Evaluation of a Monitoring Program for Assessing the Effects of Management Practices on the Quantity and Quality of Drainwater from the Panoche Water District, Western San Joaquin Valley, California

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CONVERSION FACTORS

Multiply	By	To obtain
cubic meter (m^3)	0.0008107	acre-foot
cubic meter per year (m^3/y)	0.0008107	acre-foot per year
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
meter per year (m/y)	3.281	foot per year
square kilometer (km^2)	0.3861	square mile

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

EVALUATION OF A MONITORING PROGRAM FOR ASSESSING THE EFFECTS OF MANAGEMENT PRACTICES ON THE QUANTITY AND QUALITY OF DRAINWATER FROM THE PANOCHE WATER DISTRICT, WESTERN SAN JOAQUIN VALLEY, CALIFORNIA

By David A. Leighton *and* John L. Fio

ABSTRACT

An evaluation was made of an existing monitoring program in the Panoche Water District for 1986-93. The Panoche Water District is an agricultural area located in the western San Joaquin Valley of California. Because irrigation drainage from this area has high concentrations of dissolved solids and selenium, management strategies have been developed to improve the quality of drainwater discharge. The purpose of the Panoche Water District's monitoring program is to assess the effects of water- and land-use practices on local ground water and drainflow from the district. Drainflow from the district consists of the discharge from 50 separate on-farm underground tile-drainage systems.

The Panoche Water District maintains information on water deliveries, planned and actual crop types, and planned and actual acreages planted each year. In addition, the water district monitors ground-water and drainage-system discharges using a variety of data-collection methods. A total of 62 observation well sites are used to monitor ground-water level and quality. A total of 42 sites were monitored for drainflow quantity, and drainflow quality samples were collected from the outlets of each of the 50 drainage systems. However, these data were collected inconsistently and (or) intermittently during the period studied. All data obtained from the water district were compiled and stored in a geographic information system database.

Water delivered for irrigation by the Panoche Water District is a mix of imported water and local ground water pumped directly into delivery canals. Although delivered water is a mix, information on the proportion of water from the two sources is not reported. Also, individual growers pump directly to their crops unknown quantities of ground water, the total of which could be greater than 60 percent of total applications during years when water district deliveries are greatly reduced (for example, the years during and following a drought).

To evaluate the effects of irrigation on ground-water and drainflow quality, data on the combined chemical characteristics and the volume of water applied to crops are needed as part of the district's monitoring program. For example, without these data, this study could estimate only the effects of irrigation on ground-water recharge for 1986 (60.4×10^6 m^3/y), 1987 (74.2×10^6 m^3/y), and 1988 (56.0×10^6 m^3/y) in the Panoche Water District water years when the amount of ground water pumped by individual growers was probably small. Water-level data show a significant decline of the water table in the upslope, undrained parts of the study area, and little or no significant change in the downslope, drained parts of the study area. Pumping from productions wells, most of which are located in the upslope part of the study area, may have contributed to the decline of the water table in the upslope area. The quantities of drainflow, dissolved solids, and selenium discharged from the study area decreased during the study period. However, drainflow, dissolved solids, and selenium discharged from individual on-farm drainage systems did not decrease. These data also illustrate the need for consistent and regular monitoring of the factors that affect drainage in the western San Joaquin Valley.

INTRODUCTION

Shallow ground water that contains high concentrations of dissolved solids has adversely affected agriculture in western San Joaquin Valley, California. To help address this problem, subsurface drains were installed to lower the water table below the root zone. Discharge from these drains, which was impounded at Kesterson National Wildlife Refuge until 1985, contains high concentrations of selenium (Deverel and others, 1984; Presser and Barnes, 1984) that caused high mortality rates in waterfowl (Ohlendorf and others, 1986). Drainage-management strategies to decrease the quantity and improve the quality of discharged drainwater are described in the San Joaquin Valley management plan (San Joaquin Valley Drainage Program, 1990). Successful implementation of the plan requires monitoring of the drainflow and the response of the ground-water system to strategies in the plan. To accomplish this, the Monitoring and Assessment Subcommittee of the Interagency Technical Committee of the San Joaquin Valley Drainage Implementation Program developed guidelines for the collection and management of data to monitor ground-water and surface-water conditions in the western San Joaquin Valley (San Joaquin Valley Drainage Implementation Program, 1994). Monitoring activities recommended by the committee as well as those that have been implemented are shown in table 1. A key element of the guidelines is to ensure the efficient allocation of resources by making use of existing data-collection programs.

Table 1. Monitoring activities recommended by the Technical Committee of the San Joaquin Valley Drainage Implementation Program as well as those implemented by the Panoche Water District.

Category	Recommended	Implemented
Water- and land-use	Spatial distribution of actual crops grown	Estimated crop maps made prior to the growing season, annual crop acreage reports.
	Water deliveries for subareas of water district.	Water deliveries for entire district.
	Ground-water pumpage volumes.	None.
	Water-quality samples of ground pump- age before and after irrigation season.	None.
Ground water - shallow zone	Water-level measurements during periods of minimum and maximum irrigation.	Monthly or biweekly measurements.
	Water-quality samples during periods of minimum and maximum irrigation.	None.
Ground water - semi-confined zone	Water-level measurements at cluster sites during periods of maximum and minimum irrigation.	Monthly or biweekly measurements, but no wells perforated near bottom of semi-confined zone.
	Water-quality samples annually.	None.
Surface and drainage water	Continuous-flow measurements at district outflow.	Monthly flow at PE-14.
		Monthly flow at some on-farm drainage systems.
	Water-quality samples monthly.	Monthly measurements of electrical conductivity, selenium, and boron at PE-14.
		Monthly total dissolved solids and quarterly electrical conductivity, selenium, and boron at on-farm drainage systems.

Several data-collection programs are being conducted by water districts in the western San Joaquin Valley, but little effort has been made to assess the usefulness of the data. Although the management decisions implemented by individual growers are unknown, changes in water management at the water-district level are documented. Deliveries of Federal and State Project water have been reduced substantially since the late 1980's because of climatic conditions and changes in project operations. The decrease in available surface water for irrigation has provided incentive to growers to improve water-conservation practices, implement new irrigation technologies, and alter the types and acreage of crops grown. However, pumping of ground water has increased in order to supplement imported water. These activities can affect the shallow ground-water system and the quantity and quality of the ground water intercepted by the drainage systems.

The purpose of this study, done by the U.S. Geological Survey (USGS) in cooperation with the California Department of Water Resources, is to evaluate the effectiveness of existing data-collection activities for assessing water-management practices and their effects on drainwater. The results of this study will help guide plans for the design, modification, and (or) implementation of data-collection and assessment programs for this and other areas of the western San Joaquin Valley. Surface-water, ground-water, land-use, and drainflow data at the water-district scale from 1986 to 1993 were used in this study.

Study Area

The study area boundary is coincident with the boundary of Panoche Water District in the central part of the western San Joaquin Valley (fig. 1). Average annual precipitation in the study area is about 230 mm/y (NOAA, 1994) measured at Los Banos, California. The 160 km^2 water district is located on alluvial fan and interfan deposits in the vicinity of Little Panoche and Panoche Creeks. On-farm drainage systems consisting of perforated drain laterals, which underlie about 49 percent of the study area, typically are buried between 1.8 and 2.7 m below land surface, and horizontal spacing ranges from about 30 to 180 m (Fio, 1994). The topography generally slopes downward to the northeast and the drainage systems generally are located in the downslope parts of the study area. The location of the study area relative to the alluvial fans and the area containing subsurface drainage systems is shown in figure 2.

The Panoche Water district was selected for this study for four reasons: (1) The water district represents an intermediate step between the field and regional scales of observation recommended in the long-term monitoring plan, (2) it represents an effective management unit for implementing drainage-management strategies, (3) it has a good monitoring program relative to other areas of the valley, and (4) previous work has been done to evaluate the effects of the regional ground-water-flow system on drainflow (Fio, 1994; Fio and Leighton, 1994).

Geohydrologic Setting

The San Joaquin Valley is a large asymmetric trough that has been filled with as much as 9.7 km thickness of unconsolidated sediments (Page, 1986). In the western part of the valley these sediments were deposited by ephemeral and intermittent streams draining the foothills and Coast Ranges that border the valley. The resulting deposits are typically dominated by gravel and sand at the upper slopes and along stream channels, and by silt and clay at the fan margins and in areas of relatively gentle topographic relief (Laudon and Belitz, 1991).

The regional ground-water flow system in the San Joaquin Valley is divided into a semi-confined zone and an underlying confined zone separated by a thick clay layer (the Corcoran Clay Member of the Tulare Formation) (Page, 1986). The saturated thickness of the semi-confined zone is as great as 150 m in the central part of the western valley (Belitz and Heimes, 1990).

Previous studies in the same area assessed the effects of regional ground-water flow on dissolved-solids and selenium concentrations in on-farm drainflows (Fio and Leighton, 1994) and the contribution of regional ground-water flow to on-farm drainflow (Fio, 1994). These reports provide a detailed description of the geohydrologic setting in the study area.

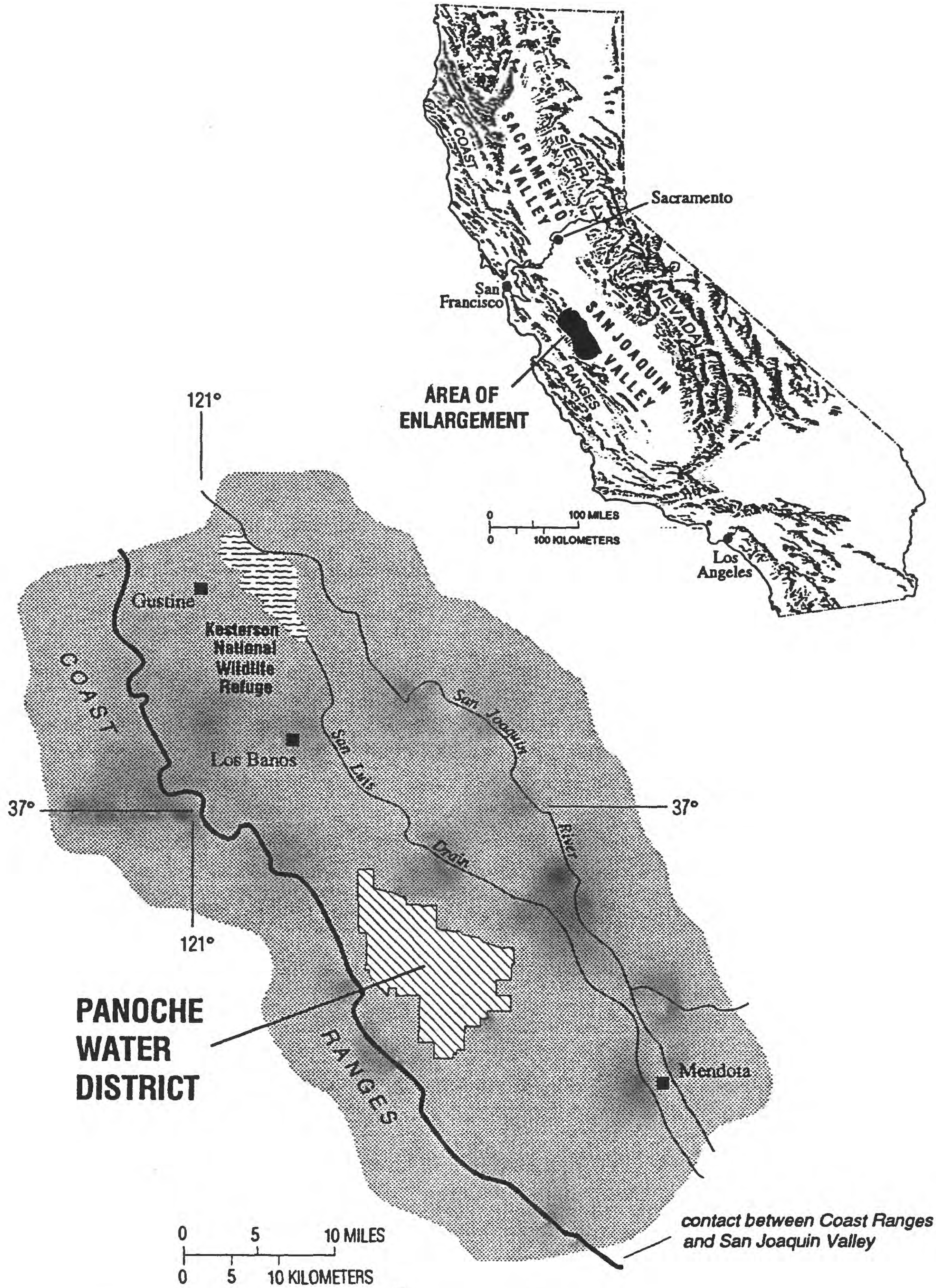
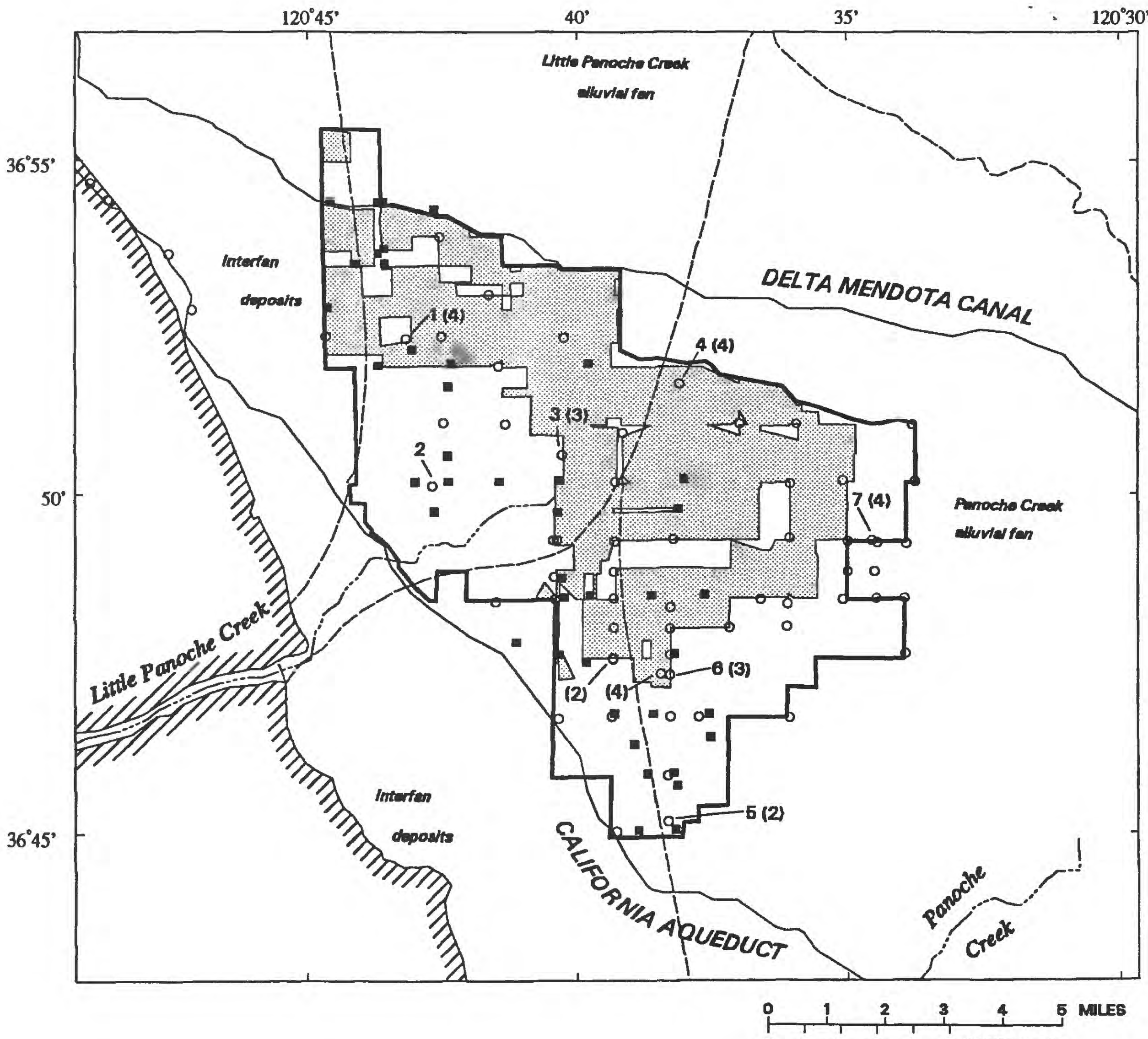


Figure 1. The Panoche Water District within the western San Joaquin Valley, California.



EXPLANATION

AREA UNDERLAIN BY DRAINAGE SYSTEMS

BOUNDARIES

Western boundary of valley deposits

Study area

Alluvial fans

■ PRODUCTION WELL

○ OBSERVATION WELL SITE - Cluster sites identified by cluster site identification number. Number in parentheses indicates the number of wells at sites having more than one well.

Figure 2. Location of drained areas, production wells, and observation well sites within and in the vicinity of the Panoche Water District.

The focus of this study, with respect to the ground-water system, is the upper 30 m of the semi-confined zone. This interval is composed of a series of discontinuous, interfingering coarse- and fine-grained deposits that dip down toward the east and the central part of the valley. These deposits are the principal source of dissolved solids and selenium in this and other areas of the western San Joaquin Valley (Tidball and other, 1986).

Acknowledgments

The technical and editorial review of this report was by Jim Baker, Tony Buono, Clark Londquist, Steve Phillips, Carol Sanchez , all of the California District, and Tim Rowe of the Nevada District. The authors thank these individuals for the special effort that went into the team-style review of the report. Also, a special thanks is made to Jerry Woodcox for his individual editorial review of the report.

METHODS

Available monitoring data were acquired from Panoche Water District for the period 1986-93. For convenience, data were compiled and analyzed on the basis of the Panoche Water District's water year (PWDWY), which extends from March through February of the following year. The district collects data on surface-water deliveries, land use (crop-projection maps and crop-acreage reports), ground-water levels, and quantity and quality of drainflow. These data were combined with ground-water-level and ground-water-quality data collected by Fio (1994) and Fio and Leighton (1994).

Database Development

Most of the data were compiled into a geographic information system (GIS) database. A GIS consists of computer software and hardware used for storing, managing, analyzing, and displaying spatial data. Spatial data on geographic features (for example, well locations and drainage-system locations) and attributes of these features (for example, well depths, ground-water levels and drainflows) are stored in individual spatial data layers and related files. Data layers that were developed for previous studies in the area (Fio, 1994; Fio and Leighton, 1994; and Irrigation Training and Research Center, 1994) were used. Data on water deliveries, land use, ground-water levels and quality, and drainage quantity and quality were linked with the GIS data layers for use in spatial and temporal analyses.

Water-Use and Land-Use Data

Data on annual water deliveries to growers were provided by the water district (Marcos Hedrick, Panoche Water District, written commun., 1994) for the entire study period (1986-93 PWDWY). Monthly water delivery data also were available for the period March 1989 to February 1994. Water-delivery quantities were reported as a total by the district and consist of imported surface water and ground water pumped by the growers and diverted into the district's water delivery canals. However, the total does not include ground water pumped by the growers and applied directly to crops. Data on ground-water pumpage from these individual wells were not available to the water district and, therefore, were not available for this study.

Crop-acreage data reported by the Irrigation Training and Research Center (1994) were used for 1986-92 PWDWY and data provided by the water district were used for 1993 PWDWY (Marcos Hedrick, Panoche Water District, written commun., 1994). The data reported by the Irrigation Training and Research Center (1994) were obtained from annual reports of actual crop acreages submitted by the water district to the U.S. Bureau of Reclamation.

Meteorological Data

Monthly precipitation data were obtained from the Los Banos meteorological station operated by the National Oceanographic and Atmospheric Administration (NOAA, 1986-94) located about 19 km northwest of the study area. Monthly reference evapotranspiration data were summarized from California Irrigation Management Information System (CIMIS) station #7 from daily values for the period 1986-92 PWDWY by the Irrigation Training and Research Center (1994), and monthly data for 1993 PWDWY were obtained directly from the CIMIS database.

Ground-Water Data

Within the study area are 42 production wells (fig. 2) that yield ground water from the semi-confined and confined aquifer zones below the interval of interest in this investigation. These wells are owned by the individual growers, and only minimal construction and production data are available. As previously mentioned, ground water pumped from these wells is either diverted into the district's water delivery canals or applied directly to crops.

A network of 62 observation-well sites (fig. 2) was established in early 1990 to collect data on ground-water levels and quality. The individual observation wells range in depth from 2.6 to 15.6 m, and the cluster wells (as many as four wells at each site) range in depth from 3.8 to 29.3 m. The cluster wells provide an understanding of the vertical distribution of hydraulic head and water quality in the district. Water-level measurements from the observation wells were collected biweekly by the USGS from February 1990 through June 1991. Beginning in July 1991, the water district collected water-level measurements from the wells once or twice a month. Water-quality samples were collected from these observation wells from April through July 1990 by the USGS (Fio and Leighton, 1994). Data for these wells include well-identification number, well depth, casing diameter, perforated interval, land-surface elevation, and date drilled.

Drainflow Data

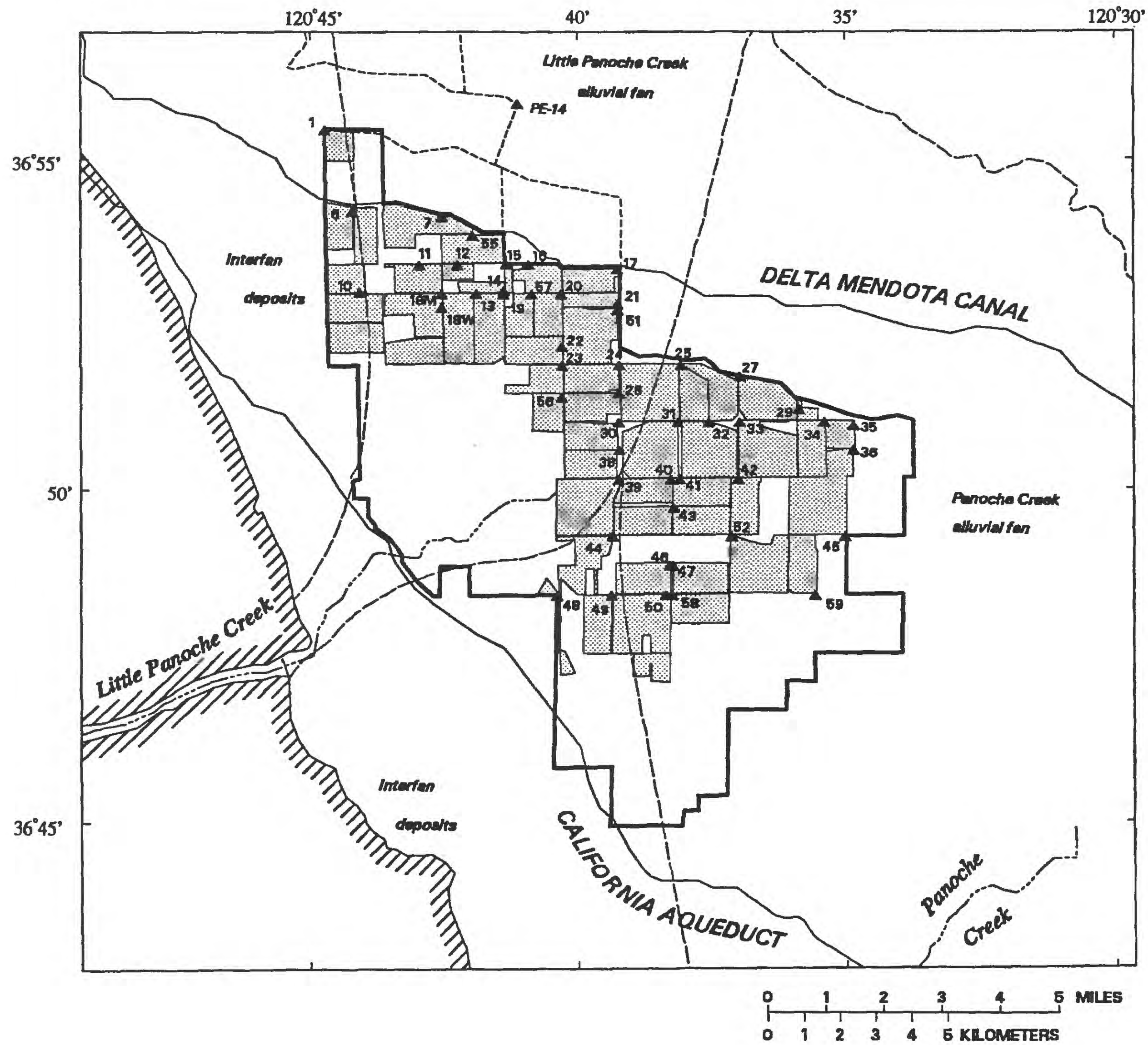
The district is responsible for the collection and disposal of drainwater from 50 separate on-farm underground-tile drainage systems (fig. 3). During the study period, drainflow data were collected discontinuously and inconsistently from the 50 drainage systems (fig. 4); data were not available from April 1990 through June 1991.

Discharge from the drainage system was measured from a total of 42 sites during the study period using a combination of in-line flow meters, weirs (from September 1986 to June 1988 only), and electrical power consumption records from collector-sump pumps. The number of sites for which discharge data were available ranged from 20 for 1 month in 1990 PWDWY to 41 for up to 12 months in 1986 PWDWY.

Drainflow quality data were collected from the outlets of the 50 drainage systems (fig. 3) in the study area. The number of sites for which drainflow-quality data were available ranged from 20 for nine months in 1991 PWDWY to 50 for 12 months in 1993 PWDWY. These data are used by the water district to determine loads of dissolved solids, selenium, and other constituents being discharged from the systems. Data on dissolved solids in the drainage water were collected approximately once a month. Data on specific conductance, an indicator of dissolved-solids concentration, and the concentrations of selenium were collected approximately four times a year.

On a monthly basis, water samples were collected and discharge was measured at site PE-14 (fig. 3), which is the primary outlet for drainage water from the Panoche Water District and three small adjacent water districts. Water samples were analyzed for specific conductance and selenium.

A data layer delineating the boundaries of the area drained by each on-farm drainage system was created initially by Fio (1994) using tile-drain construction records and maps of tile-drain line layouts and drainage-system outlets. This data layer was updated for this study using a digital data layer containing the layout of the tile-drain lines (Irrigation Training and Research Center, 1994).



EXPLANATION

AREA UNDERLAIN BY DRAINAGE SYSTEMS

BOUNDARIES

Western boundary of valley deposits

Study area

Alluvial fans

DRAINFLOW DISCHARGE CANALS FROM PANOCHE WATER DISTRICT

1 ON-FARM DRAINFLOW DISCHARGE SITES - Number next to symbol indicates Panoche Water District identification number.

PE-14 DRAINFLOW DISCHARGE SITE PE-14

Figure 3. Location of on-farm drainage systems and drainage discharge sites in the Panoche Water District and PE-14.

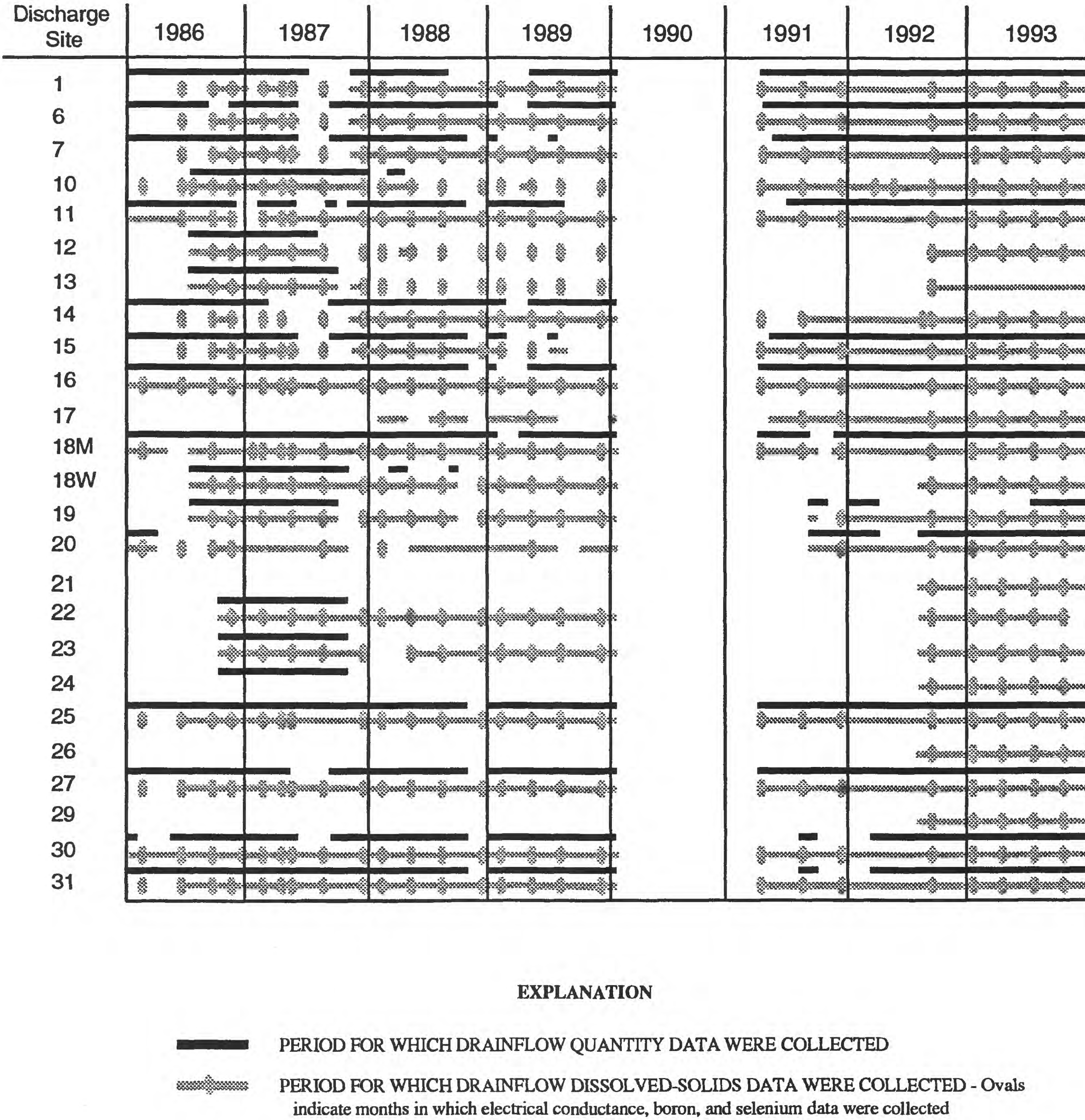
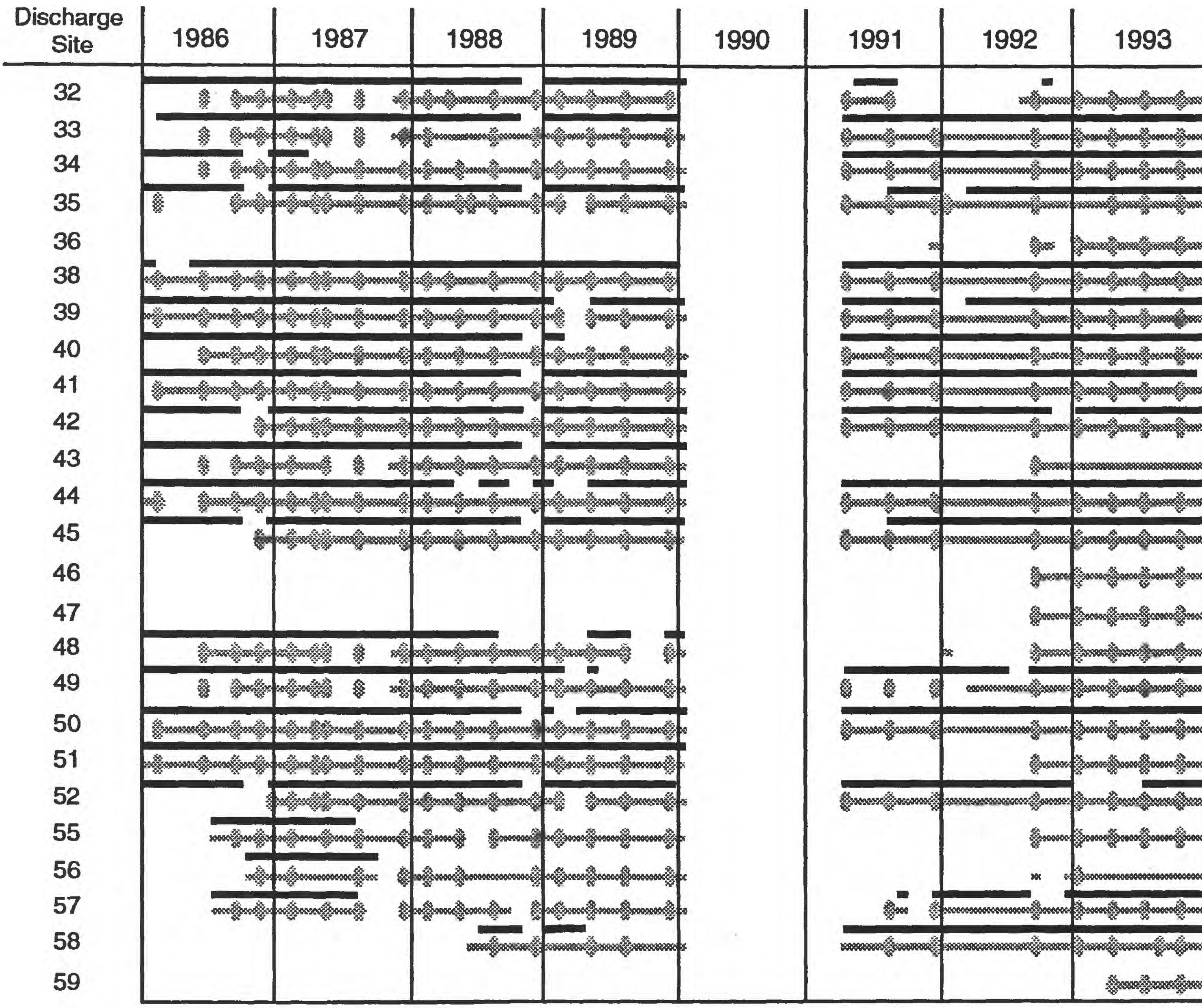


Figure 4. Periods for which drainflow quantity and quality data were collected from on-farm drainage systems in the Panoche Water District, 1986-93 Panoche Water District water years.



EXPLANATION

PERIOD FOR WHICH DRAINFLOW QUANTITY DATA WERE COLLECTED

PERIOD FOR WHICH DRAINFLOW DISSOLVED-SOLIDS DATA WERE COLLECTED - Ovals indicate months in which electrical conductance, boron, and selenium data were collected

Figure 4.--*Continued*

Estimating Recharge to the Water Table

Recharge to the water table is defined in this study as the amount of water applied that infiltrates past the crop roots and into the saturated zone. Determination of the spatial distribution of recharge in the study area requires data on the spatial distribution of water applied and consumptive use. The spatial distribution of these components of recharge was not known and recharge was calculated as the total for the entire study area only. Annual recharge to the water table was calculated using the following equation:

$$R = Wa + Pe - C, \quad (1)$$

where

R is recharge to the water table,
Wa is water applied,
Pe is effective precipitation, and
C is consumptive use.

Water applied (Wa) consists of water deliveries reported by the water district (the total of imported water and ground water pumped to delivery canals) and ground water pumped by growers that is applied directly to crops (quantity not known for this study). Precipitation is another source of water for crops. Evaporation reduces the amount of precipitation that infiltrates the soil and becomes available for crops or recharge. The amount of precipitation that infiltrates the soil, termed effective precipitation (Pe), was estimated as 50 percent of the precipitation during the months of October through February (Irrigation Training and Research Center, 1994). Monthly evapotranspiration (ETc), which is consumptive use (C) by crops, was calculated using the equation described below (Irrigation Training and Research Center, 1994).

$$ETc = Kc \times ETo \times F, \quad (2)$$

where

ETc is monthly crop evapotranspiration,
Kc is monthly crop coefficient,
ETo is monthly reference evapotranspiration, and
F is an adjustment factor for bare spots and stunted growth.

The monthly crop coefficients (Kc) were reported by the Irrigation Training and Research Center (1994), and the monthly reference evapotranspiration rates are from CIMIS station # 7. The factor used to account for bare spots in fields and stunted growth of crops was determined by visual inspection of fields during the growing season and was estimated to be 86 percent (Irrigation Training and Research Center, 1994). Evapotranspiration in fields that remained fallow during the entire year was estimated to represent bare-soil evaporation. The method used by the Irrigation Training and Research Center (1994) was modified to include bare-soil evaporation for cropped fields during months when the fields were fallow (monthly crop coefficient equals zero). Monthly crop evapotranspiration (ETc) values were summed to obtain an annual crop evapotranspiration which was multiplied by the annual acreage of each crop to determine the total consumptive use for each crop. Annual consumptive use for each crop was summed to determine the total annual consumptive use (C) for the study area.

Trend Analysis of Temporal Data

Trends in ground-water levels and seasonal variations in drainflow with were determined using the Mann-Kendall test described by Helsel and Hirsch (1992). This is a form of simple linear regression. Seasonality in the data is accounted for by using the seasonal Kendall test (Hirsch and others, 1982).

WATER AND LAND USE

Total annual water deliveries in the study area for 1986-93 PWDWY are shown in figure 5 and table 2. Water deliveries ranged from 45.5×10^6 m^3 in 1991 to 137.9×10^6 m^3 in 1987 PWDWY. The variability of water deliveries during this period was caused by reduced availability of imported water resulting from several years of drought. To compensate, unknown quantities of ground water were pumped by individual growers and applied directly to their crops. Also, other sources of water contribute to crop consumptive use. One source is the water table in the downslope areas, particularly where it is less than 2 m below land surface (see fig. 10 later in this report). Another source is precipitation. During the study period, effective precipitation (fig. 6 and table 2) ranged from 6.5×10^6 m^3 in 1990 PWDWY to 25.4×10^6 m^3 in 1992 PWDWY. The years having the largest quantity of precipitation (1991-92) are the same years having the smallest quantity of delivered water.

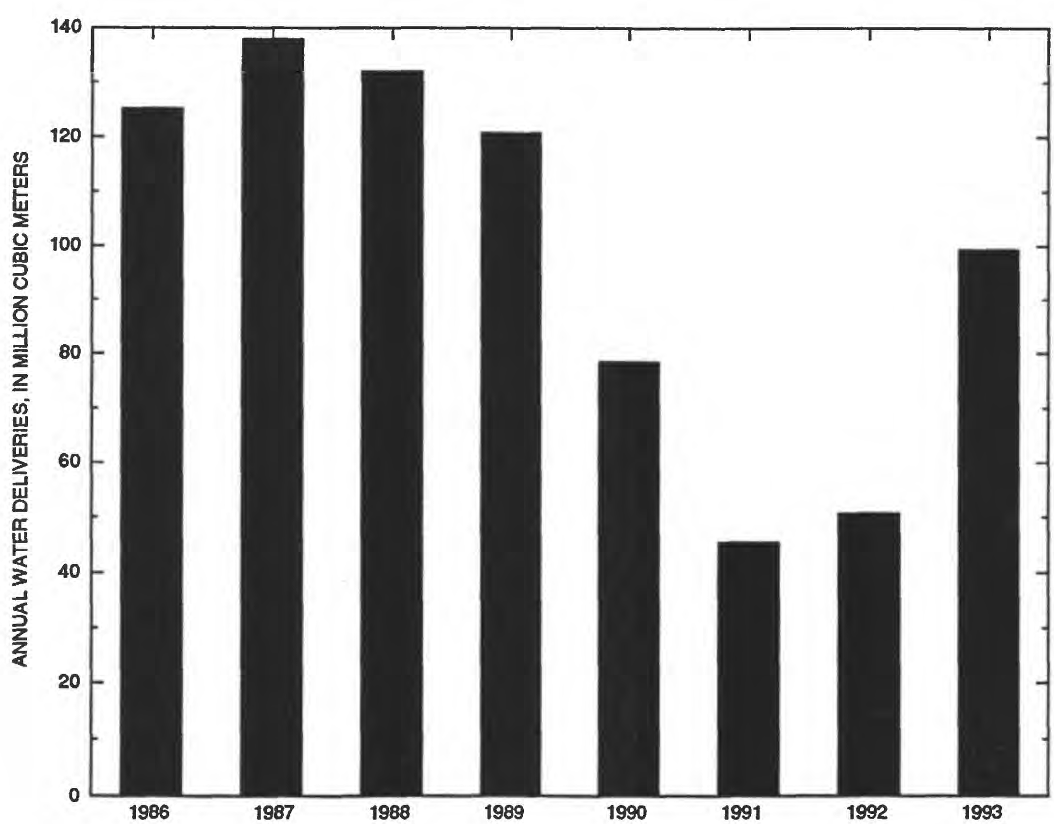


Figure 5. Annual water deliveries reported by the Panoche Water District, 1986-93 Panoche Water District water years.

Table 2. Annual water delivered, effective precipitation, consumptive use, and estimated recharge to the water table in the Panoche Water District, 1986-93 Panoche Water District water years

[Values are in millions of cubic meters. Query (?) indicates values are unknown]

Panoche Water District water year	1986	1987	1988	1989	1990	1991	1992	1993
Water delivered (Wd)[1]	125.3	137.9	132.0	120.8	78.4	45.5	50.7	99.3
Water pumped (Wp)[1]	?	?	?	?	?	?	?	?
Effective precipitation (Pe)	14.8	17.7	8.0	9.2	6.5	19.0	25.4	15.6
Consumptive use (C)......................	(79.7)	(81.4)	(84.0)	(89.1)	(81.1)	(71.4)	(71.1)	(79.2)
Estimated recharge (R)..................	60.4	74.2	56.0	([2])	([2])	([2])	([2])	([2])

[1]Annual water applied [Wa in equation (1), see p. 11] in the study area is actually the combined values of water delivered (Wd) by the Panoche Water District and water pumped (Wp) and applied directly to crops by individual growers.

[2]Recharge for 1989-93 Panoche Water District water years was not estimated because it is assumed that a significant quantity of water was pumped and applied directly to crops during these years.

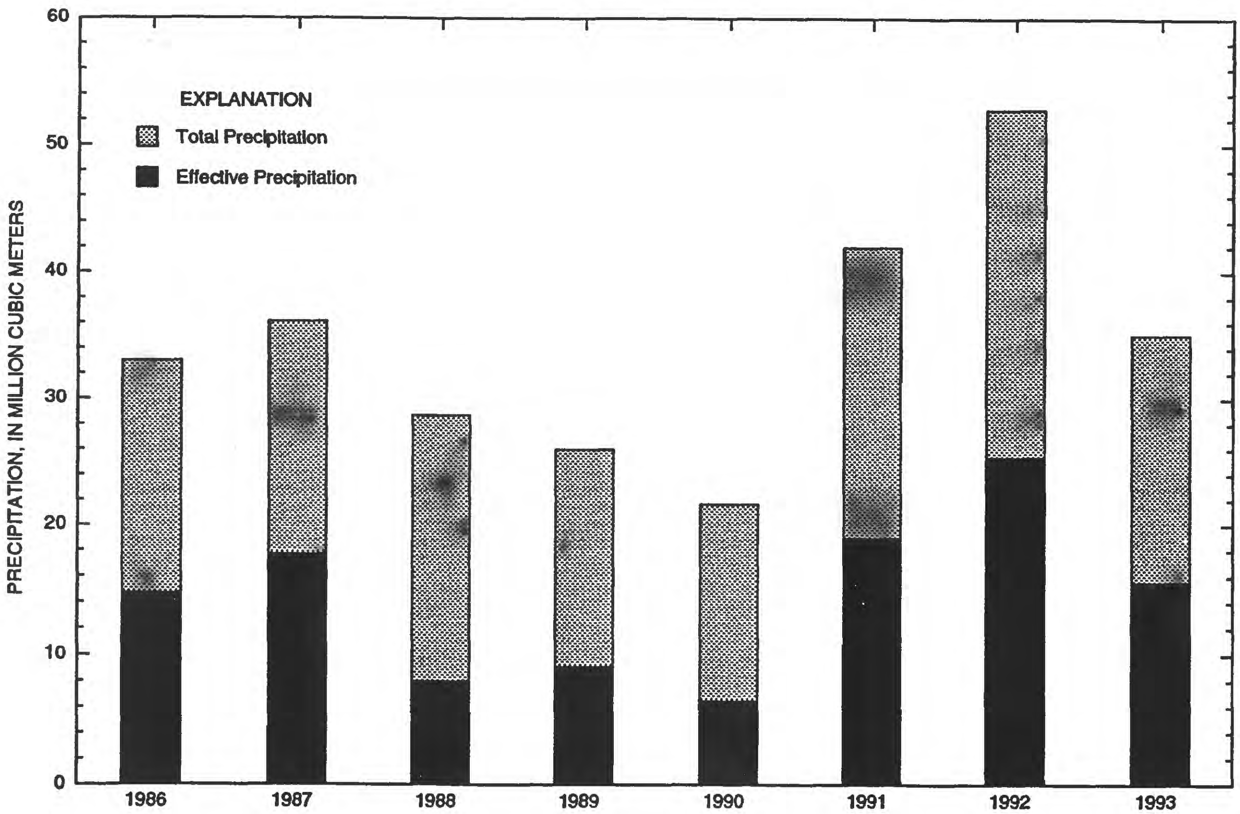


Figure 6. Annual total and effective precipitation volume, 1986-93 Panoche Water District water years.

The lack of data on ground-water pumped by individual growers results in an underestimate of water applied to crops, which also affects estimates of recharge. Furthermore, underestimates of ground water pumped by growers may be large during years of reduced availability of imported water. To evaluate the magnitude of the underestimates, comparisons of district water deliveries (table 2 and fig. 5) and consumptive use (table 2 and fig. 7) were made focusing on the year of maximum delivery (assumed minimum ground-water applications by growers) and minimum delivery (assumed maximum ground-water applications by growers) by the district. The comparison of reported water delivered (table 2) in 1987 PWDWY (maximum) and 1991 PWDWY (minimum) shows that delivery in 1991 PWDWY was only 33 percent (45.5×10^6 m^3 137.9×10^6 $m^3 = 0.33$) of that in 1987 PWDWY. However, a comparison of consumptive use (fig. 7) for the same years shows that consumptive use in 1991 PWDWY was 88 percent (71×10^6 m^3 81×10^6 $m^3 = 0.88$) of that in 1987 PWDWY. Assuming that the ratio of crop types grown (and their rates of consumptive use) are similar in both of these years and ignoring any differences in precipitation and crop uptake from the water table, one can assume that an additional 75.8×10^6 m^3 (137.9×10^6 m^3 $0.88 = 121.4 \times 10^6$ $m^3 - 45.5 \times 10^6$ $m^3 = 75.8 \times 10^6$ m^3) of water must have been applied in 1991 PWDWY. If so, then the unaccounted for water is about 60 percent (75.8×10^6 m^3 121.4×10^6 $m^3 = 0.62$) of actual water applied in 1991 PWDWY; this unaccounted for water would have to be ground water pumped by individual growers.

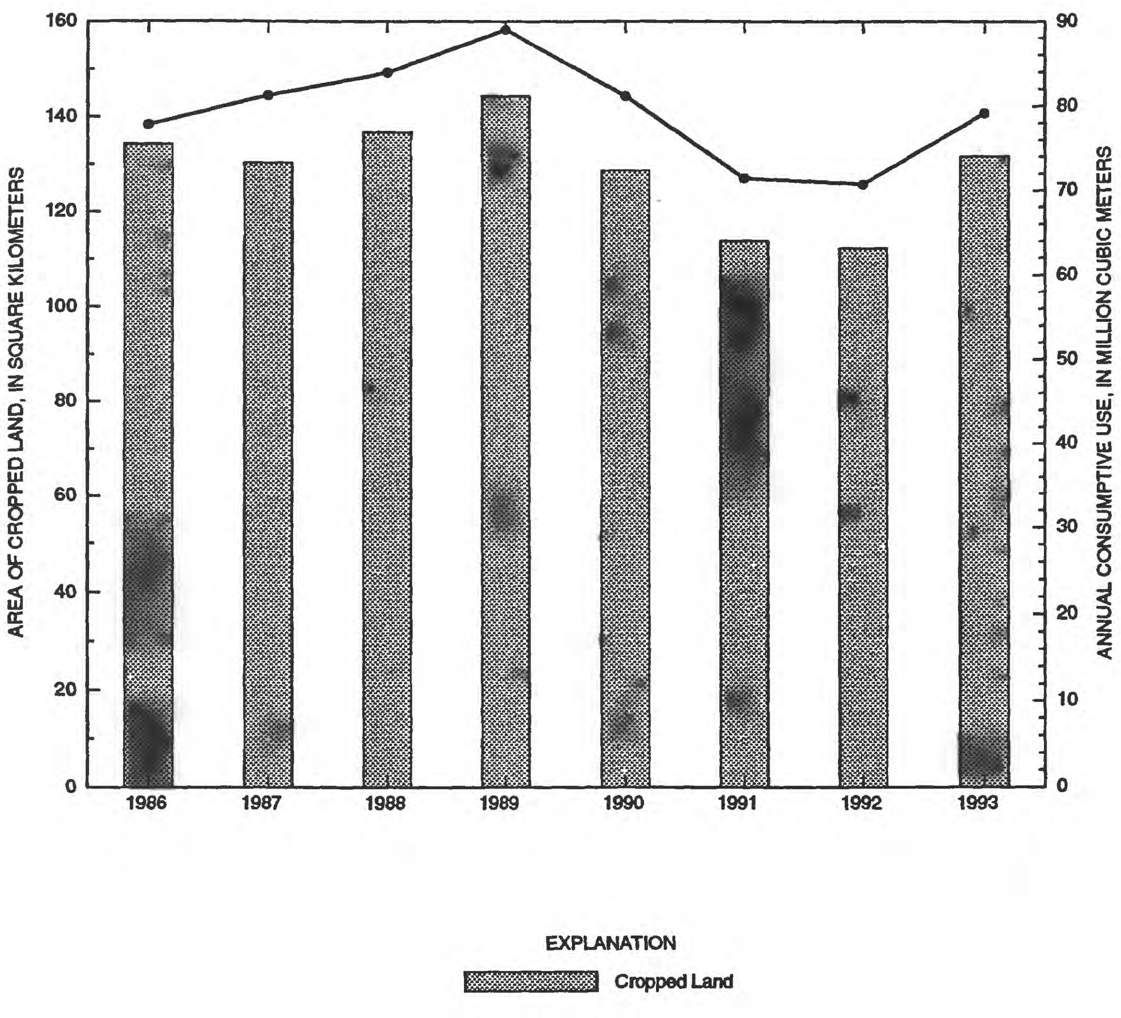


Figure 7. Annual area of cropped land and estimated consumptive use, 1986-93 Panoche Water District water years.

RECHARGE TO THE WATER TABLE

Annual recharge from 1986 PWDWY to 1988 PWDWY was estimated (table 2) using equation 1. Recharge values for the remaining years of the study were not estimated because of inadequate data. During these years, which were years of reduced water deliveries, direct application of ground water pumped by individual growers is assumed to be a large component of total water applied to crops. Although variation in recharge may occur as a result of changes in management strategy or availability of imported water, reasonable estimates of recharge are not possible without good estimates of the quantities of ground water applied to the crops.

Other factors also affect the comparability of recharge estimates made in this study with those made in other studies in the area for the same period. For example, estimates of consumptive-use parameters (effective precipitation and crop coverages) used in this study differed from those of Fio (1994). Fio estimated average annual recharge for the years 1987 PWDWY and 1988 PWDWY to be 55.6×10^6 m^3, in comparison with an average annual recharge of 65.1×10^6 m^3 estimated in this study. The method used by Fio considered the total quantity of precipitation to be effective precipitation. Evaporation of a part of the total precipitation was incorporated into the calculation of consumptive use (Ayars and Schrale, 1989). This results in higher consumptive-use estimates than those reported in this study. The annual average consumptive use reported by Fio (1994) for 1987 PWDWY and 1988 PWDWY was 112.0×10^6 m^3 in comparison with an annual average of 82.7×10^6 m^3 in this study. In their consumptive use estimates, Ayars and Schrale (1989) also assumed that 95 percent of the field is covered by fully grown crops, whereas 86 percent (F in equation 2) was assumed in this study. If consumptive use used in this study were recalculated using a crop coverage of 95 percent, it would result in an annual average consumptive use of 90.8×10^6 m^3 for 1987 PWDWY and 1988 PWDWY and an estimate of recharge of 56.8×10^6 m^3, which is similar to the estimate of 55.6×10^6 m^3 reported by Fio.

On the basis of a previous study, it is known that recharge to the water table is not uniformly distributed over the study area. Fio (1994) evaluated recharge for three subareas and showed that recharge was less in drained areas than in undrained areas. Estimates of spatial variability of recharge requires knowledge of the distribution of water applied and cropping patterns. Although the district maintains water-delivery data based on land ownership, these data were not available for this study. However, even if land owner delivery data were available, the actual spatial distribution within those land holdings is unknown and, therefore, distribution of recharge is uncertain.

An additional problem in making estimates of spatial distribution of recharge is the lack of actual crop maps, and therefore good spatial estimates of consumptive use. Although crop maps are developed by the water district, they are developed prior to the growing season for the purpose of projecting water demand (Marcos Hedrick, Panoche Water District, oral commun., 1995). However, comparisons of projected and actual crop acreages show significant differences. For this and the other reasons noted above the spatial distribution of recharge to the water table was not evaluated for this study.

GROUND-WATER MONITORING

The district maintains a network of 62 monitoring-well sites, including seven cluster-well sites (fig. 2). This network can be used to establish baseline conditions, to evaluate temporal changes in ground-water levels in the study area, and to determine the effects of management actions on the system. The evaluation of hydraulic-head data from individual observation wells and cluster sites can provide insight on the variability of horizontal and vertical flow conditions.

Temporal and Spatial Changes in Water Levels

Temporal trends in the water-level data from 1990 to 1993 PWDWY were analyzed using the Mann-Kendall test using 47 wells (shown in fig. 8). Of the 47 wells, 4 showed a rise, 27 were stable, and 16 showed a

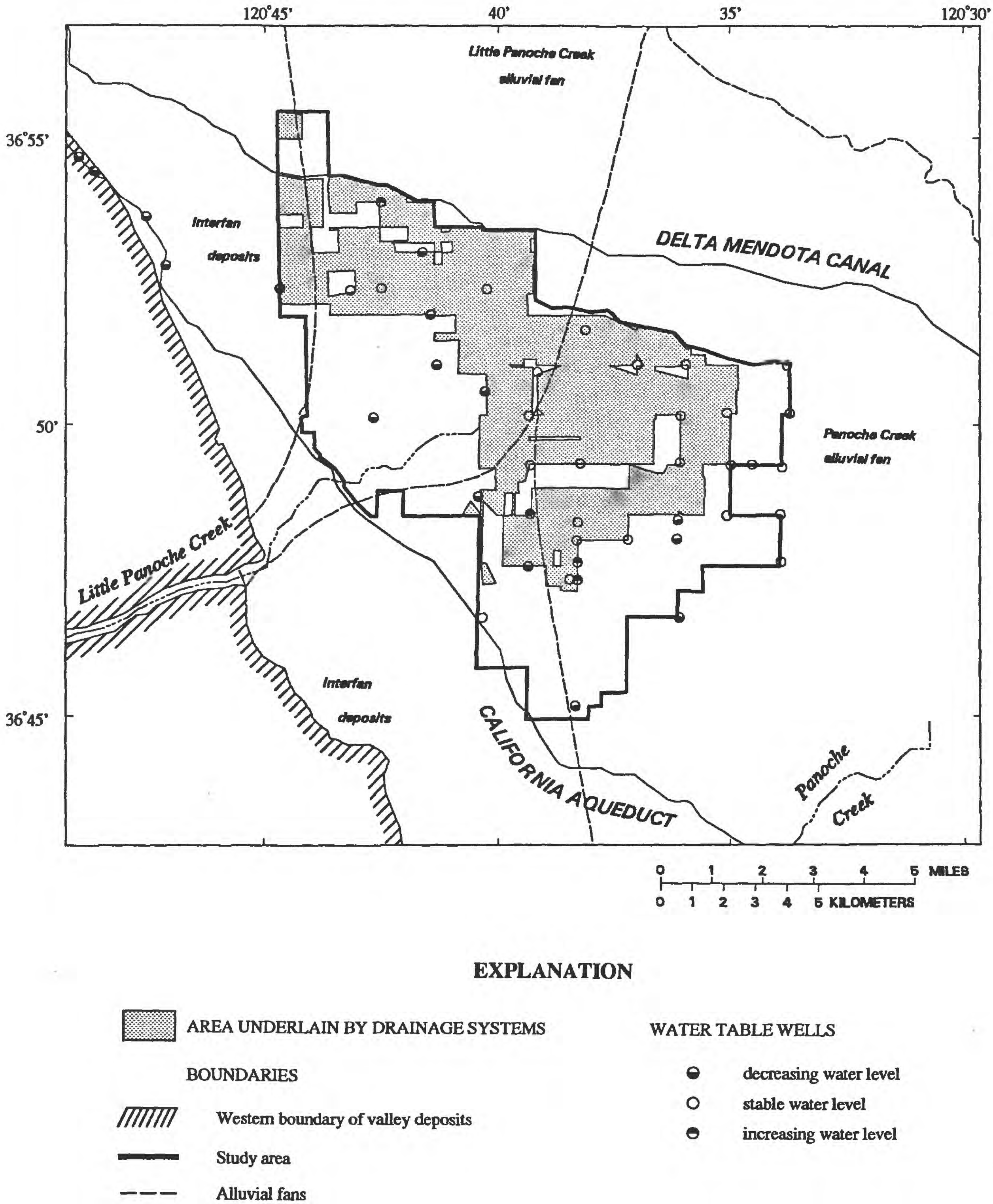


Figure 8. Distribution of water-table wells with decreasing, stable, and increasing water levels within and in the vicinity of the Panoche Water District, 1990-93 Panoche Water District water years.

decline in water levels during the period 1990-93 PWDWY. Although these changes in water levels are statistically significant (a=0.05), the actual change in water level during 1990-93 PWDWY was small (0.3 m) in cluster well 1 in the downslope drained area, but large (1-2 m) in cluster wells 2 and 5, which are farther upslope and in the undrained areas (see fig. 11 later in this report). Seasonally, maximum water levels generally occur during the period of maximum irrigation (not unexpectedly) and the minimum water levels generally occur during the period of minimum irrigation.

Wells with rising or stable water levels generally are in the downslope area (fig. 8), which is the area underlain by drains. Wells with declining water levels generally are in the upslope, undrained part of the study area. This may be partly explained by the distribution of coarse- and fine-grained sediment in the study area. Water levels in the predominantly coarse-grained sediments in the upslope areas may respond faster to changes in recharge and pumpage than water levels in the predominantly fine-grained sediments in the downslope areas. Additionally, Fio (1994) identified areas in the downslope part of the study area where upward flow of ground water from deeper zones occurs. This upward flow may inhibit declines in water levels in the downslope part of the study area. Also, drainage systems have a stabilizing influence on water levels in the downslope areas.

Changes in water levels were evaluated by analyzing the extent of the area with a shallow water table. In this study, the area where the water table was within 2 m of land surface was considered to have a shallow water table. The total area with a shallow water table varies monthly depending on water application (fig. 9). As would be expected, the area with a shallow water table is generally largest in July (during the peak irrigation period) and smallest in autumn and early winter (during the period of minimum irrigation) (fig. 10). Sparse data indicate that the area of the shallow water table may reach a minimum in November and December. However, data from October were used in figures 9 and 10 because the data set for the study period was more complete for October than for November or December.

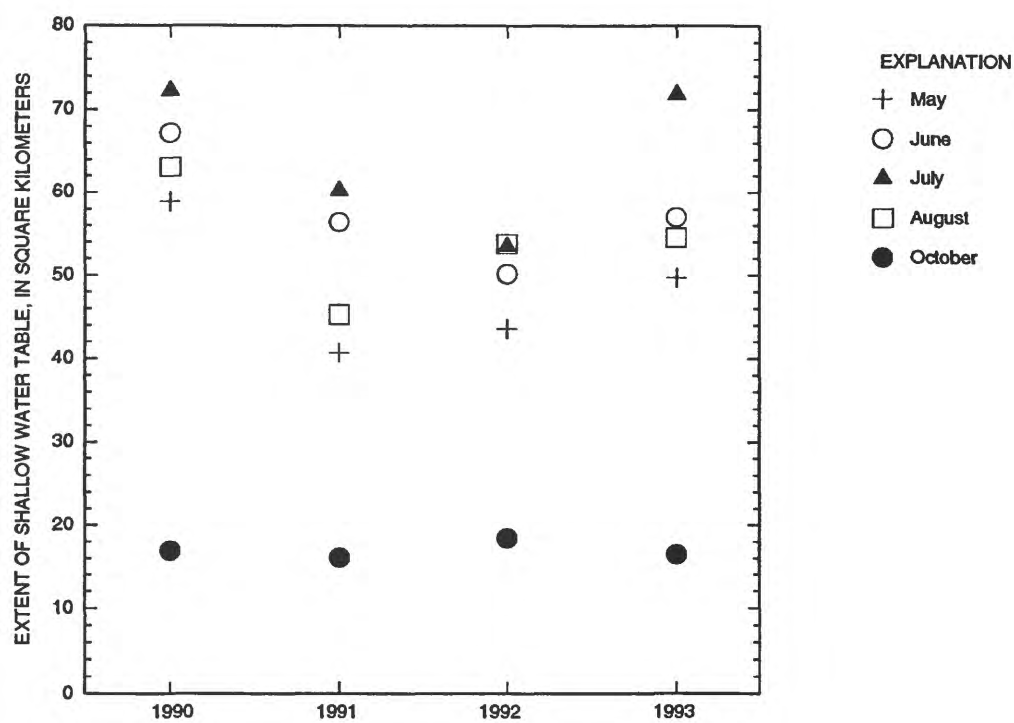


Figure 9. Estimated total area underlain by a shallow water table (less than 2 m below land surface) in May, June, July, August, and October, 1990-93

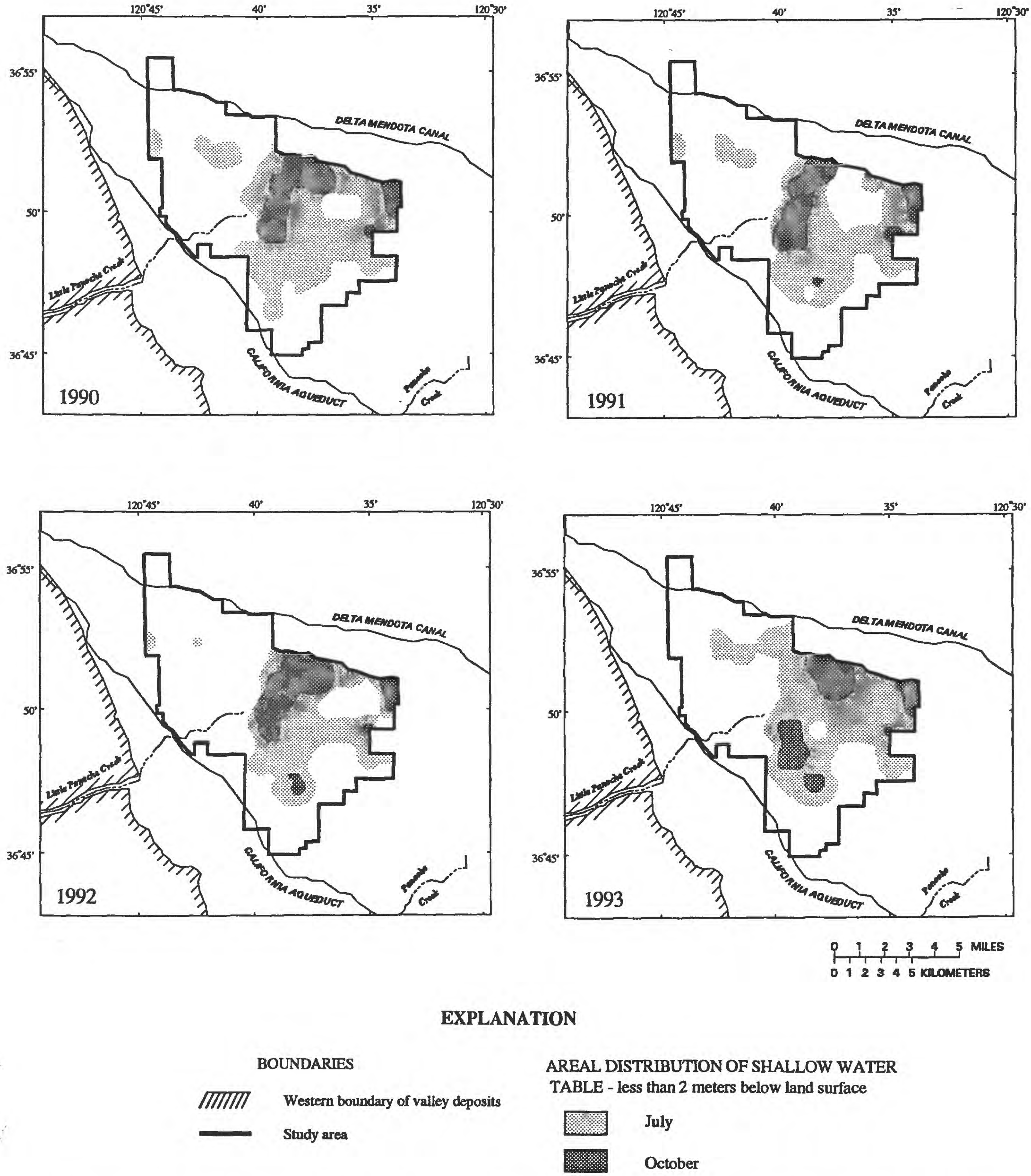


Figure 10. Estimated areal distribution of the shallow water table (less than 2 m below land surface) in July and October, 1990-93.

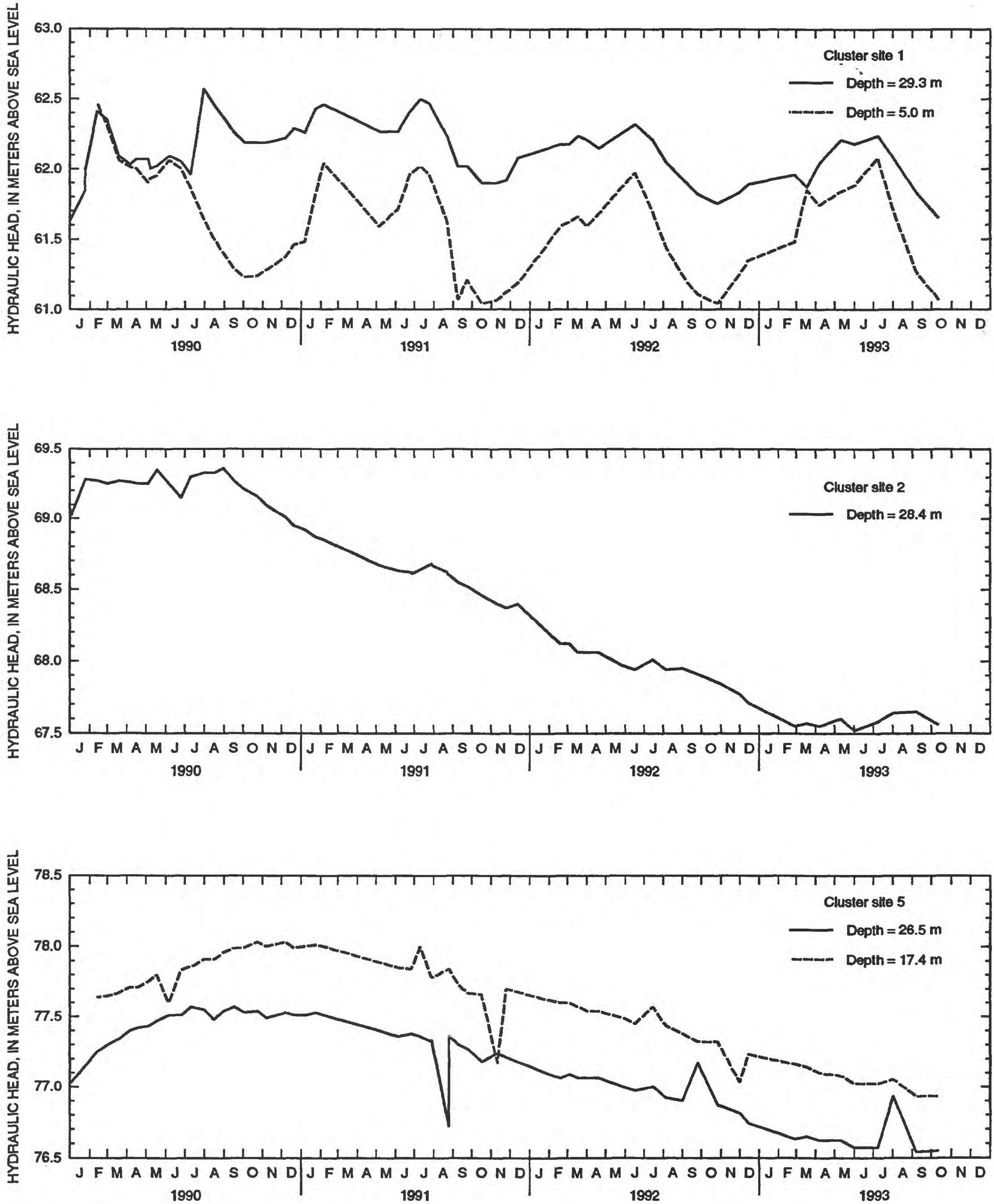


Figure 11. Hydrographs of selected wells in the Panoche Water District, January 1990 through October 1993.

The variations in the total area underlain by a shallow water table during peak irrigation for 1990-93 PWDWY follows the trend of the annual changes in water deliveries (fig. 5). In 1990-91 PWDWY, the quantity of water delivered was decreasing. This decrease probably resulted in the decrease in the area underlain by a shallow water table. In 1992 PWDWY, the quantity of water delivered increased slightly from 1991 PWDWY; however, the area underlain by the shallow water table continued to decline, but at a slower rate (see fig. 9). The large increase in water delivered in 1993 PWDWY resulted in a corresponding increase in the area underlain by the shallow water table, particularly in July. The total area underlain by a shallow water table in October varies slightly from year to year and apparently is insensitive to changes in spring and summer irrigation patterns.

Hydraulic Heads and Vertical Gradients at Cluster Sites

Hydraulic-head data from the six cluster sites that have wells deeper than 25 m were used to analyze changes in water level-trends in the deepest zone monitored and to analyze vertical gradients at those locations. These wells have 0.6-m perforated intervals centered at depths ranging from 26.4 to 29.3 m below land surface. Hydraulic heads in all the deep wells showed a declining trend from 1990 to 1993 PWDWY. The maximum decline was at cluster site 2 (fig. 11), which is in the upslope, undrained area where most of the production wells are located. Cluster site 1 is typical of the drained area where the declining trend in the hydraulic head is less than in the undrained area (fig. 11).

Hydraulic-head data from the shallowest and deepest wells at cluster sites 1, 3, 4, and 6, located in the drained area, indicate an upward component of flow (highest head or water level is in the deepest well). This indicates that, as would be expected, the drainage systems (which are located above the shallowest wells) are functioning as a zone of areal ground-water discharge. Data from cluster site 5, located in the undrained area, indicate a downward component of flow (highest head or water level is in the shallowest well), which probably is a response to ground-water production from below the monitored zone (fig. 11). Data from cluster site 7 (not shown in fig. 11) indicated no vertical flow. Data from cluster site 2 were not used in this analysis because, although it is referred to as a cluster site, only one well was completed at that location.

DRAINFLOW MONITORING

Discharge from the study area contributes flow and dissolved-solids loads to the primary drainage outlet from this study area, which is also the drainage outlet for three adjacent smaller water districts. Quantity and quality of discharge for this outlet is monitored at PE-14; however, the contribution of each of these districts to the total discharge is not known. Discharge at PE-14 (fig. 12A) ranged from 0.01×10^6 m^3/d in October 1992 to 0.20×10^6 m^3/d in July 1987. Monthly dissolved-solids concentrations (fig. 12B) ranged from 1,460 mg/L in November 1986 to 3,330 mg/L in October 1992. Monthly loads of dissolved solids ranged from 1.3×10^6 kg in October 1992 to 12.1×10^6 kg in July 1987 (fig. 12C). Monthly loads of selenium ranged from 20.4 kg in November 1991 to 364 kg in August 1989.

On-Farm Drainflow Discharge

During the study period, the water district made estimates of drainflow using sporadic data collected using three different methods: flow meters at sump discharge points; power records from sump pumps; and weirs along open channels. On the basis of a review of these data, it is not possible to make a reasonable estimate of total drainflow discharge within the study area.

Drainflow-discharge data were available from 20 to 41 of the 50 drainage systems in the study area in any given year (fig. 4). Flow-meter data were available from a maximum of 30 drainage systems in any given year. Drainflow estimates using power records were made for a maximum of 12 drainage systems in any given year. Weir data were available from 9 sites from September 1986 to June 1988 only.

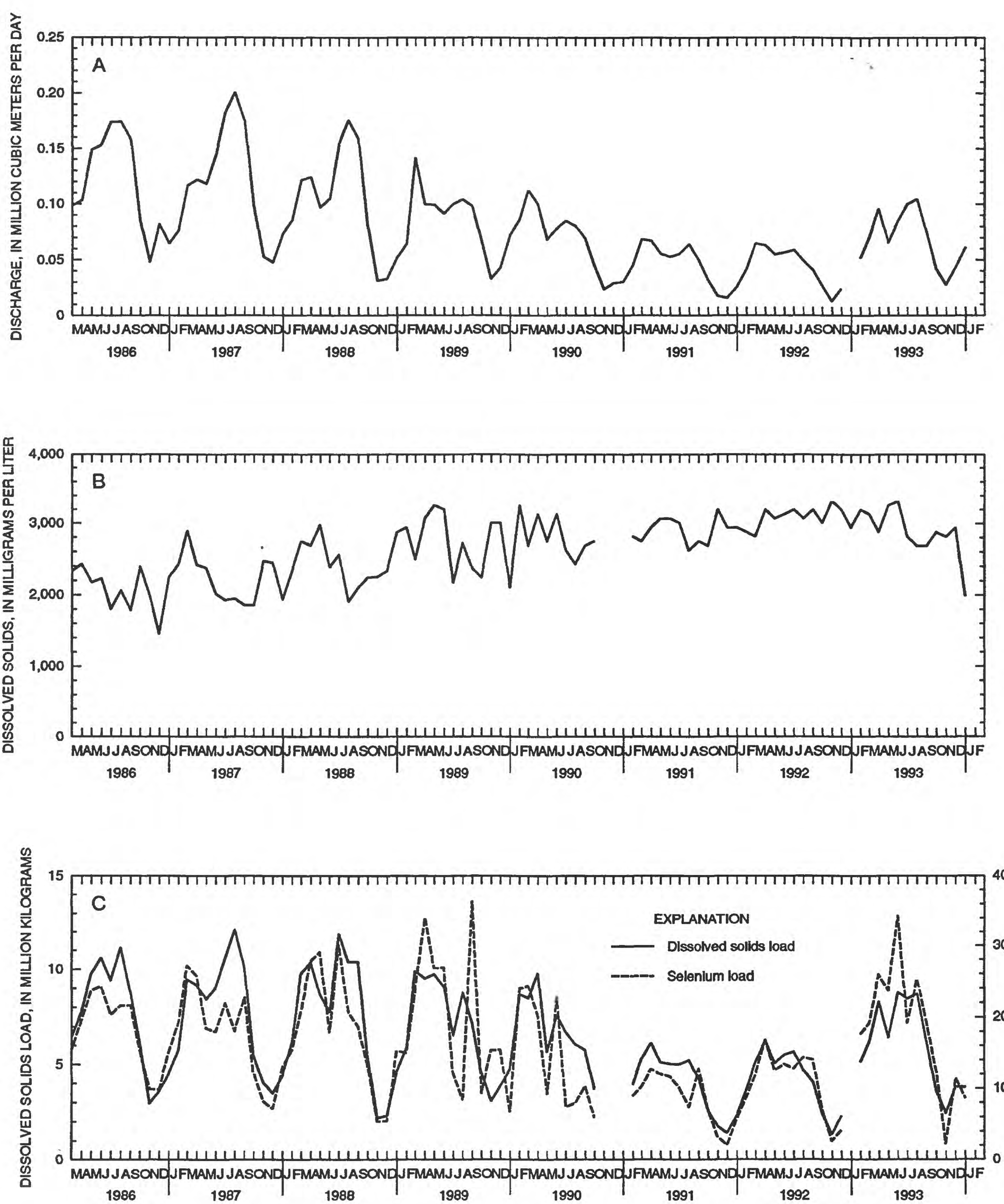


Figure 12. Drainflow discharge (**A**), dissolved-solids concentrations (**B**), and dissolved-solids and selenium loads (**C**) measured at site PE-14 adjacent to the Panoche Water District, 1986-93.

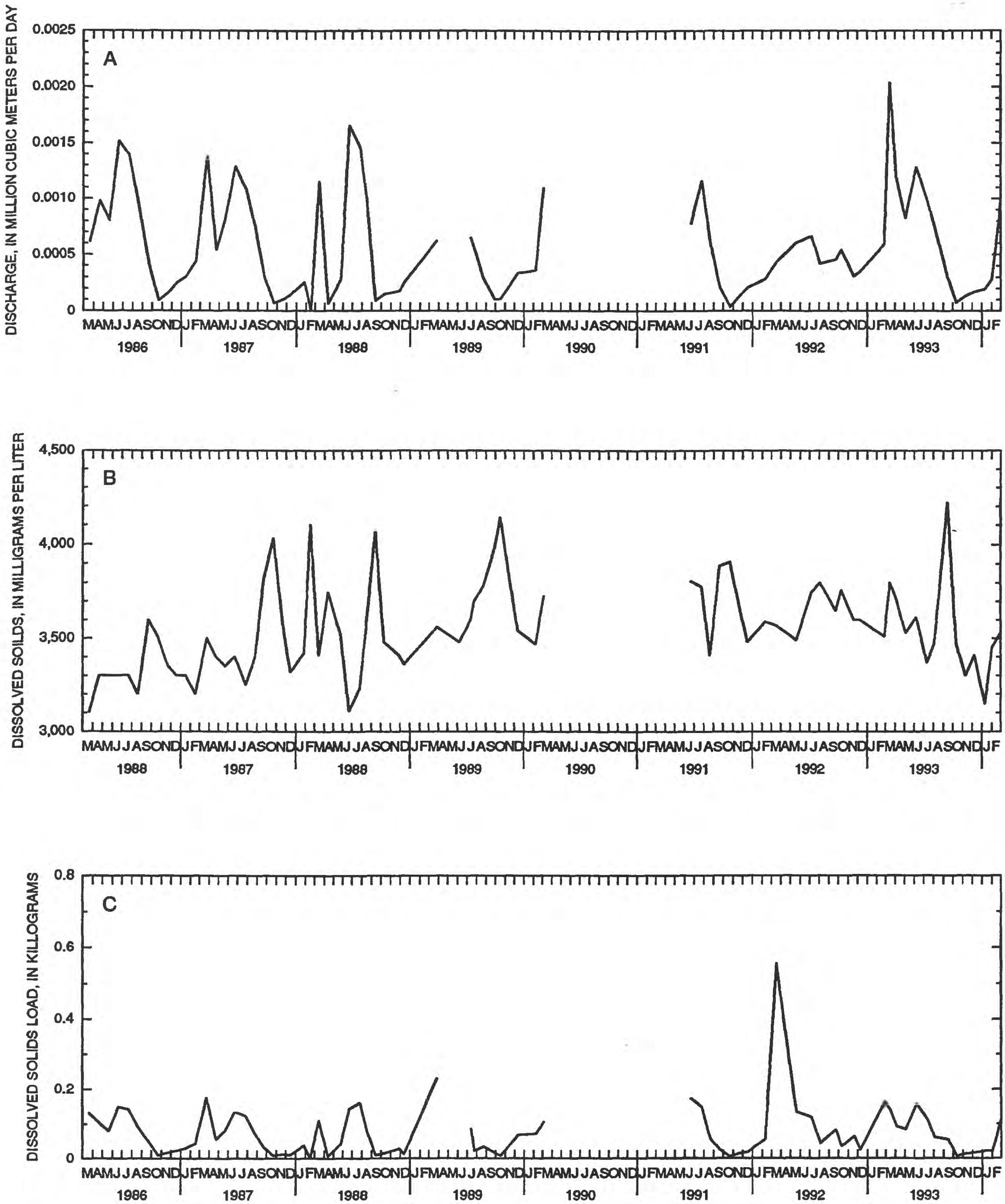


Figure 13. Drainflow discharge **(A)**, and concentration of dissolved-solids concentrations **(B)**, and dissolved-solids load **(C)** from a selected on-farm drainage system in the Panoche Water District, 1986-93.

Although flow records for the entire study area preclude making an analysis of total discharge from the district, data at 23 individual drainage systems are nearly complete, except for the period from April 1990 through June 1991. Drainflow rates from one of these systems are shown in figure 13. This site illustrates the expected seasonality in drainflow; that is, minimum drainflows generally occur during periods without irrigation and maximums occur during periods of irrigation.

On-Farm Drainflow Quality

Samples of on-farm drainage discharge were collected at the outlets from the 50 separate drainage-system sites during the study on a regular basis (dissolved solids monthly, and selenium quarterly). However, only 33 sites had a nearly complete period of record for this study (see fig. 4) and no data were available for any site from April 1990 to June 1991. Concentrations of dissolved solids and dissolved-solids load in drainflow from a selected drainage system are shown in figure 13. Dissolved-solids concentration ranged from 3,100 mg/L in March 1986 to about 4,200 mg/L in September 1993. Dissolved-solids load ranged from less than 0.01 kg in February to 0.56 kg in March 1992.

An analysis of dissolved-solids concentrations using the seasonal Kendall test on data from the 33 sites indicates a different trend in the data collected before April 1990 from those collected after June 1991. The analysis also indicates that in most cases dissolved-solids concentrations increased or remained unchanged during the first period (1986-90 PWDWY) and decreased or remained unchanged during the second period (1991-93 PWDWY).

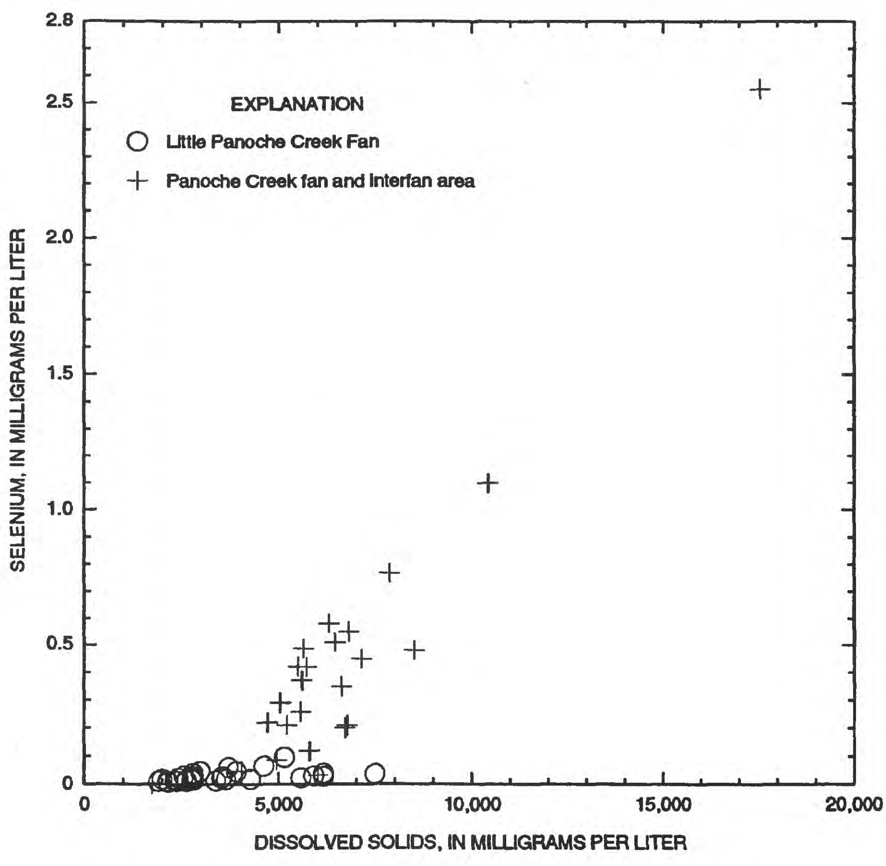


Figure 14. Relation between dissolved-solids and selenium concentrations in drainflow samples collected from 1986 to 1993 in the Panoche Water District.

The relation between dissolved-solids and selenium concentrations is different in drainflow originating from fields located on the Little Panoche Creek alluvial fan from that in drainflow originating from fields located on the Panoche Creek alluvial fan and the interfan areas (fig. 14). In the Panoche Creek fan and interfan area, the selenium concentration in drainflow increases with increasing dissolved solids. However, in the Little Panoche Creek fan area there does not appear to be a strong correlation. The difference in this relation is related to differences in ground-water quality between the two alluvial fans (Fio and Leighton, 1994). Ground-water samples from the Little Panoche Creek alluvial fan were found to have low dissolved-solids and selenium concentrations and ground-water samples from the Panoche Creek alluvial fan and the interfan areas were found to have higher dissolved-solids and selenium concentrations. Spatial differences in ground-water quality may be the result of many factors, including differences in geologic source materials, regional ground-water flow, and the effects of recharge and evaporative processes in the shallow ground-water system.

EVALUATION OF THE MONITORING PROGRAM

Water Applied to Crops

Applied water consists of imported surface water, ground water pumped into the delivery canals, and ground water applied directly to crops. However, water-delivery data available for this study do not provide information on the quality of imported water, separate totals of imported surface water and ground water pumped into the delivery canals, information on the spatial distribution of water delivered in the study area, and information on the quantity and quality of ground water applied directly to crops. Without this information, reasonable estimates of the quantity and distribution of water applied in the district, as well as the relative contributions of dissolved solids and selenium from each source of applied water cannot be made. This is particularly true during years of reduced deliveries of imported water, when ground-water pumpage represents a large part of applied water. Without this information, it is difficult or impossible to make reliable estimates of recharge and to evaluate hydrologic processes affected by recharge.

Land Use

Although the water district develops maps of projected crop coverages prior to the growing season, the maps are for the purpose of projecting water demand. Following the growing season, the district reports total acreages by crop type; however, these reports do not provide the spatial distribution of actual crops grown. These data are needed to make reasonable estimates of the spatial distribution of consumptive use and recharge.

Ground Water Levels and Quality

The district has a good network of monitoring wells, which they use effectively for collecting data on the areal and vertical distribution of hydraulic head. Selected wells from this network also could be used to monitor ground-water quality both areally and vertically, including individual observation wells in the undrained areas and all cluster wells in the district. Also, in order to better understand the quality of water being applied to fields, information on water quality from production wells is needed.

Drainflow

The district has collected drainflow quantity and quality data from the 50 drainage systems in the study area. However, data have been collected inconsistently from site to site. In order to understand total drainflow discharge from the study area, each drainage system needs to be instrumented to continuously measure and record discharge. Continuous discharge data, combined with monthly water-quality data from each drainage system, are needed to accurately estimate total and individual constituent loads being discharged from the study area.

Measurements of quantity and quality of discharge made at PE-14 are consistent with those recommended by the San Joaquin Valley Drainage Implementation Program (1994).

REFERENCES

Ayars, J. E. and Schrale, Gerrit, 1989, Irrigation efficiency and regional subsurface drainflow on the west side of the San Joaquin Valley: Final Report in Contract B564488, submitted to California Department of Water Resources Office of Water Conservation, 120 p.

Belitz, Kenneth, and Heimes, F. J., 1990, Character and evolution of the ground-water flow system in the central part of the western San Joaquin Valley, California: U.S. Geological Survey Water-Supply Paper 2348, 28 p.

Deverel, S. J., Gilliom, R. J., Fujii, Roger, Izbicki, J. A., and Fields, J. C., 1984, Areal distribution of selenium and other inorganic constituents in shallow ground water of the San Luis Drain service area, San Joaquin Valley, California: A preliminary study: U.S. Geological Survey Water-Resources Investigations Report 84-4319, 67 p.

Fio, J. L., 1994, Calculation of a water budget and delineation of contributing sources to drainflows in the western San Joaquin Valley, California: U.S. Geological Survey Open-File Report 94-45, 39 p.

Fio, J. L. and Leighton, D. A., 1994, Effects of ground-water chemistry and flow on quality of drainflow in the western San Joaquin Valley, California: U.S. Geological Survey Open-File Report 94-72, 28 p .

Helsel, D. R., and Hirsch, R. M., 1992, Statistical methods in water resources: Studies in Environmental Science 49, Elsevier Science Publishers, New York, NY, 521 p.

Hirsch, R. M., Slack, J. R., and Smith, R. A., 1982, Techniques in trend analysis for monthly water quality data: Water Resources Research, v. 18, no. 1, p. 107-121.

Irrigation Training and Research Center, 1994, Grasslands Basin Irrigation and Drainage Study - Volume 1 - Final Report: Irrigation Training and Research Center, California Polytechnic State University, San Luis Obispo, various pagination. .

Laudon, Julie, and Belitz, Kenneth, 1991, Texture and depositional history of late Pleistocene-Holocene alluvium in the central part of the western San Joaquin Valley, California: Bulletin of the Association of Engineering Geologists, v. 28, no. 1, p. 73-88.

Ohlendorf, H. M., Hothem, R. L., Bunck, C. M., Aldrich, T. W., and Moore, J. F., 1986, Relationships between selenium concentrations and avian reproduction: North American Wildlife and Natural Resources Conference, 51st, Reno, Nevada, Transactions, 1986, p. 330-342.

National Oceanic and Atmospheric Administration, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, and 1994, Climatological Data, Annual Summaries, California: 1986 through 1994, vols. 90 through 98, nos. 13.

Page, R. W., 1986, Geology of the fresh ground-water basin of the Central Valley, California: U.S. Geological Survey Professional Paper 1401-C, 54 p., 5 plates.

Presser, T. S., and Barnes, Ivan, 1984, Selenium concentrations in waters tributary to and in the vicinity of the Kesterson National Wildlife Refuge, Fresno and Merced Counties, California: U.S. Geological Survey Water-Resources Investigations Report 84-4112, 26 p.

San Joaquin Valley Drainage Implementation Program, 1994, Draft monitoring plan and budget for drainage affected areas of the westside San Joaquin Valley of California: Interagency San Joaquin Valley Drainage Implementation Program, 44 p.

San Joaquin Valley Drainage Program, 1990, A management plan for agricultural subsurface drainage and related problems on the westside San Joaquin Valley: Final report of the San Joaquin Valley Drainage Program, 183 p.

Tidball, R. R., Severson, R. C., Gent, C. A., and Riddle, G. O., 1986, Element associations in soils of the San Joaquin Valley, California: U.S. Geological Survey Open-File Report 86-583, 15 p.