period 1980 to 1986 is characterized by an average annual number of 7,000 wells drilled in the domestic and 1,000 wells drilled in the agricultural sector, and a total of about 10,000 wells drilled per year (including wells drilled by other sectors). Between 1987 and 1990, the annual number of wells drilled increased from 9,000 to 13,000 in the domestic sector, from 600 to 1,600 in the agricultural sector, and from 12,000 to 25,000 in total. Figure 15 depicts the increase in well drilling over the drought period, and the decreased volume of available water in California's main reservoirs.

The increase in ground-water pumping is substantially higher for the central and southern San Joaquin areas than for the northern San Joaquin area. The main reason for the difference is that the northern San Joaquin Valley was affected less by the reduced surface water deliveries than the south and central regions of the Valley. The drought led to the development of institutional incentives for the adoption of modern irrigation technologies, including tier pricing for water and credits provided by districts and the State for purchase of modern irrigation technologies. The total numbers in table 19 are in accordance with the aggregate data obtained from irrigation dealers and represented in figures 13 and 14. The survey of WD's also showed a significant difference in the response to the drought between senior and junior rights holders. This difference in response is revealed by farmers' behavior in terms of pump and automated irrigation equipment purchases. Those farmers who have senior rights are less likely to adopt modern irrigation equipment because their allocation of water has priority over junior rights holders. Thus, sales levels of pumps and automated irrigation equipment are lower for senior rights holders than for junior rights holders.

As the drought progressed and water became more and more scarce, water users from all sectors started using information services to improve their water-related decisions. Such information services included private and public extension irrigation advisors, computerized water scheduling software, and weather data. Available data on subscription to the California Irrigation Management Information Services (CIMIS) during the drought period indicates an increasing rate of subscription, suggesting improvement in irrigation management practices (fig. 16).

Summary of the Surveys' Results and Additional Information

Water Deliveries

Although 1987 was the official start of the drought in California, water deliveries to agriculture below contracted levels did not occur until 1990, due mainly to the storage capacities of reservoirs in various California watersheds. Because the low 1987 rainfall does not show up until the 1988 storage year, the drop in reservoir levels is not manifested until 1988 (fig. 17). [Since fig. 17 represents storage levels of the two largest CVP dams as of December 31 of each year, which would be before the winter rains, the important aspect to note is the change from year to year rather than the actual reservoir level in any single year.]

Although the decline in reservoir levels after 1987 is significant, it was not until 1989 and 1990 that similar declines occurred in CVP diversions (fig. 18) and in district-level deliveries. These figures reflect standard storage behavior in which reservoirs are drawn down during dry years to maintain normal levels of water use; as the drought extends, and reservoirs are not sufficiently recharged (fig. 19), water consumption must either be adjusted by pumping ground water or by transferring water to reflect the emerging scarcity.

The decline in water deliveries by 1990 is evident in table 13. Annual CVP water deliveries to water districts responding to the survey which had junior water rights were over 2 million AF annually from 1987 through 1989, but declined to 1.66 million AF in 1990 and to 1.03 million AF in 1991. These junior water rights holders were the first to experience substantial cutbacks in deliveries and had to adjust accordingly. For example, Westlands Water District, as a CVP contract holder, received its average entitlement of approximately 1.2 million AF in 1987, 1988, and 1989, but only received 0.92 million AF in 1990 and 0.34 million AF in 1991 (table 20). Water districts holding senior rights (such as riparian and appropriative rights) also experienced cutbacks in water deliveries, but nowhere near the degree experienced by the junior water rights holders. The Imperial WD, as a counter example, has appropriative rights to Colorado River water and thus maintained a stable level of approximately 5 million AF throughout the period of the drought.

Declining reservoir levels are also implicit in water deliveries by the State Water Project (SWP). SWP water deliveries hovered at or over 300,000 AF from 1987 through 1990, but declined drastically in 1991 to only 83,000 AF. Kings, Tulare, and Kern counties and southern California all experienced drastic cutbacks of SWP water deliveries in 1991.

Ground-Water Pumping

The declines in reservoir levels and subsequent cutbacks in water deliveries forced water districts and farmers served by the water projects to maintain their own water consumption via increased pumping of ground water. Once cutbacks in water delivery were implemented, the data show that ground-water pumping increased dramatically. Districts responded by pumping additional ground water from district-owned wells while farmers pumped from private wells.

Statewide, 24 percent of all districts pumped additional ground water due to the drought, as seen from the WD's survey (table 10). Well drilling across the State increased three- to four-fold. In the San Joaquin Valley and in southern California, at least 50 percent of the responding districts pumped additional ground water from district-owned wells. Additional ground water totaling 197,000 AF was pumped by 7 districts in the San Joaquin Valley. However, within districts, the response varied considerably. In 1991, some districts showed a dramatic increase in ground-water pumping. (One water district increased annual ground-water pumping from 2,000 AF to 20,000 AF per year and, as a result, is experiencing a declining water table.) In contrast, in one southern district, less ground water was pumped in response to the drought because the district resorted to severe water-delivery rationing, and successfully reduced total water usage by 30 percent from the 1986-1990 average. In the Mountain, Fresno, Kings, and Tulare regions, only 12-25 percent of the responding districts pumped additional ground water, while the Imperial and Kern responding districts pumped no ground water whatsoever.

WD survey responses also reported the degree to which farmers relied on ground water during the drought. According to the surveys, 65 percent of the districts reported that farmers pumped an additional 1.77 million AF of ground water. All of the San Joaquin water districts reported that farmers pumped additional ground water. In the Sacramento, Kings, and Tulare regions, over 80 percent of the regions' districts reported farmers pumping additional water, although a high proportion of districts did not increase ground-water use. Seven districts in each of these two regions pumped 0.6 million AF of additional ground water. In the Fresno region, the absolute amounts of ground water pumped were the largest among the regions, with two districts pumping 100,000 AF of ground water each.

In table 14, we saw that the amount of ground water pumped increased from 292,000 AF in 1987 to 347,000 AF in 1991 for all districts. In Southern California, the number of wells in use doubled and the amount of ground water pumped increased from 1,252 AF to 17,670 AF for three districts. The San Joaquin Valley had the largest number of wells, and ground water pumping in the region increased from 1989 to 1991. In sharp contrast, the number of wells and the amount of ground water pumped in the Riverside region decreased between 1987 and 1991.

Based on a sample of WD's serviced by the CVP, there was an almost 80-percent increase in the volume of ground water pumped between 1989 and 1990, and a 9-percent increase in the number of wells used between 1989 and 1991 (table 22). Interestingly, exchange contractors significantly increased pumping in 1989, 1990, and 1991 without a significant addition of wells. Junior water-rights districts significantly increased pumping in 1989, 1990, and 1991, adding a significant number of wells only in 1991.

Among individual WD's with no district-owned pumps, the Westlands WD increasingly relied on ground-water pumping by its members (table 20). In the Friant Unit, located just to the south of Westlands, cutbacks in water delivery also forced increases in ground-water pumping, as indicated by the measured change in ground-water storage (table 21 and fig. 18). When the Class 2 water (the water delivered by the CVP after all other priority needs are met) was reduced, net ground-water recharges decreased; when significant water delivery cuts occurred, there were net drawdowns of ground water. Although the Friant data predate the first significant cutbacks in 1990, it may be assumed that even more severe drawdowns occurred when Class 1 water was cut to 50 percent of its allocation. Other indirect indicators of increased ground-water pumping occurred in the Central California Irrigation District (CCID) where, over the course of 1991, ground-water levels under two towns encompassed by the district (although not part of the district) experienced declines of 45 and 50 feet while CCID itself experienced an average water level decline of 14 feet.

The index of pumps-sale ratio calculated from the survey of irrigation equipment dealers data (1986 being 100) indicates an increase in pump sales over the period of drought. The areas most affected by the drought show unusually high pump-sales ratios (column VIII in table 17).

Among the highest sales ratios are those of Riverside, Sonoma, and Tulare. Dealers in both Riverside and Tulare serve farmers who faced substantial cutbacks in their surface water deliveries. Sonoma farmers who relied mainly on ground water were compelled by the drought to dig new and deeper wells.

Adoption of Modern Irrigation Technologies

With cutbacks in water deliveries, many growers have modified management practices and crop and technology choices to address the increasing scarcity of water. With respect to technology choice, two concurrent approaches are being used. The first involves more efficient use of the grower's existing technology, such as irrigating alternate furrows and using gated pipes or siphon tubes. The second involves adoption of new irrigation technologies where they are most cost-effective. The first approach is generally used on lower-value crops such as cotton, whereas the second approach is used on higher-value crops such as vegetables.

An example is the Broadview water district where farmers are using sprinklers for pre-irrigation of cotton to achieve uniform water application prior to planting. Afterward, alternate furrow irrigation is used. [It should be noted that conditions may preclude full adoption of new irrigation technologies—for example, sprinkler or drip irrigation could not be used for later irrigations in Broadview because of the danger of cracking soils.] In the case of a high-value crop such as processing tomatoes, Broadview growers generally utilize sprinklers for the first two irrigation events. In contrast, growers in water-rights exchange districts such as CCID have generally been less inclined to adopt new production methods or technologies, probably due to the nature of their priority rights over available water. An exception to this disinclination is their increased willingness to install tailwater-return systems and sprinkler systems for high-value crops under a conservation loan program run by the district. At a broader level, the survey of water districts indicates that water districts are offering assistance to growers to change their irrigation methods. Table 10 shows that 72 percent of water districts in the Sacramento Valley offered such assistance. One water district in the Sacramento Valley offers a price rebate to participators in water conservation programs.

Over 35 percent of farmers in all the responding districts installed new sprinklers on 159,000 acres of land, while 33 percent installed new drip irrigation on 31,000 acres. Farmers in the Central Coast were more likely to adopt sprinklers and drip than farmers in other regions. In the San Joaquin Valley, Sacramento, Kings and Tulare, and Imperial regions, farmers were more likely to adopt sprinklers than drip irrigation systems. The adoption of sprinkler irrigation was significant in Kings and Tulare where farmers in seven districts adopted new sprinkler irrigation on over 42,000 acres. A substantial increase in new drip irrigation occurred in southern California where farmers in two districts installed drip on 19,000 acres of land. While analyzing the shares of different irrigation technologies in each region, one observes a tendency toward a reduction in the share of border and furrow irrigation and an increase in the share of sprinklers and drip irrigation. For example, in the Kings and Tulare region, the percentage of acreage under border irrigation declined from 31 percent in 1987 to 27 percent in 1991, while furrow irrigation declined from 36 to 26 percent over the same period. Microsprinkler shares in this region increased dramatically from 33 to 86 percent, while the share of drip increased from 9 percent to 25 percent.

In the second part of the irrigation dealers' questionnaire, dealers were asked to assess their estimates of the extent of use of different types of irrigation equipment for the 1987-1991 period and for those crops on which the irrigation equipment they sell is used. For the purpose of this study, crops were divided in four main groups: (a) citrus, (b) fruits and nuts, (c) grapes, and (d) vegetables. Dealers were asked to assess the use of different irrigation systems as a percentage of total acreage. Use of drip increased dramatically over the 1987-1991 period (figs. 4 and 6). Nevertheless, use of furrow remained above 30 percent of total acreage at the end of the period. Use of furrow continued to be the main form of irrigation on vegetables although the negligible use of drip in 1987 rose to almost 10 percent for 1990. Use of sprinkler on vegetables rose significantly; vegetables was the only crop group for which an increase in sprinkler use was observed.

A drip-use ratio (table 16, columns X to XII) was calculated for selected crops and for selected dealers, using 1987 as a base year. The high ratio values for fruits and nuts and citrus indicates a sharp increase in the use of low-volume and pressurized irrigation technologies during the 1987-1990 period.

Land Use Choices

It was hypothesized that the drought would induce a shift in cropping patterns from highly water-intensive, low-value crops toward high-value crops—possibly requiring less applied water per acre. This would reflect a movement towards increasing the return from each unit of water. Thus, one would expect to see a shift in cropping patterns away from the production of low-value crops such as alfalfa, hay, cotton, and rice, which require 4 to 7 AF of water per acre, toward drought-tolerant small grains or high-value crops such as fruits and vegetables which also require less water per acre than the field crops.

The survey results indicate that the hypothesis generally fits the facts. In the central coast, the main crops were tomatoes, rice, corn, and fruits and nuts. At least one district fallowed pasture land. In the Sacramento region, the main crops were rice, fruits and nuts, grain, alfalfa, wheat, and sugar beets. The crops with reductions in acreage include rice, sugar beets, and alfalfa; crops with increases in acres include grains, orchards, and vegetables. Roughly 48,000 acres were affected within seven districts; two districts resorted to fallowing land. The San Joaquin Valley experienced a reduction in cotton, corn, alfalfa, and grain and an increase in tomatoes, safflower, and sugar beets. Switching of crops occurred on over 2,000 acres in one district, and two districts reported fallowing land. In the Fresno region, one district switched 75 acres from sugar beets, which requires 5 AF of water per acre, to cotton, which requires 2.5 to 3.5 AF of water per acre.

In the Kings and Tulare region, cotton and alfalfa were substituted by tomatoes, other vegetables, and fallowed land. At least 45,800 acres in cotton and alfalfa were reduced in this region. Due to the drought, farmers in one water district in this region set aside 25 percent of agricultural land, amounting to 130,000 acres. In the Kern region, there was a significant fallowing of grain and lettuce land, totaling 14,830 acres. One water district leased 1,000 acres from farmers to fallow. In the Mountain region, at least two districts reported a shift from alfalfa to grain on over 500 acres. In the Imperial region, over 150 acres under alfalfa and hay were shifted to fruits. In the San Diego region, one district reported fallowing land that had been planted in vegetables.

Water Management Practices

In addition to the technology changes mentioned above, other technology choices are available to reduce water use without necessarily changing crops. In areas where water has been cut back substantially and where changes in technology may not be feasible because of uncertainty with respect to future water deliveries, some growers are opting for deficit irrigation, an extreme measure but feasible for short periods of time. In less extreme circumstances, a common choice for reducing water use involves the combination of shortening furrows from 1/2 to 1/4 mile and installing tailwater return systems. The shortened furrows result in a more even application of water and, therefore, less waste (since a longer furrow must have more water applied per unit distance to ensure minimum moisture of soil at the end of the furrow). The tailwater return systems allow reuse of irrigation water through mixing with fresh water. In many Central Valley water districts, furrow shortening and tailwater-return systems were consistently the first responses to water scarcity since they did not entail drastic technology changes.

The survey responses (table 11) show that farmers are indeed shortening furrow length and improving existing furrow irrigation. Thirty-six percent of all responding districts reported that farmers are improving existing furrow irrigation. In the Imperial, Fresno, central coast, Sacramento, and San Joaquin regions, at least 50 percent of the responding districts reported that farmers were undertaking such improvements. Furrows were shortened on over 13,840 acres throughout the State, with 6,840 acres involved in the San Joaquin region, 5,500 acres in Kings and Tulare Counties, and 1,500 acres in the Sacramento Valley. In one water district, farmers cut their furrow length in half and laser-leveled their fields; these farmers are also stretching the interval between irrigation from 10 days to 2 weeks.

Farmers also lined ditches to increase the efficiency of water delivery to existing crops. In the San Joaquin Valley, farmers lined 35 miles of ditches; 6 miles of ditches were lined in the Imperial Valley. In addition, 10 of the responding districts reported that farmers laser-leveled fields, irrigated during cooler hours, and monitored water use carefully. Seven districts reported that farmers stressed the crop by using less water, spacing out irrigation over longer intervals, and irrigating for shorter duration. Farmers in four districts used tailwater returns, plugged leaks, and installed gated pipes or siphon pipes.

WD's also helped farmers improve irrigation efficiency for existing cropping patterns by offering to assist growers in adopting irrigation scheduling. Forty-five percent of all responding districts offered this assistance to growers (table 10). Water districts tried to improve the efficiency of their deliveries by lining canals and installing pressurized pipelines. Approximately 114 miles of district canals were lined across the State, with 100 miles lined in the Imperial Valley, 6 miles lined in the San Joaquin Valley, 4 miles lined in the Riverside region, 3 miles lined in Kings and Tulare, and 1 mile lined in the Fresno region. Pressurized pipelines were installed in 12 percent of all districts responding, with the greatest number of districts in the Mountain region.

The upward trend in sales of automated irrigation equipment, is probably correlated with the upward trend in sales of pumps, since the latter are sometimes a specific component of automated irrigation equipment. Data obtained from the survey of irrigation equipment dealers indicate that dealers who sold pumps also sold automated irrigation equipment. Consistent with the data obtained for pump sales, the data show high automated sales ratios for those areas most affected by the drought. Riverside, Tulare, and Sonoma experienced the highest increase in sales of automated irrigation equipment (table 16, column IX).

Institutional Changes at the Water District Level

The principal institutional changes that occurred due to the drought are tiered water pricing and exchanges of water among growers in the same WD. Of the two, tiered water pricing is more significant since it requires administrative initiative on the part of the water districts. Tiered water pricing is essentially inverse block pricing in which an initial volume of water, based on some historical level of use, is sold at a given price and water purchased above and beyond the historical level is sold at a significantly higher price. Obviously, the type of water rights held by a district influences the price levels. In the Broadview water district, the two tier prices are $16/AF and $40/AF, and the tier volumes are set by crop. This setup is possible only because the district has field-specific accounting of water. The difference in the tier prices reflects the cost to the district of collecting and discharging the drain water resulting from excess irrigation. The first-tier volume was set at 90 percent of the average water applied during the 1986-1988 period. With a year of experience, growers successfully cut back water usage (table 23).

Tiered pricing in an exchange district such as CCID is somewhat different. Because of the district's junior water rights, the program was not implemented due to severe water shortage. Rather, the program was initiated to demonstrate improved beneficial use of water and to protect against efforts to remove their water rights. In the CCID, there was no crop-specific tier, simply a one-price tier of $5.50/AF for the first 3 AF and $16.50/AF for all additional water. The price difference covers the cost of ground-water pumping. Growers were also allowed to sell back any of their unused tier-1 water to the district. The district management was generally aware of water use by growers and tried to convince them of the importance of conservation, but there was no desire nor mandate for the district to undertake formal field monitoring to make tier pricing more effective.

The survey asked water districts if they changed their water-pricing practices in response to the drought. Of all districts responding, 51 percent indicated that they had adjusted their pricing schedules. Many districts instituted some form of tier pricing based on allowable allocations in relation to a base year. For example, one water district in the Mountain region charges $18/AF for 50 percent of the 1989 allocation and $29/AF for any water delivered above this level. Some districts in the San Diego region have four tiers of increasing prices, corresponding to 85 percent of base, 86-90 percent of base, 91-95 percent of base, and above 96 percent of base. Overall, at least 15 of the districts responding have instituted some form of surcharges based on level of use or tier pricing.

Table 10 shows what percentage of districts in each region changed their pricing practices in response to the drought. Many districts reported price increases; some prices even quadrupled. A water district in the San Diego region reported changing prices three times in 1991 alone. In the Sacramento Valley region, four districts reported price increases ranging from 16 percent to 100 percent because of the drought. Prices increased four times, ultimately to $200/AF, in a water district that had to obtain emergency water from the State's Water Bank, whose rationale and operational principles are explained in the next section.

The survey of water districts shows nine districts either sold water to or purchased water from the Water Bank in response to the drought. Water districts in the Sacramento Valley, San Joaquin Valley, mountain region, and Fresno, Kern, Kings, and Tulare Counties sold water to the State Water Bank. Districts in Kern and Kings and Tulare Counties reported purchasing water from the State Water Bank (U.S. Army Corp of Engineers, 1993).

Water districts have also been modifying water allocation schedules to growers in response to drought. Water allocation schedules have been changed in 52 percent of all districts. Eighty-six, 69, 61, 57, and 50 percent of districts in the San Diego region, San Joaquin Valley, Sacramento Valley, southern California, and in the mountain and Fresno areas, respectively, reported changes. Many districts instituted some form of mandatory or voluntary cutbacks in allocations. For example, in a water district in the Kings and Tulare region, water allocations to growers were cut from 2.1 AF per acre to 1 AF per acre in 1990; the Westlands Water District instituted rationing in response to the 1991 drought. A central coast water district instituted mandatory water rationing in April 1991, but made rationing voluntary the following July.

Fifty-four percent of all responding districts reported significant increases in the number of water exchanges among growers during the last few years; 73 percent of them believe the increase is related to the drought. These exchanges especially increased in the Kings and Tulare, Fresno, Sacramento, and San Joaquin regions (table 9). These exchanges may have taken place because farmers switching to less water-consuming crops may have had water to share with neighboring farmers who found themselves short. In one water district, growers who installed drip irrigation used ground water, and consequently may transfer their surface-water entitlement to others once a year with the district's approval. Most of these water exchanges took place toward the end of the season when farmers no longer needed their water and wanted to use the entitlement before supplies are shuts off.

State- and Federal-Level Institutional Changes

Several institutional changes at the Federal, State, and municipal levels are worth mentioning. The major institutional changes are the creation of the California Drought Water Bank, the enactment of Federal legislation (Bradley-Miller Law 102-575, Title 34 Central Valley Project Improvement Act, 1992) requiring a minimum of 800,000 acre-feet of agricultural water to be set aside for in-stream use, and the inclusion, by law, of conservation measures into water development projects by the State of California (Assembly Bill 3616; Added Stats to Assembly Bill 1160). The Bills require the California Department of Water Resources (DWR) to take all possible actions to achieve water conservation, as defined in the Bills.

The other institutional change of note is the creation of the State Water Bank, which provided a means for transferring water from districts with water surpluses to those with shortfalls. In 1991, the seller price was $125/AF and the buyer price was $175/AF at the San-Joaquin Sacramento Delta; 820,805 AF were purchased and 435,000 AF were sold. Metropolitan water districts purchased 370,000 AF and 65,000 AF were purchased by agriculture. The remainder (385,805 AF unsold) was used for environmental purposes, such as amendment of the water flow in the rivers for fish and wildlife. The massive sale of water to the Bank resulted in the fallowing of 166,000 acres. In 1992, the Bank purchased 177,595 acre-feet, allowing transfer of water between water-rights holders.

In response and in continuation to Assembly Bill 3616 (Efficient Water Management Practices For Agricultural Water Suppliers) and the stats to Assembly Bill 1160 (Agricultural Water Conservation and Management Act of 1992), a Memorandum of Understanding regarding urban water conservation in California (DWR, 1991c) was signed in late 1991. In addition, a Memorandum of Understanding regarding agricultural water management for water suppliers in California (DWR, 1993) was signed in 1994. These actions, both legislative and voluntary, reflect behavioral change on the part of all water-related agencies and individual users.

Voluntary and legal institutional responses during the drought period by various communities and State agencies were compiled by the U.S. Army Corps of Engineers (1993). In 1987, no drought-related events were recorded in California. In 1988, 17 actions in various municipalities, counties, and State agencies were recorded. In 1989, 8 events were recorded. In 1990, 36 events were recorded. In 1991, 72 events were recorded, and in the last year of drought, 16 events were recorded.

Conclusions

Water use patterns and water institutions have undergone major modifications as a result of the California drought of 1987-1992. Deliveries of water to irrigation districts declined at an increasing rate as the drought progressed. With reduced deliveries, water allocation schedules to individual farmers changed, and water fees began to increase.

Junior water-rights holders were the first affected by the drought. Federal and State project water allocations fell very rapidly compared with non-project water (considered senior-rights water). In addition, water districts began to upgrade canals and replace canals with pipelines; many districts began using State loan programs, both those available before the drought that had not fully been utilized, and new programs for investment in upgrading irrigation systems.

One of the major consequences of the continuous drought was a substantial increase in the use of ground water. New wells were drilled and existing wells were upgraded, resulting in an overall increase in the share of ground water in irrigation water supply.

Changes in irrigation technologies were observed during the drought period. Farmers chose to adopt modern (water-saving and yield-increasing) irrigation technologies for higher value and perennial crops. Regional differences were observed as well, although the general trend was similar across regions. Regions which were more severely affected by water cuts were more likely to adopt modern irrigation technologies earlier and with higher rates of adoption over time.

In terms of land use choices, farmers affected by drought put greater emphasis on high-value crops than on the lower value field crops. Over time, more low-value field cropland was fallowed. This was most apparent in regions, such the central and southern San Joaquin Valley, that were severely affected by the drought.

The study indicated an increase in the use of improved management of water scheduling, automation, information-based equipment, and state weather information services during the drought years.

Introduction of new water institutions for the allocation of water, such as a water market (the Drought Water Bank), Federal and State legislation to ensure protection of environmental amenities, water conservation agreements in the urban and agricultural sectors, and changes in pricing of water for irrigation (and residential use) were observed as the drought progressed. Among other incentive mechanisms introduced by water districts as the drought progressed are versions of tiered water pricing and subsidized loan programs for individual farmers to adopt modern irrigation technologies.

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Tables

Table 1--Precipitation, runoff, and reservoir storage in California during the drought

Year	1987	1988	1989	1990	1991	1992
			Percent of average			
Precipitation	61	82	86	69	76	89
Runoff	48	48	70	45	43	43
Reservoir storage	84	66	74	60	61	56

Source: DWR (1991a, 1995).

Table 2--Water deliveries by the State Water Project (SWP) and the Central Valley Project (CVP) during the drought

Project	1987	1988	1989	1990	1991	1992
			1,000 acre-feet/year			
SWP	3462	3701	4158	3900	1638	1736
CVP	6854	6598	5353	5272	4230	4000

Source: U.S. Army Corp of Engineers (1993) for SWP in 1987-1992 and for CVP in 1987-1991; and DWR, 1994, for CVP in 1992.

Table 3--Production regions and counties of California

North Coast	Central Coast	Sacramento Valley	San Joaquin Valley	Mountain	Southern California	Miscellaneous[1]
			Counties			
Del Norte	Sonoma	Tehama	San Joaquin	Siskiyou	Santa Barbara	Fresno
Humboldt	Lake	Glenn	Stanislaus	Modoc	Ventura	Kings
Mendocino	Napa	Butte	Merced	Trinity	Los Angeles	Tulare
	Marin	Colusa	Madera	Shasta	Orange	Kern
	Contra Costa	Sutter		Lassen	San Bernardino	Riverside
	Alameda	Yuba		Plumas		Imperial
	San Mateo	Yolo		Sierra		San Diego
	Santa Clara	Solano		Nevada		
	Santa Cruz	Sacramento		Placer		
	San Benito			El Dorado		
	Monterey			Amador		
	San Luis Obispo			Calaveras		
				Tuolumne		
				Mariposa		
				Mono		
				Inyo		

Note: San Francisco County is in the Central Coast Region and Alpine County is in the Mountain Region; neither county is included in the Census of Agriculture, therefore neither is included here.

[1]These counties are big so they are used as separate production regions in the analysis.

Table 4--Distribution of water districts by production region in California

Production region	Number of water districts
North Coast	0
Central Coast	5
Sacramento Valley	19
San Joaquin Valley	13
Fresno	8
Kings and Tulare	17
Kern	8
Mountain	9
Southern California	15
Riverside	6
Imperial	2
San Diego	41
Total	116

Table 5--Area and number of owners and operators served in each production region

Region	Service area		Number of owners	Number of operators	Area with tile drainage systems
	Gross	Irrigable			
	Acres				*Acres*
Central coast	1,102,360	248,663	1,262	1,247	35,004
Sacramento Valley	666,765	548,304	4,792	2,891	5,000
San Joaquin Valley	928,195	778,570	20,698	15,521	35,700
Fresno	861,284	820,587	4,095	6,746	9,500
Kings and Tulare	2,078,284	1,542,619	33,977	26,608	50,000
Kern	523,000	431,950	3,388	863	6,480
Mountain	344,771	120,656	2,890	3,128	0
Southern California	432,807	171,249	1,650	2,041	9,000
Riverside	1,209,807	638,195	655	4,051	102,020
Imperial	1,078,637	503,499	6,836	5,550	200
San Diego	244,657	119,481	3,741	2,279	0
Total	9,461,567	5,923,773	8,3984	70,925	252,904

Table 6--Infrastructure of water delivery systems and storage capacities by Water District

Region	Number of districts reporting	Canals Unlined	Canals Lined	Pipelines Regular	Pipelines Pressurized	District storage
			Miles			*Acre feet*
Central coast	5	71	125	130	22	67,000
Sacramento Valley	19	1,689	56	685	30	446,609
San Joaquin Valley	13	1,067	520	2,182	0	981,132
Fresno	8	559	62	1,292	0	50,010
Kings and Tulare	17	4,840	470	545	0	22,208
Kern	8	408	130	354	0	159,180
Mountain	9	708	30	132	1,157	21,210
Southern California	15	0	11	1,206	488	150,850
Riverside	6	263	127	1,009	0	0
Imperial	2	743	984	11	N/A	1,910
San Diego	14	0	4	3,052	399	4,409,928
Total	116	10348	2519	10598	2056	6,311,037

N/A=not available.

Table 7--Types of water-related services provided, by production region

	All districts	Central coast	Sacra-mento	Mountain	San Joaquin	Fresno	Kings & Tulare	Kern	Southern California	Riverside	Imperial	San Diego
	Percent											
Surface water, agriculture	93	80	89	100	100	100	94	88	87	83	100	100
Ground water, agriculture	31	20	26	11	38	25	18	13	67	50	0	36
Surface water, urban	43	60	16	67	31	25	6	25	80	50	50	93
Ground water, urban	23	20	11	11	15	13	6	13	60	67	0	36
Ground water, recharge	25	40	0	0	31	25	47	38	40	67	0	0
Drainage control	24	60	42	11	54	25	12	0	7	33	100	0
Flood control	17	40	21	11	31	13	24	13	7	33	0	0
Electricity	23	20	21	11	46	25	24	13	27	17	50	14
Parks	6	0	5	0	8	13	0	13	13	0	0	7
Tail water return	1	0	0	0	0	13	0	0	0	0	0	0
Sewage and water reclamation	6	0	0	0	0	0	0	0	27	17	0	14
Meters monitoring	1	20	0	0	0	0	0	0	0	0	0	0
Canal operations	2	0	5	0	0	0	6	0	0	0	0	0
Conservation program	2	0	0	0	0	0	6	0	7	0	0	0

Table 8--Method of water distribution

	On demand	By arrangement	By rotation	Lead time turn on	Lead time turn off
	Percentages			*Average hours*	
All districts	79	7	25	25	14
Central coast	75	25	25	19	17
Sacramento	88	12	6	29	17
Mountain	67	0	33	7	2
San Joaquin	67	9	27	28	11
Fresno	71	0	43	40	13
Kings & Tulare	88	13	25	34	23
Kern	57	0	50	38	28
Southern California	93	0	13	6	4
Riverside	40	0	60	24	24
Imperial	100	50	0	60	5
San Diego	92	0	17	0	12

Table 9--Institutional arrangements for exchange of water

	All districts	Central coast	Sacra-mento	Moun-tain	San Joaquin	Fresno	Kings & Tulare	Kern	Southern California	Riverside	Imperial	San Diego
	Percent of districts in the region (values may exceed 100)											
Allowed to exchange	49	75	55	20	50	83	64	71	17	0	100	0
Need approval	87	100	90	50	100	100	89	83	0	N/A	100	80
Inquire about payment	15	67	20	0	0	0	11	0	0	N/A	50	33
Exchange regularly	49	33	54	33	60	67	80	50	20	N/A	0	0
Percent of water exchanged	10	1	16	33	10	5	7	8	10	N/A	N/A	N/A
Increase in exchanges	54	0	75	0	50	83	78	40	0	N/A	0	0
Due to drought	73	0	100	N/A	60	50	100	50	N/A	N/A	N/A	N/A

N/A=not available.

Table 10--Responses by districts to the drought

	All districts	Central coast	Sacra-mento	Moun-tain	San Joaquin	Fresno	Kings & Tulare	Kern	Southern California	Riverside	Imperial	San Diego
	Percent of districts[1]											
Pumped additional ground water (AF)	24 (274,165)[1]	20 (2,000)	19 (20,000)	14 (3,000)	54 (197,060)	25 (5,255)	12 (25,000)	0 (N/A)	53 (20,350)	17 (1,500)	0 (N/A)	7 (N/A)
Lined canals (miles)	11 (113.5)	N/A	N/A	14	23 (6)	13 (1)	19 (2.5)	0 (N/A)	0 (N/A)	33 (4)	100 (100)	0 (NA)
Installed pressurized pipes	12	20	6	25	15	13	7	0	14	17	0	14
Changed water allocation	52	40	61	50	69	50	25	29	57	33	0	86
Changed water pricing	51	0	44	38	46	25	53	57	47	50	50	100
Offered help to growers in irriga-tion scheduling.	45	60	61	11	38	50	35	71	29	80	100	36
Offered help to growers for changes in irriga-tion practices	38	40	72	33	31	13	25	14	43	33	100	36
Other	49	75	59	67	33	63	18	33	60	50	0	62

[1]In parenthesis are acre feet or miles.
N/A=not available.

Table 11--Farmers' responses to drought

	All districts	Central coast	Sacra-mento	Moun-tain	San Joaquin	Fresno	Kings & Tulare	Kern	Southern California	Riverside	Imperial	San Diego
						Percent[1]						
Pump additional ground water (1,000 AF)	65 (1,774.6)[1]	50 (N/A)	83 (59.3)	33 (NA)	100 (76.6)	63 (675.3)	88 (623.1)	57 (281.0)	67 (59.3)	50 (NA)	0 (NA)	29 (NA)
Switch crops (100 acres)	33 (1,589.1)	33 (NA)	59 (480.6)	25 (5.0)	18 (20.0)	25 (150.8)	47 (783.0)	50 (148.3)	17 (NA)	0 (NA)	50 (6.0)	0 (NA)
Line ditches (miles)	6 (41.0)	33 (NA)	7 (NA)	0 (NA)	8 (35.0)	13 (NA)	6 (NA)	0 (NA)	0 (NA)	0 (NA)	50 (NA	0 (NA)
Shorten furrow (100 acres)	25 (138.4)	67 (NA)	31 (15.0)	13 (NA)	50 (68.4)	50 (NA)	25 (55.0)	29 (NA)	0 (NA)	0 (NA)	50 (NA)	0 (NA)
Improve furrow	36	67	50	11	50	75	35	29	25	17	100	0
Install new sprink-lers (100 acres)	36 (1,590.5)	67 (0.7)	29 (31.0)	38 (NA)	50 (67.4)	38 (1,020.0)	47 (427.9)	14 (NA)	15 (2.0)	20 (2.5)	50 (35.0)	42 (4.0)
Install new drip (100 acres)	33 (310.9)	67 (19.3)	24 (0.5)	44 (NA)	25 (28.5)	50 (152.0)	29 (16.6)	13 (NA)	25 (190.0)	33 (NA)	0 (NA)	64 (4.0)
Other	42	50	53	22	50	71	50	33	8	33	0	64

[1]In parenthesis are acres, acre feet, or miles.
N/A=not available.

Table 12--Irrigated and fallowed acreage, by production region

	1987		1988		1989		1990		1991	
	Irrigated	Fallowed	Irrigated	Fallowed	Irrigated	Fallowed	Irrigated	Fallowed	Irrigated	Fallowed
	1,000 acres									
All districts	2,607.2 (60)[1]	251.9 (45)	2,704.0 (59)	257.9 (45)	2,706.9 (59)	269.1 (45)	2,741.0 (62)	251.7 (47)	2,374.1 (60)	391.4 (47)
Central coast	21.8 (2)	0.2 (1)	23.6 (2)	0.3 (1)	21.2 (2)	0.6 (1)	22.4 (3)	1.0 (1)	22.4 (3)	1.5 (1)
Sacramento Valley	361.4 (13)	92.0 (12)	365.7 (12)	89.2 (11)	380.8 (12)	75.5 (11)	379.8 (12)	83.0 (11)	323.3 (12)	137.2 (12)
Mountain	28.2 (5)	0 (2)	27.7 (5)	0 (2)	28.0 (5)	0 (2)	26.9 (5)	1.6 (3)	24.7 (6)	2.3 (3)
San Joaquin Valley	529.6 (8)	24.7 (6)	511.0 (8)	27.7 (6)	515.4 (8)	26.8 (6)	530.7 (8)	21.0 (7)	546.0 (9)	19.8 (7)
Fresno	717.8 (7)	67.4 (7)	739.5 (7)	46.2 (7)	721.8 (7)	65.0 (7)	733.8 (7)	53.3 (7)	678.6 (7)	108.7 (7)
Kings and Tulare	186.2 (10)	3.3 (9)	172.9 (10)	5.2 (9)	179.0 (10)	5.0 (9)	174.0 (10)	7.6 (9)	94.4 (9)	14.8 (9)
Kern	151.4 (4)	30.9 (4)	249.9 (5)	61.3 (5)	241.7 (5)	70.1 (5)	248.4 (5)	62.0 (5)	67.1 (4)	84.9 (4)
Southern California	6.6 (2)	N/A (0)	6.5 (2)	N/A (0)	7.1 (2)	N/A (0)	7.1 (2)	N/A (0)	0.6 (1)	N/A (0)
Riverside	105.0 (2)	0 (1)	105.0 (2)	0 (1)	105.0 (2)	0 (1)	105.0 (2)	0 (1)	105.0 (2)	0 (1)
Imperial	465.4 (2)	33.4 (1)	470.2 (2)	28.1 (1)	475.0 (2)	25.3 (1)	480.6 (2)	19.7 (1)	481.8 (2)	19.7 (1)
San Diego	33.9 (5)	0 (2)	32.0 (4)	0 (2)	32.0 (4)	0 (2)	32.2 (6)	2.5 (2)	30.2 (5)	2.5 (2)

[1]Numbers in parentheses are numbers of districts responding.
NA=Not available.

Table 13--Water deliveries by source, by production region

		1987	1988	1989	1990	1991
				Acre feet[2]		
All districts	CVP[1]	2,084,274 (49)[2]	2,067,786 (49)	2,132,563 (49)	1,664,500 (49)	1,032,418 (49)
	CVP Exchange	570,910 (28)	576,490 (29)	557,010 (29)	543,060 (29)	444,529 (29)
	SWP[3]	313,160 (33)	320,972 (33)	473,919 (33)	393,002 (34)	83,567 (34)
	Riparian	114,109 (27)	104,669 (27)	139,422 (28)	98,668 (28)	148,150 (28)
	Appropriative A[4]	5,019,207 (40)	4,702,058 (40)	5,301,460 (40)	5,084,864 (40)	4,876,070 (38)
	Appropriative B[5]	2,672,010 (27)	2,891,018 (27)	2,948,408 (27)	2,982,735 (27)	2,974,957 (26)
	Other	174,478 (23)	32,045 (22)	40,515 (23)	71,477 (24)	121,070 (25)
Central coast	CVP	124,037 (2)	142,133 (2)	139,203 (2)	145,082 (2)	108,450 (2)
	CVP Exchange	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
	SWP	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
	Riparian	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
	Appropriative A	68,769 (3)	76,291 (3)	71,154 (3)	73,829 (3)	64,000 (3)
	Appropriative B	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
	Other	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
Sacramento Valley	CVP	380,153 (13)	363,314 (13)	385,790 (13)	305,808 (13)	250,792 (13)
	CVP Exchange	0 (7)	0 (7)	0 (7)	0 (7)	0 (7)
	SWP	0 (7)	0 (7)	0 (7)	0 (7)	0 (7)
	Riparian	0 (5)	0 (5)	0 (5)	0 (5)	0 (5)
	Appropriative A	1,464,926 (9)	1,368,775 (9)	1,493,667 (9)	1,411,244 (9)	1,209,288 (8)
	Appropriative B	0 (6)	0 (6)	0 (6)	0 (6)	0 (6)
	Other	151,000 (7)	0 (6)	0 (6)	0 (6)	0 (6)
Mountain	CVP	18,693 (6)	16,719 (6)	18,263 (6)	13,358 (6)	13,500 (6)
	CVP Exchange	0 (4)	0 (4)	0 (4)	0 (4)	0 (4)
	SWP	0 (4)	0 (4)	0 (4)	0 (4)	0 (4)
	Riparian	33,000 (4)	33,000 (4)	33,000 (4)	33,000 (4)	33,000 (4)
	Appropriative A	172,940 (5)	183,086 (4)	181,867 (4)	178,183 (5)	118,800 (4)
	Appropriative B	0 (4)	0 (4)	0 (4)	0 (4)	0 (4)
	Other	9,916 (3)	8,874 (3)	12,385 (3)	10,743 (3)	9,326 (3)
San Joaquin Valley	CVP	199,509 (6)	187,203 (6)	205,873 (6)	133,823 (6)	165,900 (6)
	CVP Exchange	532,400 (3)	536,810 (4)	536,810 (4)	522,860 (4)	428,829 (4)
	SWP	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)
	Riparian	24,125 (3)	30,703 (3)	27,792 (3)	40,445 (3)	34,000 (3)
	Appropriative A	445,976 (3)	253,499 (3)	526,848 (3)	456,535 (3)	369,895 (3)
	Appropriative B	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)
	Other	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)
Fresno	CVP	1,273,229 (5)	1,277,599 (5)	1,284,219 (5)	993,690 (5)	395,225 (5)
	CVP Exchange	20,200 (2)	20,200 (2)	20,200 (2)	20,200 (2)	15,700 (2)
	SWP	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)
	Riparian	9,700 (3)	9,700 (3)	9,700 (3)	9,700 (3)	7,600 (3)
	Appropriative A	221,810 (4)	90,382 (4)	144,222 (4)	82,752 (4)	141,300 (4)
	Appropriative B	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)
	Other	0 (2)	0 (2)	0 (2)	0 (2)	0 (2)

Cont.

Table 13-- Water deliveries by source, by production region (continued)

		1987	1988	1989	1990	1991
				Acre feet[2]		
Kings and Tulare	CVP	81,465 (7)	72,400 (7)	90,475 (7)	65,110 (7)	91,700 (7)
	CVP Exchange	18,310 (1)	19,480 (1)	0 (1)	0 (1)	0 (1)
	SWP	50,738 (2)	51,760 (2)	55,939 (2)	38,157 (2)	0 (2)
	Riparian	284 (1)	266 (1)	162 (1)	523 (1)	0 (1)
	Appropriative A	132,523 (3)	66,593 (3)	112,666 (3)	58,468 (3)	126,800 (3)
	Appropriative B	(0)	(0)	(0)	(0)	(0)
	Other	(0)	(0)	(0)	(0)	15,732 (1)
Kern	CVP	(0)	(0)	(0)	(0)	(0)
	CVP Exchange	(0)	(0)	(0)	(0)	(0)
	SWP	184,941 (4)	178,465 (4)	285,711 (4)	244,291 (5)	2,500 (5)
	Riparian	47,000 (1)	31,000 (1)	68,000 (1)	15,000 (1)	72,000 (1)
	Appropriative A	(0)	(0)	(0)	(0)	(0)
	Appropriative B	(0)	(0)	(0)	(0)	(0)
	Other	(0)	(0)	(0)	37,000 (2)	73,000 (2)
Southern California	CVP	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)
	CVP Exchange	0 (3)	0 (3)	0 (3)	0 (3)	0 (3)
	SWP	21,599 (5)	20,460 (5)	25,188 (5)	24,987 (5)	9,737 (5)
	Riparian	0 (2)	0 (2)	768 (3)	0 (3)	1,550 (3)
	Appropriative A	1,787 (3)	1,599 (3)	1,801 (3)	1,779 (3)	31,257 (3)
	Appropriative B	330 (3)	698 (3)	634 (3)	891 (3)	310 (3)
	Other	0 (2)	0 (2)	1,080 (3)	1,145 (3)	0 (3)
Riverside	CVP	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
	CVP Exchange	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
	SWP	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
	Riparian	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
	Appropriative A	34,955 (2)	23,699 (2)	28,567 (2)	33,727 (2)	24,847 (2)
	Appropriative B	4,790 (2)	5,267 (2)	5,345 (2)	7,197 (2)	0 (1)
	Other	7,564 (1)	17,755 (1)	22,895 (1)	21,989 (1)	21,012 (1)
Imperial	CVP	(0)	(0)	(0)	(0)	(0)
	CVP Exchange	(0)	(0)	(0)	(0)	(0)
	SWP	(0)	(0)	(0)	(0)	(0)
	Riparian	(0)	(0)	(0)	(0)	(0)
	Appropriative A	2,457,444 (2)	2,628,626 (2)	2,719,656 (2)	2,773,311 (2)	2,773,912 (2)
	Appropriative B	2,666,891 (1)	2,885,053 (1)	2,942,429 (1)	2,974,647 (1)	2,974,647 (1)
	Other	(0)	(0)	(0)	(0)	(0)
San Diego	CVP	7,188 (6)	8,418 (6)	8,740 (6)	7,630 (6)	6,851 (6)
	CVP Exchange	0 (6)	0 (6)	0 (6)	0 (6)	0 (6)
	SWP	55,882 (5)	70,287 (5)	71,081 (5)	85,567 (5)	71,330 (5)
	Riparian	0 (6)	0 (6)	0 (6)	0 (6)	0 (6)
	Appropriative A	18,077 (6)	9,508 (6)	21,012 (6)	15,036 (6)	15,970 (6)
	Appropriative B	0 (6)	0 (6)	0 (6)	0 (6)	0 (6)
	Other	5,998 (5)	5,416 (5)	4,155 (5)	600 (5)	2,000 (5)

[1]Central Valley Project.
[2]Numbers in parentheses are number of districts responding.
[3]State Water Project.
[4]Senior rights holders.
[5]Junior rights holders.

Table 14--Number of wells and acre-feet of ground water pumped

	1987		1988		1989		1990		1991	
	Wells	AF pumped	Wells	AF pumped	Wells	AF pumped	Wells	AF pumped	Wells	AF pumped
All districts	493 (66)[1]	292,758 (44)	721 (66)	400,266 (44)	442 (66)	230,719 (44)	449 (66)	291,832 (45)	480 (68)	347,748 (50)
Central Coast	8 (3)	199 (3)	8 (3)	302 (3)	8 (3)	200 (3)	8 (3)	2,576 (3)	8 (3)	2,000 (3)
Sacramento Valley	21 (13)	4,400 (6)	21 (13)	4,382 (6)	21 (13)	7,986 (6)	26 (13)	13,707 (6)	26 (14)	21,500 (7)
Mountain	2 (6)	0 (3)	2 (6)	0 (3)	3 (6)	0 (3)	3 (6)	1,378 (4)	3 (6)	3,000 (4)
San Joaquin Valley	296 (9)	194,787 (6)	526 (9)	319,599 (6)	246 (9)	131,801 (6)	247 (9)	150,779 (6)	251 (9)	176,008 (8)
Fresno	54 (7)	25,998 (6)	54 (7)	24,871 (6)	54 (7)	35,298 (6)	55 (7)	61,372 (6)	60 (7)	73,905 (6)
Kings and Tulare	46 (12)	31,253 (11)	46 (12)	29,444 (11)	46 (12)	28,707 (11)	46 (12)	26,545 (11)	46 (12)	24,057 (11)
Kern	0 (4)	0 (3)	0 (4)	0 (3)	0 (4)	0 (3)	0 (4)	0 (3)	2 (4)	4,000 (3)
Southern California	18 (5)	1,252 (3)	18 (5)	185 (3)	19 (5)	462 (3)	19 (5)	2,234 (3)	37 (5)	17,670 (3)
Riverside	41 (1)	33,735 (1)	39 (1)	21,367 (1)	38 (1)	26,131 (1)	38 (1)	33,242 (1)	33 (1)	23,104 (1)
Imperial	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)	0 (1)
San Diego	7 (5)	1,134 (1)	7 (5)	117 (1)	7 (5)	134 (1)	7 (5)	0 (1)	14 (6)	2,505 (3)

[1]Numbers in parentheses are number of districts responding.

Table 15--Distribution of dealers by county (total of 28 dealers)

County	Dealers	County	Dealers	County	Dealers
Butte	1	Merced	1	Santa Barbara	2
Colusa	1	Monterey	1	Sonoma	2
Fresno	2	Napa	2	Stanislaus	1
Kern	1	Riverside	3	Sutter	1
Los Angeles	1	San Diego	1	Tulare	4
Mendocino	1	San Joaquin	2	Yolo	1

Table 16--General characteristics of irrigation dealers

I	II	III	IV	V	VI	VII	VIII	XI	X
			Agri.		Pump				
			revenue	Irriga-	sales	Automated	Drip use ratios (1990/1987)		
			as % of	tion	ratio	equip. sales			
Dealer			of total	consul-	1990/	ratio		Fruits	
ID No.	County	Town	revenue	tant	1987	(1990/1987)	Citrus	and nuts	Grapes
9	Colusa	Arbuckle	90	YES	1.52	1.19	6.00		
11	Sonoma	Santa Rosa	50	YES	1.06	1.27			1.20
12	Fresno	Selma	98	YES	N/A	1.46			
13	Riverside	Riverside	69	YES	2.90	3.12	1.25		
14	Santa	Santa	80	YES	1.27	1.14			
18	Fresno	Fresno	100	YES	N/A	N/A			2.00
20	Tulare	Porterville	100	NO	3.27	N/A			
23	Los An-	Los Ange-	100	YES	1.76	1.27	1.48	1.48	
26	Riverside	Riverside	90	NO	1.32	1.00	1.17	N/A	
27	Tulare	Woodlake	99	YES	N/A	3.28	N/A	N/A	
29	San Joa-	Stockton	90	YES	1.00	1.27		2.00	2.00
30	Sonoma	Sebastopol	65	YES	3.21	3.33			
31	Tulare	Delano	99	YES	N/A	0.00	1.05	3.00	1.17
35	Napa	Santa Elena	100	YES	N/A	1.14			N/A
37	Stanislaus	Oakdale	75	NO	1.44	1.28		N/A/11	
38	Santa	Santa	95	YES	1.41	1.19			1.36
41	San Joa-	Lodi	95	YES	N/A	N/A		3.00	1.25
44	San Diego	Santee	20	YES	N/A	1.27		1.29/1.29	
49	Monterey	Salinas	100	YES	1.00	1.27		1.05	
52	Napa	Napa	50	YES	N/A	N/A			1.10
54	Sutter	Yuba City	60	NO	N/A	1.05		N/A/3.00	
56	Butte	Durham-	90	YES	1.56	1.42		2/4.0	
57	Tulare	Visalia	99	NO	N/A	N/A	1.50		
58	Kern	Shafter	98	YES	1.70	N/A			
59	Merced	Dos Palos	98	YES	1.32	1.15		N/A	
61	Mendocino	Ukiah	70	YES	1.36	1.19			N/A
62	Riverside	Riverside	40	NO	3.02	2.90	1.12	1.00	
63	Yolo	Woodland	90	NO	1.33	1.00			

N/A=not available.

Table 17--Distribution of counties with dealers according to major regions of California

North	Central SJV	Southern SJV	North coast	South coast	Southern California
Madera	Fresno	Kern	Sonoma	Los Angeles	Riverside
Merced		Kings	Napa	San Diego	Imperial
Sacramento		Tulare	Monterey	San Luis Obispo	
San Joaquin			Mendocino	Santa Barbara	
Stanislaus				Ventura	
Sutter					

Table 18--Dealers' expectations of water saving and yield increase by switching irrigation technologies

Dealer ID no.	County	Crops	Sprinkler vs. furrow: Yield increase	Sprinkler vs. furrow: Water savings	Drip vs. furrow: Yield increase	Drip vs. furrow: Water savings
			Percent			
9	Colusa	Almonds/trees	30	40	40	60
11	Sonoma	Grapes	0	44	25	95
		Pasture	50	44	0	95
		Orchards	25	44	30	95
13	Riverside	Citrus	15	25	15	35
		Table grapes	N/A	N/A	20	25
		Row crops	10	15	20	40
14	Santa Barbara	Not specified	10	30	10	50
18	Fresno	Vineyards	N/A	30	N/A	50
		Trees	N/A	30	N/A	50
20	Tulare	Grapes	N/A	N/A	30	40
		Oranges	N/A	N/A	25	35
23	Los Angeles	Citrus	30	50	25	65
26	Riverside	Citrus	25	30	25	30
		Avocados	25	30	25	30
27	Tulare	Citrus	20	30	25	40
		Fruits	15	20	20	25
		Walnuts	15	20	20	25
29	San Joaquin	Vegetables	20	30	75	30
		Fruits/Nuts	50	30	30	30
		Grapes	10	30	30	75
31	Tulare	Grapes	N/A	N/A	15	40
		Almonds	0	25	15	40
		Citrus	20	35	10	40
37	Stanislaus	Almonds	10	15	10	20
		Walnuts	10	20	5	15
		Pasture	20	30	N/A	N/A
38	Santa Barbara	Vineyard	30	30	50	50
		Strawberries	30	30	50	50
		Row crops	30	30	50	50

Cont.

Table 18-- Dealers' expectations of water saving and yield increase by switching irrigation technologies (continued)

Dealer ID no.	County	Crops	Sprinkler vs. Furrow Yield increase	Sprinkler vs. Furrow Water savings	Drip vs. Furrow Yield Increase	Drip vs. Furrow Water savings
				Percent		
49	Monterey	Lettuce	30	30	30	50
		Broccoli	30	40	N/A	N/A
		Strawberry	40	30	30	40
52	Napa	Vines	20	256	30	80
56	Butte	Almonds	25	50	30	70
		Walnuts	15	40	20	60
		Prunes	10	50	20	70
		Sugar beets	20	40	N/A	N/A
57	Tulare	Citrus	0	25	0	35
		Fruits	0	30	0	35
		N/A				
58	Keren	Cotton	N/A	30	N/A	N/A
		Grapes	N/A	30	N/A	50
		Trees	N/A	30	N/A	50
59	Merced	Tomatoes	15	35	20	50
		Cotton	10	35	10	40
		Sugarbeet	20	40	N/A	N/A
61	Mendocino	Grapes	10	50	15	50
		Pears	16	50	15	50
62	Riverside	Citrus	15	40	15	70
		Avocados	25	40	25	70

N/A=not available.

Table 19--Water sources and fallowed acreage, 1987-1991

	Project water	Nonproject water	Ground water pumped	Acreage fallowed
		1,000 acre-feet		
		Northern San Joaquin		
1987	1,112	2,086	199	117
1988	1,087	1,653	324[1]	117
1989	1,128	2,048	140	102
1990	962	1,903	164	104
1991	846	1,613	198	157
		Central and southern San Joaquin		
1987	1,818	411	189	109
1988	1,787	198	186	119
1989	1,954	335	196	148
1990	1,372	203	388	129
1991	511	436	677	211
		All other regions		
1987	258	5,482	36	34
1988	289	5,879	22	28
1989	300	6,047	27	26
1990	307	6,126	39	25
1991	249	6,071	48	30
		Total		
1987	3,188	7,980	425	259
1988	3,163	7,730	532	264
1989	3,382	8,430	363	276
1990	2,641	8,248	592	258
1991	1,606	8,120	923	397

[1]One water district drastically increased the amount of ground water pumped this year because the appropriative source was reduced.

Table 20--Westlands water district water use, 1980-1990

Year	Irrigable area	Irrigated area	Project water	Ground-water	Total water	Project water	Ground-water
	Acres		*Acre-feet*			*Acre-feet per acre*	
1980-81	563,301	489,556	1,244,446	99,000	1,343,446	2.54	0.20
1981-82	563,862	491,907	1,236,639	105,000	1,341,630	2.51	0.21
1982-83	567,184	497,621	1,090,888	31,000	1,121,888	2.19	0.06
1983-84	571,219	499,330	1,473,883	73,000	1,546,883	2.95	0.15
1984-85	568,554	503,917	1,315,548	228,000	1,543,548	2.61	0.45
1985-86	568,986	506,981	1,194,113	145,000	1,359,708	2.36	0.29
1986-87	566,844	508,255	1,309,252	159,000	1,468,252	2.58	0.31
1987-88	568,083	528,277	1,270,213	160,000	1,380,917	2.40	0.30
1988-89	567,817	536,128	1,157,908	175,000	1,332,908	2.16	0.33
1989-90	568,083	533,959	920,681	300,000	1,220,681	1.72	0.56

Table 21--Contract water availability and ground-water storage change, friant unit 1978-1988

Year	Class 1[1] water	Class 2[2] water	Total	Ground-water storage change
		Acre-feet		
1978	800,000	1,388,800	2,188,800	1,274,453
1979	800,000	868,115	1,668,115	343,792
1980	800,000	1,377,212	2,177,212	428,994
1981	800,000	302,987	1,102,987	-125,919
1982	800,000	1,376,288	2,176,288	1,032,360
1983	800,000	1,378,084	2,178,084	656,828
1984	800,000	689,042	1,489,042	23,107
1985	800,000	192,966	992,966	-220,487
1986	800,000	1,301,079	2,101,079	502,953
1987	728,000	0	728,000	-630,714
1988	640,000	0	640,000	-650,000

[1]Water with senior rights.
[2]Water with junior rights.

Table 22--Number of wells and ground water pumped, 1987-1990, selected CVP WD sample

Water district	1987 No. of. wells	1987 Ground-water pumped	1988 No. of wells	1988 Ground-water pumped	1989 No. of wells	1989 Ground-water pumped	1990 No. of wells	1990 Ground-water pumped	1991 No. of wells	1991 Ground-water pumped
		AF		*AF*		*AF*		*AF*		*AF*
Broadview	0	0	0	0	0	0	0	0	1	150
CCID	42	17,000	42	33,000	42	24,000	43	48,000	43	65,000
Internat'l	12	0	12	0	12	0	12	0	12	0
James	52	25,998	52	24,871	52	35,298	53	60,172	55	70,000
La Branza	4	1,787	4	1,599	4	1,801	4	1,779	4	2,258
Lindsay-Strathmore	6	653	6	644	6	507	6	625	6	657
Tranqu'ty ID	2	0	2	0	2	0	2	1,200	4	3,755
Banta								0		600
Carbona ID	0	0	0	0	0	0	0		1	
Glen-Colusa	0	0	0	0	1	3,500	1	3,500	1	3,500
Rec. dist. 108	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3	10,000
Bella Vista	2	N/A	2	N/A	3	N/A	3	1,378	3	3,000
Total	120	45,438	120	60,114	122	65,106	124	116,654	133	160,570

N/A=not available.

Table 23--Broadview water district tiering levels, prices, and results, 1989-1991

Crop	Average application in 1986-88	Tiering level	Average application 1989	1990	1991
			Acre-feet/acre		
Cotton	3.20	2.9	3.34	2.84	2.40
Tomatoes	3.22	2.9	2.72	3.03	2.69
Melons	2.11	1.9	1.93	1.79	1.46
Wheat	2.30	1.9	3.02	2.18	1.60
Sugar beets	4.58	3.9	3.73	2.54	*
Alfalfa seed	2.06	1.9	1.84	1.88	1.36
Rice	5.65	5.1	5.40	*	*

*=Not grown.

Boxes

Box 1--Open-ended answers to question 8--additional steps taken by the water districts in response to the drought

1. Sold water to the water bank and/or dealt with the water banking system.
2. Instituted ordinances and/or mandatory reductions and/or penalties.
3. Provided loans for waste water reuse and/or rebates for proved conservation and/or made district money available for on-farm improvements.
4. Recharged ground water with imported State water.
5. Rescheduled water from last year.
6. Rented wells from farmers and/or leased out land from farmers and fallowed it.
7. Recaptured tail water and/or used reclaimed water.
8. Postponed capital purchases.
9. Installed meters and/or controlled canal levies and did home water audits and/or accelerated replacement of meters.
10. Purchased water from the water bank.
11. Placed restrictions on watering at certain times and/or monitored and controlled spills daily.
12. Installed conservation programs and/or distributed information on conservation.
13. Started irrigation earlier.
14. Placed a surcharge on water purchased from another district.
15. This water district had no water shortage.
16. This water district tried to get a Bureau of Reclamation contract but did not.

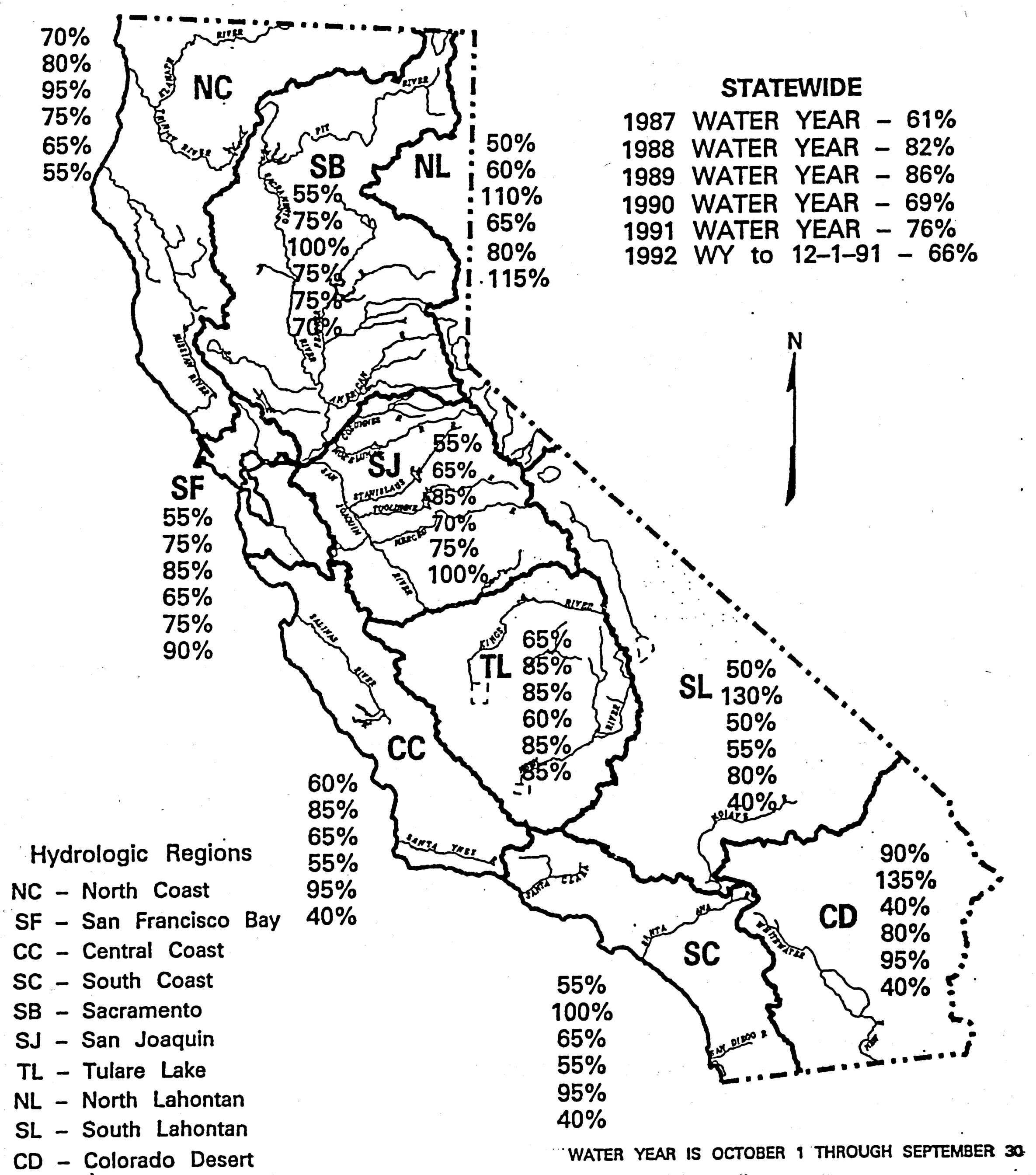
Box 2--Open-ended answers to question 9--additional steps taken by farmers in response to the drought

1. Laser leveled fields and/or did torpedo and dragging.
2. Irrigated during cooler hours and/or monitored water use carefully and/or worked irrigators around the clock.
3. Did tail water returns.
4. Installed gated pipes and/or plugged leaks and/or installed siphon pipes.
5. Stressed the crops and/or used less water with longer intervals in between and/or irrigated for shorter periods of time.
6. Put borders closer together.
7. No double cropping.
8. Trimmed, thinned, or cut down trees.
9. Fallowed land to sell water to State water bank.
10. This district had no water shortage.
11. Drilled private wells.
12. Did heavy mulching.

Figures

Figure 1--California production regions

(Values are annual precipitation in percent of average)



Source: DWR (1991a)

Figure 2--Water systems and decision junctions

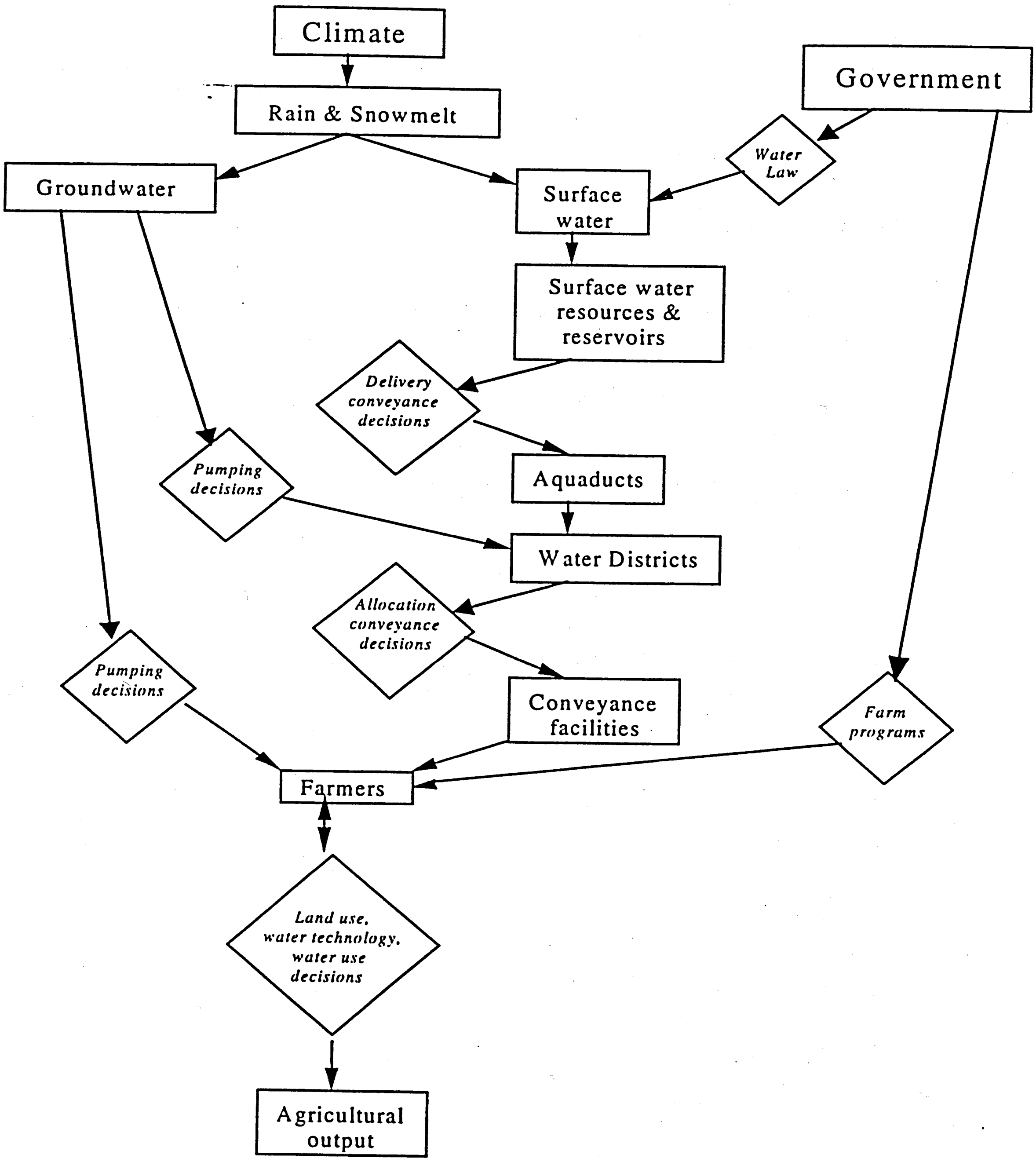


Figure 3--Use of irrigation technologies on citrus, 1987-1991

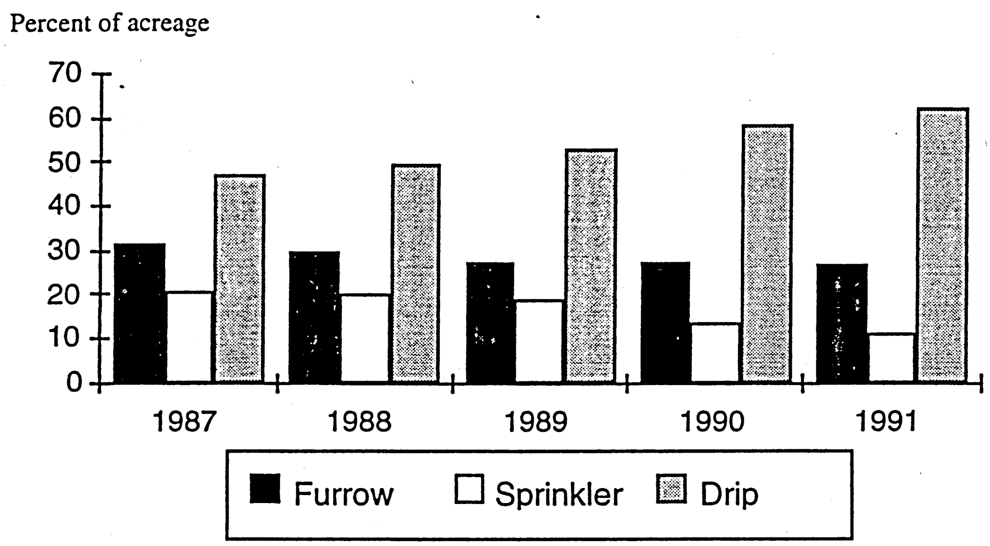


Figure 4--Use of different irrigation technologies on fruits and nuts, 1987-1991

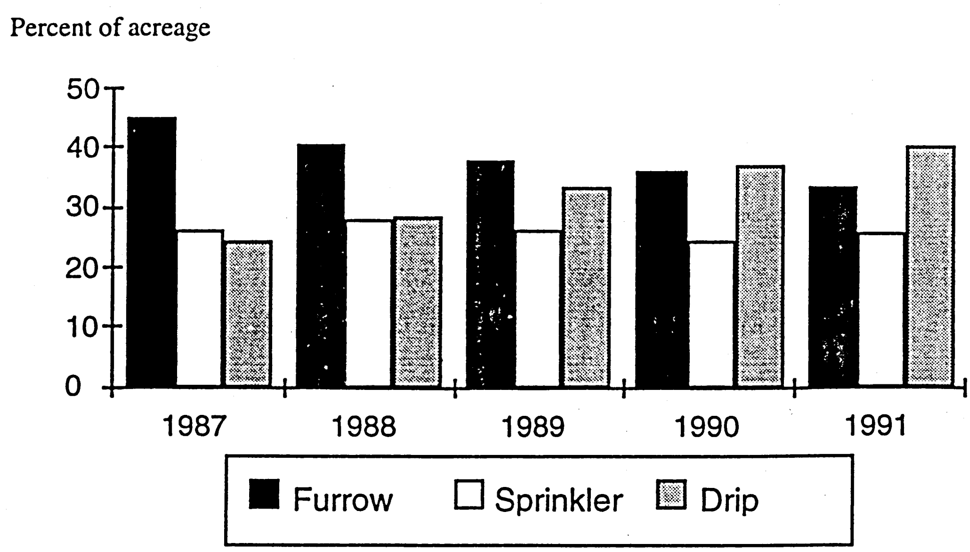


Figure 5--Use of irrigation technologies on grapes, 1987-1991

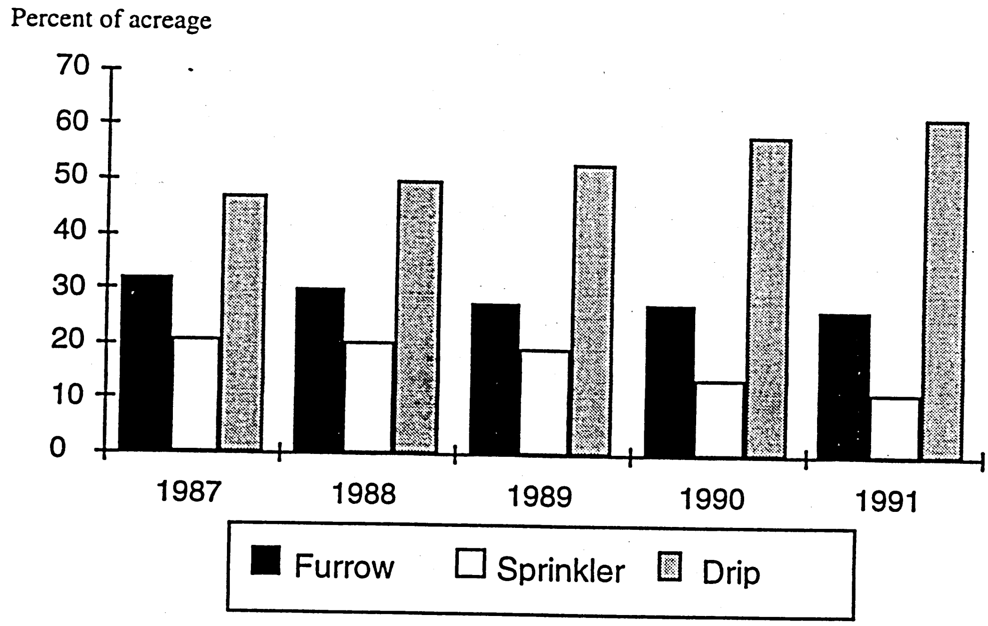


Figure 6--Use of irrigation technologies on vegetables, 1987-1991

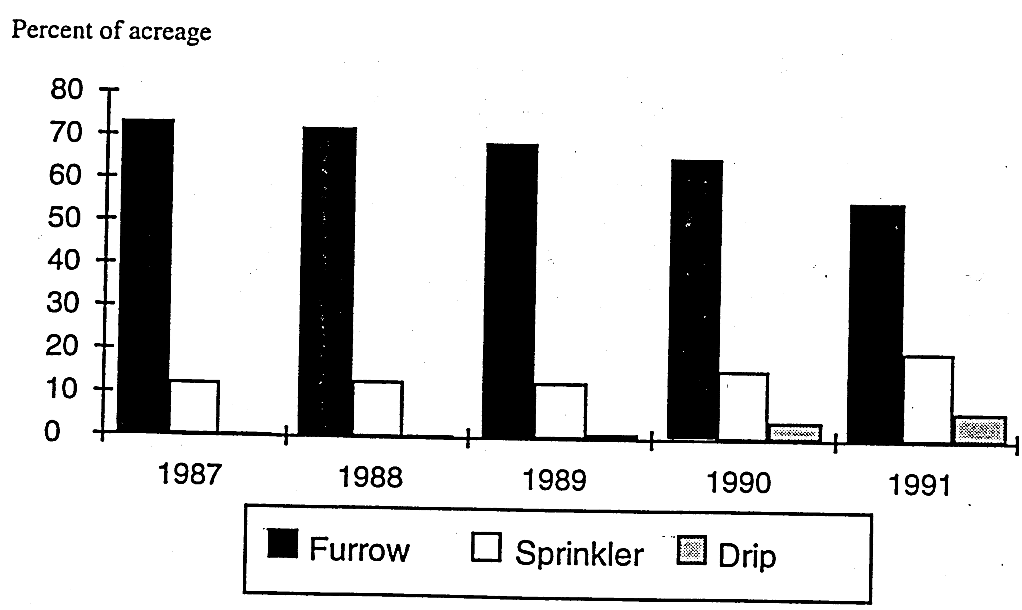


Figure 7--Use of irrigation technologies in the north, 1987-1991

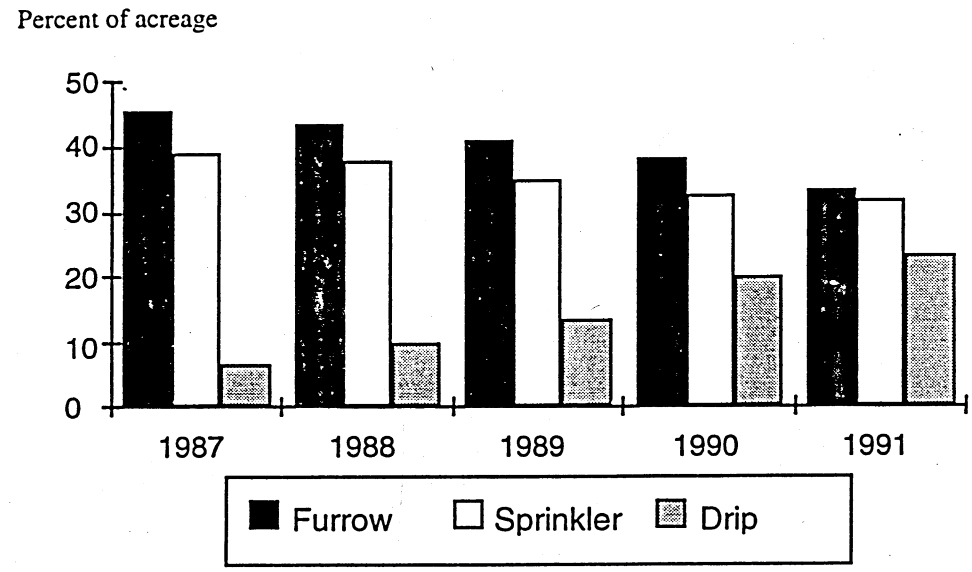


Figure 8--Use of irrigation technologies in the south, 1987-1991

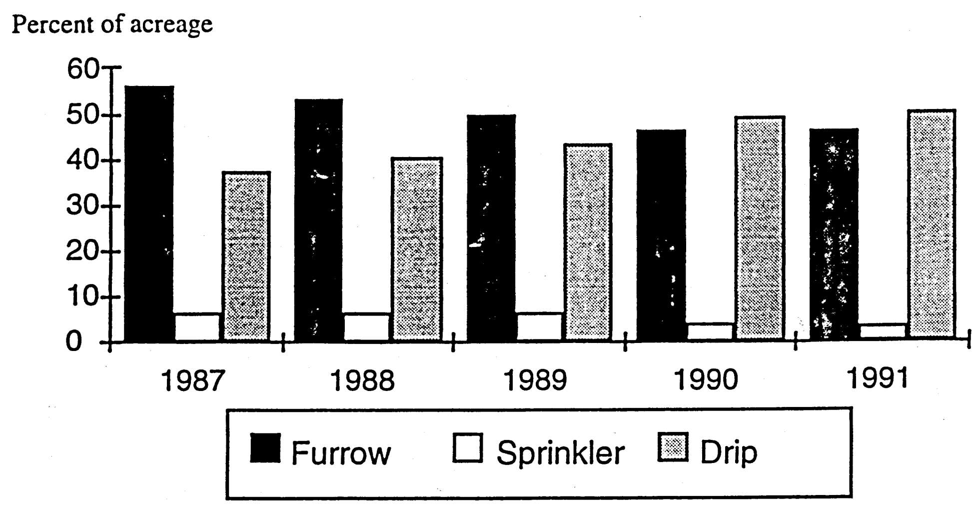


Figure 9--Use of irrigation technologies in the north coast, 1987-1991

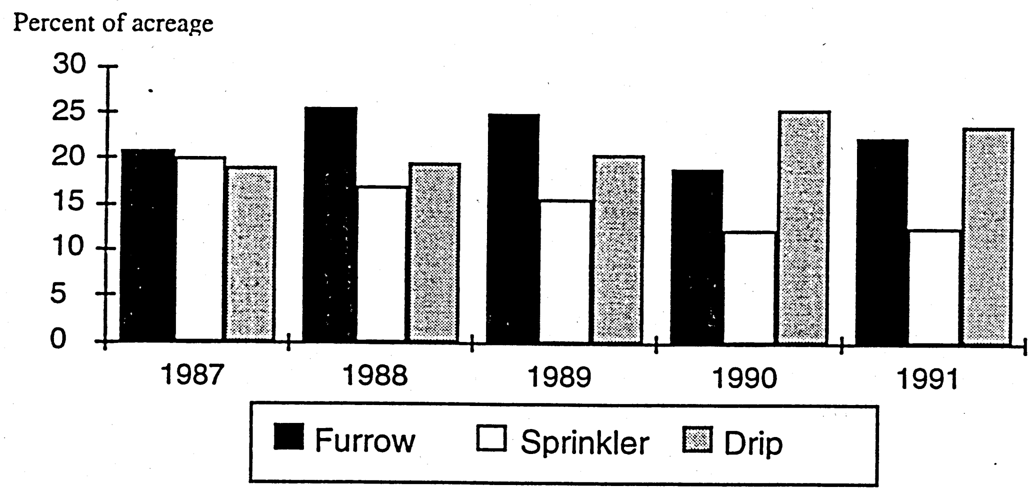


Figure 10--Use of irrigation technologies in the south coast, 1987-1991

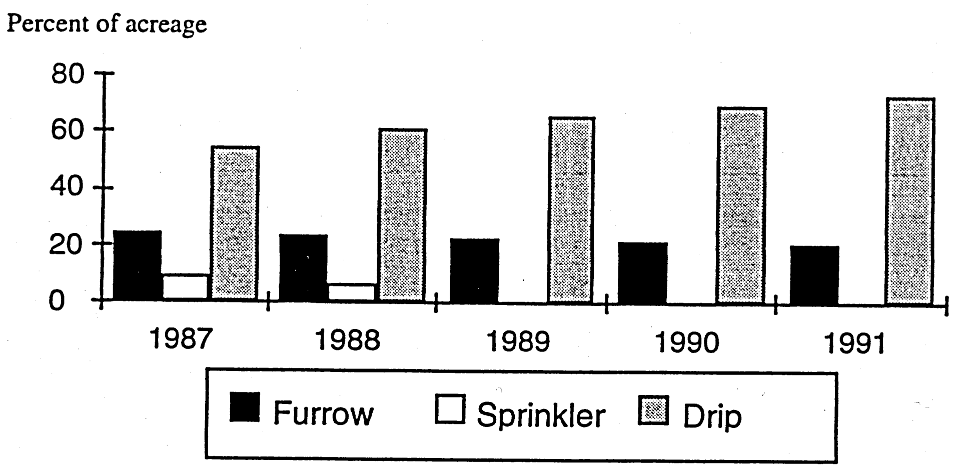


Figure 11--Use of irrigation technologies in Riverside, 1987-1991

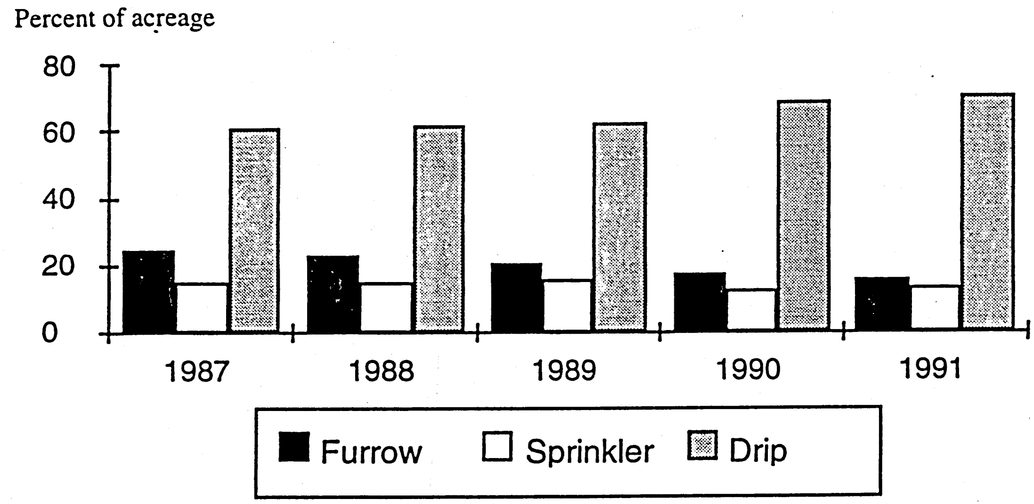


Figure 12--Adjusted average index for sales of pumps, 1987-1990

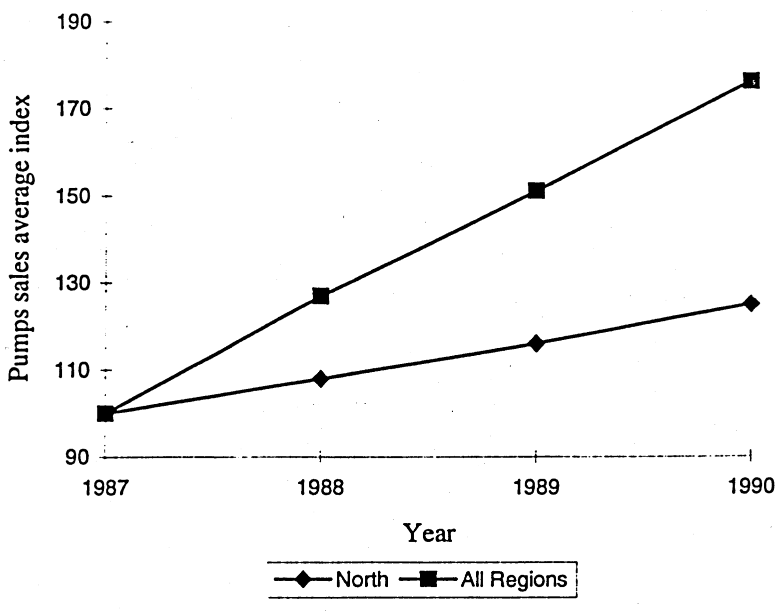


Figure 13--Percentage change in pump sales, 1987-1991 by pump type

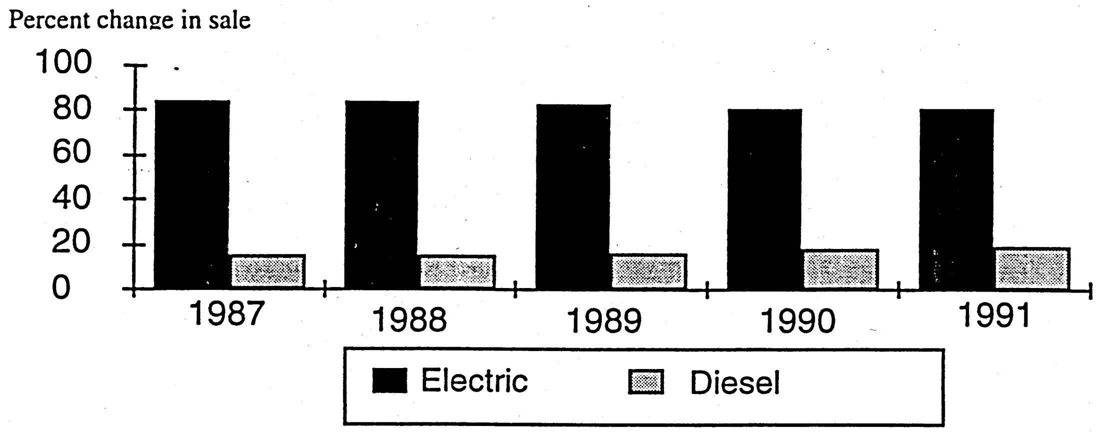


Figure 14--Adjusted average index of automated irrigation equipment, 1987-1991

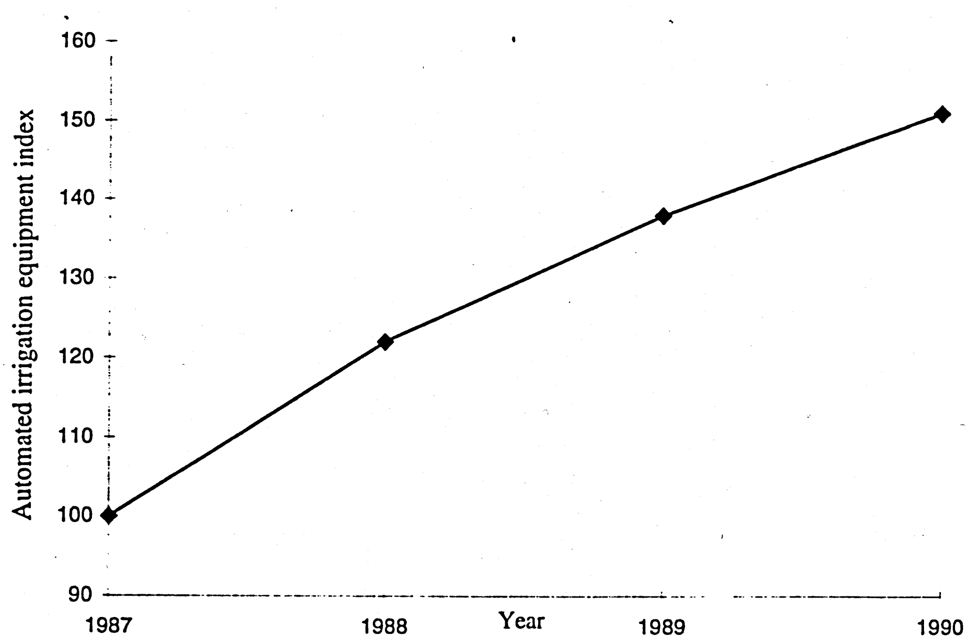


Figure 15--Water in California's main reservoirs, and number of wells drilled during the drought

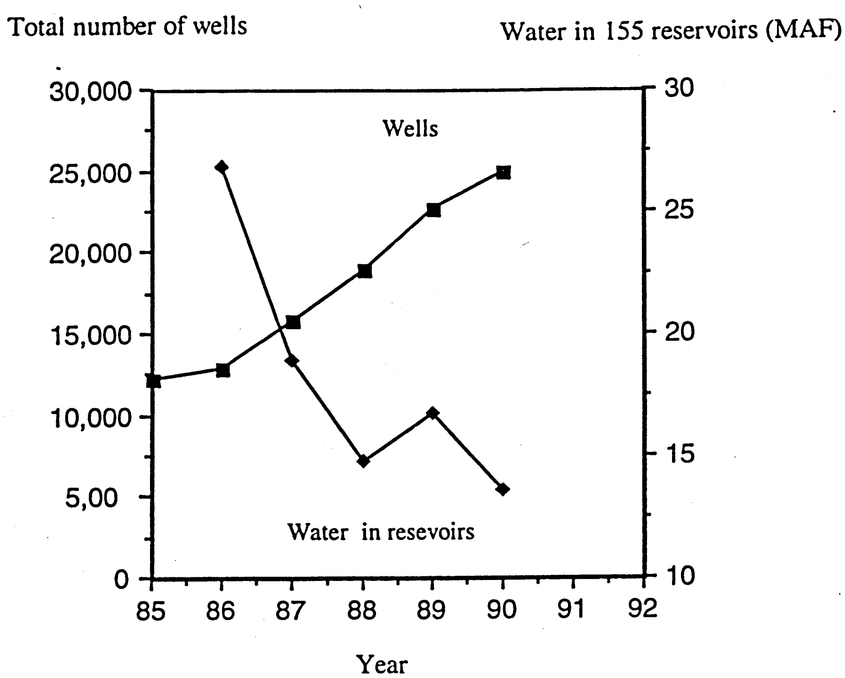
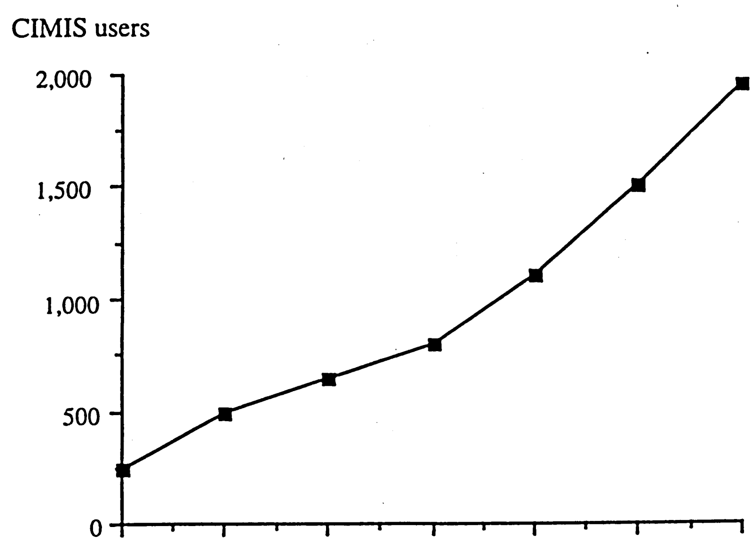
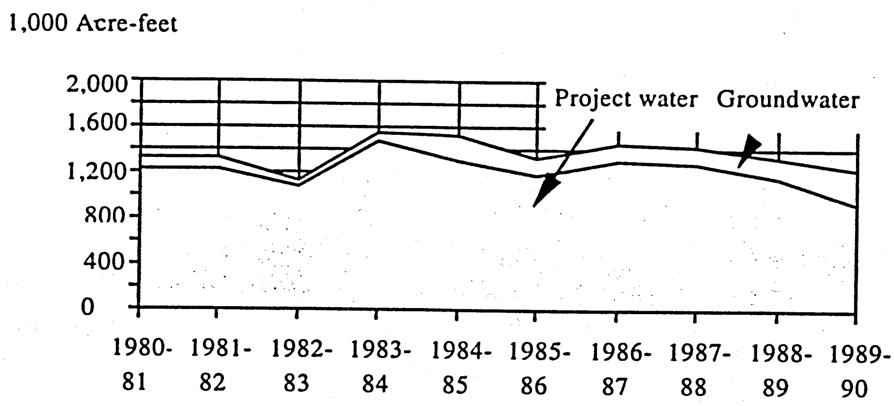


Figure 16--CIMIS subscription during the drought in California



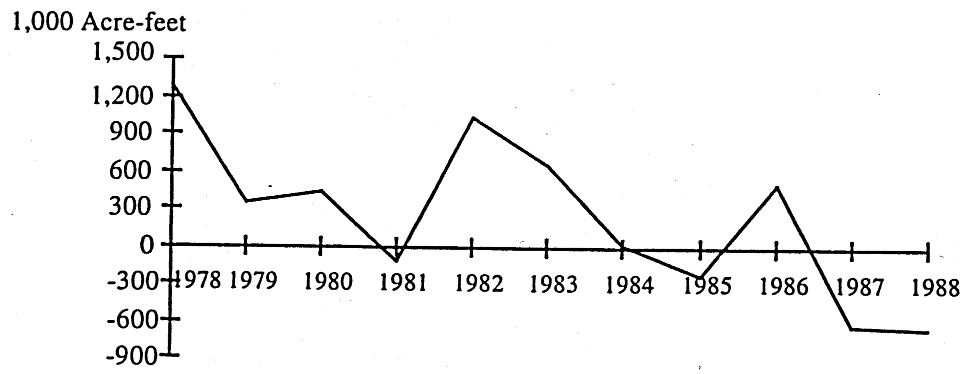
Source: DWR (1993)

Figure 17--Westland water district water supply, 1980/81-1989/90



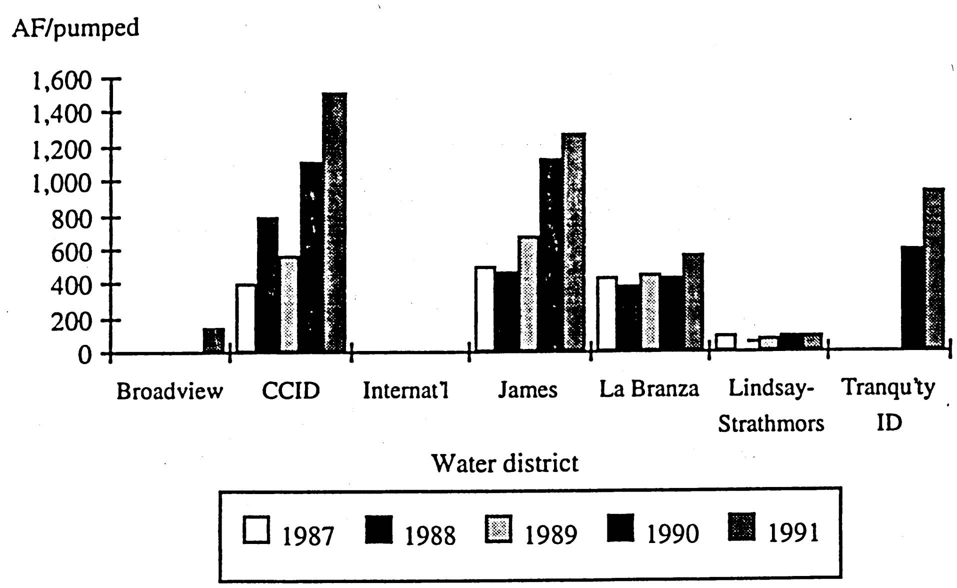
Source: Zilberman et al. (1992).

Figure 18--Friant unit ground water storage level change, 1978-1988



Source: Zilberman et al. (1992).

Figure 19--Average pumping rates, 1987-1991 (CVP sample)



Source: Zilberman et al. (1992).

Appendix 1: Water District Questionnaire

W.D. Code	W.D. Name & Address	Contact Person	Phone	Comments

Date sent____________________________________

(1) Water District Code: Pg____, Row____, Col____.

(2) Closest town:_____________________________________

(3) Service area: Gross:____________acres; Irrigable___________acres

Main crops____

(4) What services does district provide (check):

a______surface water supply for irrigation
b______ground water supply for irrigation
c______surface water supply for urban users
d______ground water supply for urban users
e______ground water recharge
f______drainage control
g______flood control
h______electricity generation and sale
i______other (specify)____

(5) No. of agricultural landowners:_____________; farming operations:__________

(6) Area with tile drainage system:____________________acres

(7) District water distribution system:

a Unlined canal____________________miles
b Lined canal_______________________miles
c Pipeline/pressurized system___________miles
d Storage within district-owned reservoirs___________AF

(8) Steps taken by district as a response to the 1991 drought (please check):

a___pump additional ground water (approx how many AF district wide___________)
b___line district canals (approx how many miles___________)
c___offer assistance to growers for adopting irrigation scheduling
d___install pressurized pipelines
e___offer assistance to growers for other changes in irrigation methods
f___change water allocation schedule to growers
(please explain___________)
g___ change water pricing practice for growers
(please explain___________)
h___other (please specify___________)

(9) Other steps taken by farmers as a response to 1991 drought (please check):

a___pump additional ground water (approx how many AF district wide___________)
b___switch to less water-consuming crops
c___from which crops___________to which crops___________
d___approx how many acres___________
e___line on-farm ditches (approx how many miles___________)
f___shorten irrigation furrow length (approx how many acres involved___________)
g___improve existing furrow irrigation (surge, cut back, etc.)
h___Introduce new sprinkler irrigation (approx how many acres involved___________)
i___Install drip (approx how many acres involved___________)
j___Other (specify___________)

(10) What type of arrangement does the district have for delivering water to growers?
a___Demand
b___Arranged
c___Rotation/schedule (please provide details___________)
d___Other (please specify___________)

(11) What is the lead time for water delivery? ___________hours

(12) Is there a maximum or minimum duration of flows? Y N ______hours (max/min)

(13) What is the lead time to shut water off? ____hours

(14) What changes to lead time for turn on/off have been made because of drought?

____

____

(15) Please send a current set of water allocation rules. Price schedule in the district________________

(16) Have these allocation rules been changed significantly since 1985? Y N

(17) When were these charges adopted? _____________

(18) If growers want to exchange delivery of district water among themselves, do they have to notify district and obtain its approval? Y N

(19) If yes, does the district inquire whether any payment was involved? Y N

(20) Does the district ever withhold approval and, if so, for what types of reasons?___________________________

(21) Do water exchanges take place regularly? Y N

(22) If yes, can you estimate about what percent of the district water supply might be involved in transfer in a typical year?___________%

(23) What are the reasons that farmers engage in these exchanges?_________________

(24) Has there been any significant change in the number of exchanges during the last few years? Y N

(25) If yes, is it related to the drought? Y N

(26) What was the total irrigated acreage served, and how many acres were fallowed due to the drought conditions
Irrigated acreage served in 1987_______________ Fallowed_______________
Irrigated acreage served in 1988_______________ Fallowed_______________
Irrigated acreage served in 1989_______________ Fallowed_______________
Irrigated acreage served in 1990_______________ Fallowed_______________
Irrigated acreage served in 1991 (expected)______ Fallowed_______________

(27) Please list main crops affected by land fallowing:
a Crops with reductions in area farmed_______________
b Crops with increases in area farmed_______________

(28) Has the district made any significant addition/renovation of its water distribution system since 1985? Y N

(29) If yes, please explain (what, when, why)_______________
____

(30) Source of district's water supply (fill in relevant sources)

	CVP Contract [AF]	CVP Exchange [AF]	SWP Contract Contract [AF]	Riparian Rights [AF]	Appropriative Rights [AF] Source A	Source B
Source name						
Contract entitlement						
1987 delivery/diversion						
1988 delivery/diversion						
1989 delivery/diversion						
1990 delivery/diversion						
1991 delivery/diversion (expected)						

(31) Pumped ground water supplied by district
1987 number of wells___________; amount pumped___________AF
1988 number of wells___________; amount pumped___________AF
1989 number of wells___________; amount pumped___________AF
1990 number of wells___________; amount pumped___________AF
1991 number of wells___________; amount pumped___________AF (expected)

From here after, area preirrigated with sprinklers and then for the entire season with furrow is considered furrow

(32) District-wide Irrigation Technology Shares (%)

	Border	Furrow	Hand-moved sprinklers	Linear move	Microsprinklers	Drip
1987						
1988						
1989						
1990						
1991						

(33) For the five main crops in your district, please estimate potential changes in yield and water saving as a result of changes in irrigation practices:

% water saving | % yield increase

Crop__surf. to sprinkl___; surf. to lin move___;surf. to drip___; surf. to sprinkl__; surf. to lin move__; surf. to drip__
Crop__surf. to sprinkl___; surf. to lin move___;surf. to drip___; surf. to sprinkl__; surf. to lin move__; surf. to drip__
Crop__surf. to sprinkl___; surf. to lin move___;surf. to drip___; surf. to sprinkl__; surf. to lin move__; surf. to drip__
Crop__surf. to sprinkl___; surf. to lin move___;surf. to drip___; surf. to sprinkl__; surf. to lin move__; surf. to drip__
Crop__surf. to sprinkl___; surf. to lin move___;surf. to drip___; surf. to sprinkl__; surf. to lin move__; surf. to drip__

(34) For the five main crops in your district, please estimate average water application rates and yields in your district

Crop________, average water application________af/acre; average yield________[yield unit________]
Crop________, average water application________af/acre; average yield________[yield unit________]
Crop________, average water application________af/acre; average yield________[yield unit________]
Crop________, average water application________af/acre; average yield________[yield unit________]
Crop________, average water application________af/acre; average yield________[yield unit________]

(35) For the five main crops in your district, please estimate technology shares

Crop [acres]	Border Share [%]	Furrow Share [%]	Hand moved Sprinkler Share [%]	Linear move Sprinkler Share [%]	Microsprinklers Share [%]	Drip Share [%]
			1987			
			1988			
			1989			
			1990			
			1991			

Appendix 2: Dealers' Questionnaire

Part I: General Background.

1-Location of company (county): _______

2-City:_______

3-Please indicate in percentage terms what is the % of total revenue that agriculture represents in your overall business? _______%

4-Mark the activities which describe most accurately the main source of sales for your company:

	YES	NO
Marketing:	___	___
Design of equipment:	___	___
Sales of irrigation equipment:	___	___
Installation:	___	___
Other (specify):_______________	___	___

5-Do you sell automated irrigation equipment: ______ a-YES b-NO

6-If your answer to question 4 was YES, please indicate in percentage terms the change (increase (+) or decrease (-)) on sales of automated irrigation equipments during the following years (use 1987 as base year)

	Increase (+)/Decrease(-)
1987	100 %
a-1988:	_______%
b-1989:	_______%
c-1990:	_______%

7-Do farmers in your area use the services of irrigation consultants? _______ a-YES b-NO

8-If your answer to question 6 was YES, what % of farmers use their services? ___%

9-In decreasing order, list the three most important regions in which your dealership sells irrigation equip ment (by counties):

a-_________
b-_________
c-_________

10-Please allocate which % of your total revenue each of the following types of irrigation represents:

a-Drip	______________	________%
b-Sprinkler	______________	________%
c-Micro	______________	________%
d-Other (specify)	______________	________%

11-Did you observe farmers switching crops during 1990 ? ___________ YES NO

12-If YES, do you believe this change was due to the 1990 drought? _____ YES NO

13-In percentage terms, list the 3 most observed changes in crop pattern you observed:

% of farmers who switched

a. from___________to_________%
b. from___________to_________%
c. from___________to_________%

14-This question pertains to the 3 most important crops for which the irrigation equipment you sell is used on. Compared to furrow, if a farmer adopts drip and/or sprinkler irrigation, by what percent will yield increase? What would be the effect (in % terms) in water use? (Water savings)

Crop 1: ______________

	Yield Increase	Water Savings
Furrow vs sprinkler:	______%	______%
Furrow vs drip:	______%	______%

Crop 2: ______________

	Yield Increase	Water Savings
Furrow vs sprinkler:	______%	______%
Furrow vs drip:	______%	______%

Crop 3: ______________

	Yield Increase	Water Savings
Furrow vs sprinkler:	______%	______%
Furrow vs drip:	______%	______%

Part II: Crops produced in your area:

This section pertains to the 3 most observed crops among your clients:

Crop II-1

- Crop for which you sold more irrigation equipment:______.

15-Please estimate what % of land was used with this crop for these technologies during the following years:

Year	Furrow/Border	Sprinkler	Drip/Micro	Combination (Specify)
1987				
1988				
1989				
1990				
1991				

16-For this crop, what is the source of water in percentage terms and your observed price range.

	%	Price Range ($A/F)
Ground	______%	from_____to ______
Surface	______%	from_____to ______

Crop II-2

17-Second most important crop for which you sold more irrigation equipment:_____.

18-Please estimate what % of land was used with this crop for these technologies during the following years:

Year	Furrow/Border	Sprinkler	Drip/Micro	Combination (Specify)
1987				
1988				
1989				
1990				
1991				

19-For this crop, what is the source of water in percentage terms and your observed price range.

	%	Price Range ($A/F)
Ground	______%	from_____to ______
Surface	______%	from_____to ______

Crop II-3

20-Third most important crop for which you sold more irrigation equipment:_______.

21-Please estimate what % of land was used with this crop for these technologies during the following years:

Year	Furrow/Border	Sprinkler	Drip/Micro	Combination (Specify)
1987				
1988				
1989				
1990				
1991				

22-For this crop, what is the source of water in percentage terms and your observed price range.

	%	Price Range ($A/F)
Ground	______%	from_____to ______
Surface	______%	from_____to ______

Part III: Pump Data:

23-Does your dealership sell and/or rent pumps? YES NO

24-In % terms, what kind of pumps do you sell the most :

Booster	________%
Deep Well Turbine	________%
Other (specify) _________	________%

25-Using 1987 as base year (100), please indicate the change (increase (+) or decrease(-)) in percentage terms in sales of pumps during the following years:

	Increase (+)/Decrease(-)
1987	100 %
a-1988:	________%
b-1989:	________%
c-1990:	________%

26-Source of energy in % terms used by pumps sold by your dealership during the following years:

Year	Electricity	Diesel	Gas	Other (specify)
1987				
1988				
1989				
1990				
1991				

27-Average and range horsepower (HP) of pumps sold by your dealership during the following years:

	Average	Range
1991:	________________HP	from___to____
1990:	________________HP	from___to____
1989:	________________HP	from___to____
1988:	________________HP	from___to____
1987:	________________HP	from___to____

28-Average well depth observed in your area:_______ft.

29-Range of well depth observed in your area: From______ft to______ft

Part IV: Irrigation District(s):

30-List which Irrigation Districts operate in your region:

District IV-1

a- Name:_________

b-Price of water delivered by district:

Ground:

Surface:

c-Main crops grown in the district's area:

c-1______

c-2______

c-3______

District IV-2

a- Name:_________

b-Price of water delivered by district:

Ground:

Surface:

c-Main crops grown in the district's area:

c-1______

c-2______

c-3______

District IV-3 a- Name:_________

b-Price of water delivered by district:

Ground:

Surface:

c-Main crops grown in the district's area:

c-1______

c-2______

c-3______

Do Not Write Bellow This Line

No: [___]

Part IV: Irrigation District(s):

30-List which Irrigation Districts operate in your region:

District IV-1

a- Name:________

b-Price of water delivered by district:

Ground:

Surface:

c-Main crops grown in the district's area: c-1______

c-2______

c-3______

District IV-2

a- Name:________

b-Price of water delivered by district:

Ground:

Surface:

c-Main crops grown in the district's area: c-1______

c-2______

c-3______

District IV-3 a- Name:________

b-Price of water delivered by district:

Ground:

Surface:

c-Main crops grown in the district's area: c-1______

c-2______

c-3______

Do Not Write Bellow This Line__________

Nr: [___]