ESTIMATION OF A WATER BUDGET FOR THE CENTRAL PART OF THE WESTERN SAN JOAQUIN VALLEY, CALIFORNIA

By Jo Ann M. Gronberg *and* Kenneth Belitz

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Conversion Factors

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	0.001233	cubic hectometer
acre-foot per acre (acre-ft/acre)	0.0000003	cubic hectometer per square meter
foot (ft)	0.3048	meter
foot per second (ft/s)	0.3048	meter per second
inch (in.)	25.4	millimeter
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer

Temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by the following equation: °C = (°F-32)/1.8.

Vertical Datum

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

Definition of Terms:

Crop-water requirement (***CWR***).--The depth of water per unit area that needs to be applied to a specific crop for maximum yield and is calculated from consumptive use and effective precipitation values for each crop. It does not include direct precipitation.

Consumptive use (*CU*).--The depth of water per unit area transpired by a specific crop, retained in plant tissue, and evaporated from adjacent soil surfaces during the growing season.

Effective precipitation (***EP***).--The part of precipitation evapotranspired during the crop growing season that reduces the crop-water requirement. It includes the evapotranspiration of precipitation, which occurs during the growing season, as well as that which occurs before the growing season and is carried over into the following season as stored soil moisture.

Irrigation efficiency (***IE***).--The percentage of the total amount of water applied that is directly evaporated from soil and plant surfaces or retained within the root zone to be transpired at a later time.

Irrigation requirement (***IR***).--The depth of water required to meet crop-water requirement for normal crop production plus leaching requirements and losses caused by inefficiency in irrigation.

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Abstract

Quantitative estimates of water-table recharge from irrigation water applied to agricultural lands and ground-water pumpage are essential for developing a numerical simulation model of the regional ground-water flow system in the central part of the western San Joaquin Valley, California. Surface-water delivery and crop-acreage data are available by section and water district for 11 water districts in the study area, which is about 550 square miles. Ground-water pumpage estimates, based on electricity usage, are available for 26 townships and parts of townships that comprise the study area. Using the available data, initial water budgets for 1980 and 1984 indicate that ground-water pumpage data cannot be reliably disaggregated at scales less than a township. However, the initial water budgets do indicate an inverse relation between irrigation efficiency and depth to water table. In the revised water budgets, ground-water recharge and ground-water pumpage are estimated for the study subareas using the available surface-water delivery and crop-acreage data, along with estimated irrigation efficiencies. In addition, the distribution of ground-water pumpage above and below the Corcoran Clay Member of the Tulare Formation of Pleistocene age was determined on the basis of the vertical distribution of well perforations in the study area.

INTRODUCTION

The San Joaquin Valley, California, is one of the most productive agricultural areas in the United States. Continued agriculture in large parts of the western valley is subject to potentially adverse environmental effects of the high concentrations of selenium and other soluble trace elements present in the soil, ground water, and agricultural drainwater. The occurrence and movement of soluble constituents are related to the movement of ground water in which they are dissolved. Thus, the ground-water flow system must be understood in order to manage these contaminants.

A key component in understanding the ground-water flow system in the central part of the western San Joaquin Valley is the development of a numerical simulation model. The principal driving forces of the flow system are ground-water pumpage and application of water for irrigation. Development of an accurate model of the flow system requires estimation of the areal distribution of recharge, and the areal and vertical distribution of ground-water pumpage. This report presents a water-budget approach to make estimates of these factors.

This study is part of a comprehensive investigation by the U.S. Geological Survey of the hydrology and geochemistry of the San Joaquin Valley. The studies are being done as part of the Regional Aquifer-System Analysis Program of the U.S. Geological Survey and in cooperation with the San Joaquin Valley Drainage Program.

The authors would like to thank Byron Steinert, Westlands Water District, for providing information on crop-water requirement.

DESCRIPTION OF STUDY AREA

The San Joaquin Valley is a northwest-southeast trending valley bounded by the Coast Ranges to the west, and the Sierra Nevada to the east. The San Joaquin Valley has an arid to semiarid climate that is characterized by hot summers and mild winters.

Average precipitation is 6.5 to 8 in. on the valley floor, decreasing from north to south, and occurring mostly in the winter. Temperatures range from an average daily minimum of about 35°F to an average daily maximum of about 102°F (Gilliom and others, 1989).

The study area is south of the Merced-Fresno County line in the central part of the western San Joaquin Valley (fig. 1). It is bounded to the west by the Coast Ranges, to the east by the San Joaquin River and Fresno Slough, and to the north and south by the lateral extent of the Little Panoche Creek and Cantua Creek alluvial fans. The study area corresponds to the model grid used for simulating the ground-water flow system. Preliminary results of steady-state modeling for this area are presented by Phillips and Belitz (1991).

HYDROGEOLOGY

The study area is underlain by the Pleistocene Corcoran Clay Member of the Tulare Formation of Pleistocene age, which divides the ground-water flow system into an upper semiconfined zone and a lower confined zone. In the semiconfined zone, three hydrogeologic units can be distinguished: Coast Ranges alluvium, Sierran sand, and flood-basin deposits.

The Coast Ranges alluvium consists of poorly sorted alluvial-fan deposits derived from the Coast Ranges to the west. The thickness ranges from more than 800 ft near the Coast Ranges to 0 ft near the valley axis (Miller and others, 1971). Textures range from more than 80 percent sand and gravel in the fanhead regions to more than 80 percent silt and clay in the distal regions (Laudon and Belitz, 1991).

As the Coast Ranges alluvium thins to the east, it interfingers with sediment derived from the Sierra Nevada. At depth, the Sierran deposits are primarily well-sorted micaceous sand. The Sierran sand is as much as 400 ft thick in the valley trough and thins to the east and west (Miller and others, 1971).

Flood-basin deposits form a thin layer (5 to 35 ft thick) of fine-grained materials in the valley trough. They are primarily composed of sediments derived from the Coast Ranges and the Sierra Nevada.

The Corcoran Clay Member of the Tulare Formation consists of silty clay to clayey silt in the upper two-thirds of the unit and sand-silt-clay to clayey silt in the lower one-third of the unit (Bull, 1975). The base of the unit ranges from more than 850 ft in depth along the Coast Ranges to 400 ft along the valley trough (Bull and Miller, 1975). The Corcoran Clay Member ranges in thickness from 20 to 120 ft (Miller and others, 1971).

The lower confined zone below the Corcoran Clay Member consists of poorly consolidated flood-plain, deltaic, alluvial-fan, and lacustrine deposits of the Tulare Formation. The confined zone extends several hundred feet below the Corcoran Clay Member before saline water is encountered.

Belitz and Heimes (1990) provide a description of the character and evolution of the ground-water flow system in the central part of the western San Joaquin Valley. Gilliom and others (1989) provide a preliminary assessment of the sources, distribution, and mobility of selenium in the San Joaquin Valley.

IRRIGATION HISTORY

The study area consists of all or parts of 11 water districts: Firebaugh, Mercy Springs, Eagle Field, Oro Loma, Widren, Tranquillity, Fresno Slough, Panoche, Broadview, San Luis, and Westlands Water Districts (fig. 2). Agricultural activity in the study area began as early as the 1870's (Belitz and Heimes, 1990). Agricultural irrigation with ground water was recognized as early as 1912-24 in parts of the area now occupied by Tranquillity, Panoche, Broadview, and Westlands Water Districts (Bull and Miller, 1975; and Association of California Water Agencies, written commun., 1985). By 1940, the area irrigated by ground water increased to encompass all the area now within the Mercy Springs, Broadview, and Panoche Water Districts. By 1950, most of the study area was irrigated by ground water, except for the area now within the Firebaugh and Oro Loma Water Districts (which by 1940 were irrigated wholly by surface water, or supplemented by ground water) and the area along the boundary of the valley deposits.

Most of the water needed to meet agricultural demands was pumped from beneath the Corcoran Clay Member of the Tulare Formation. By 1952, the

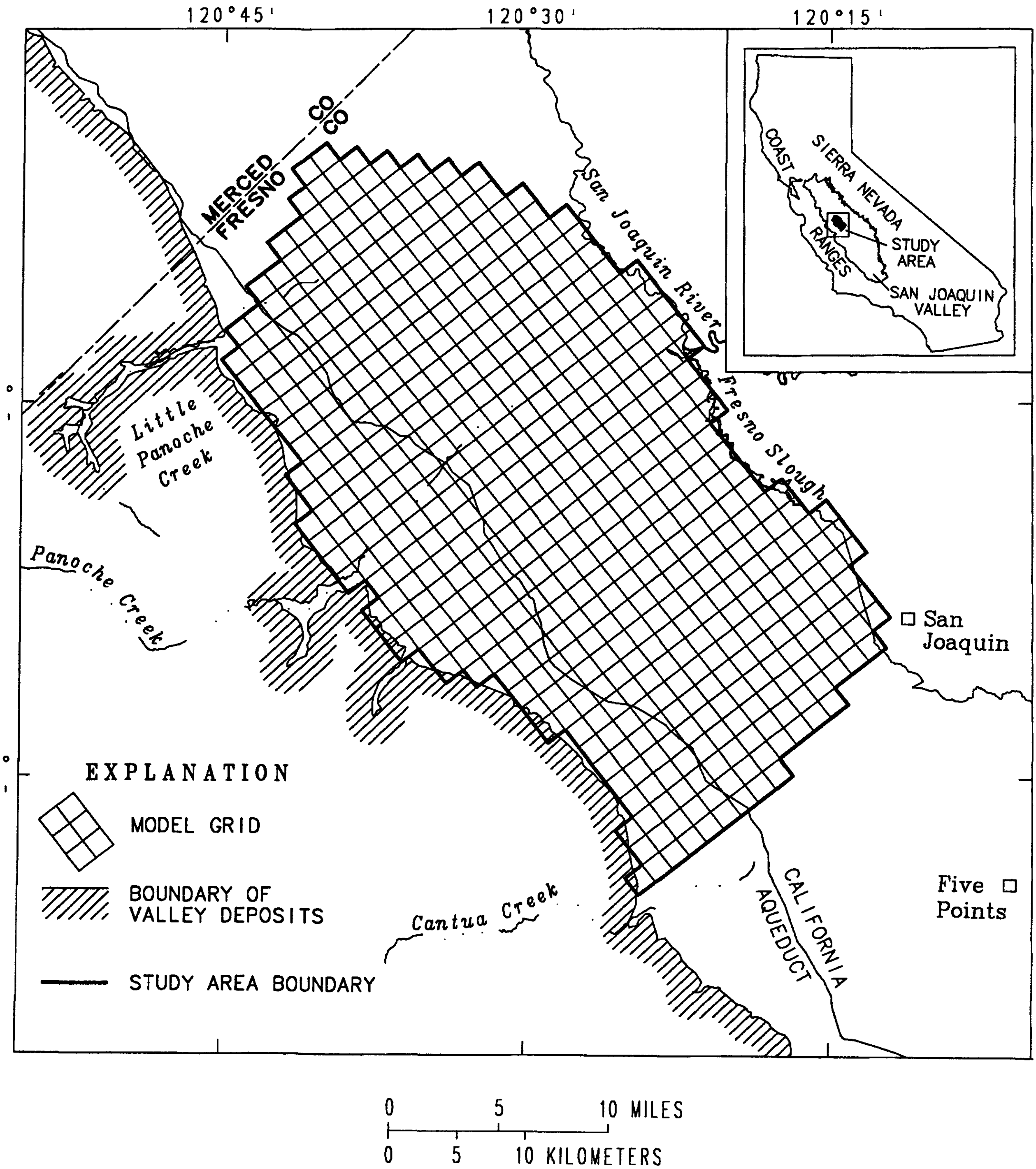

Figure 1. Location of study area.

pumping had caused the potentiometric head in the central part of the western valley to be drawn down 100 to 200 ft from the presumed predevelopment altitude. By 1967, the potentiometric head had been drawn down 300 to 400 ft from the presumed predevelopment altitude. As a result of land subsidence, increased pumping lifts, and degradation of water quality, surface water was imported from the Sierra Nevada through the Central Valley Project (CVP).

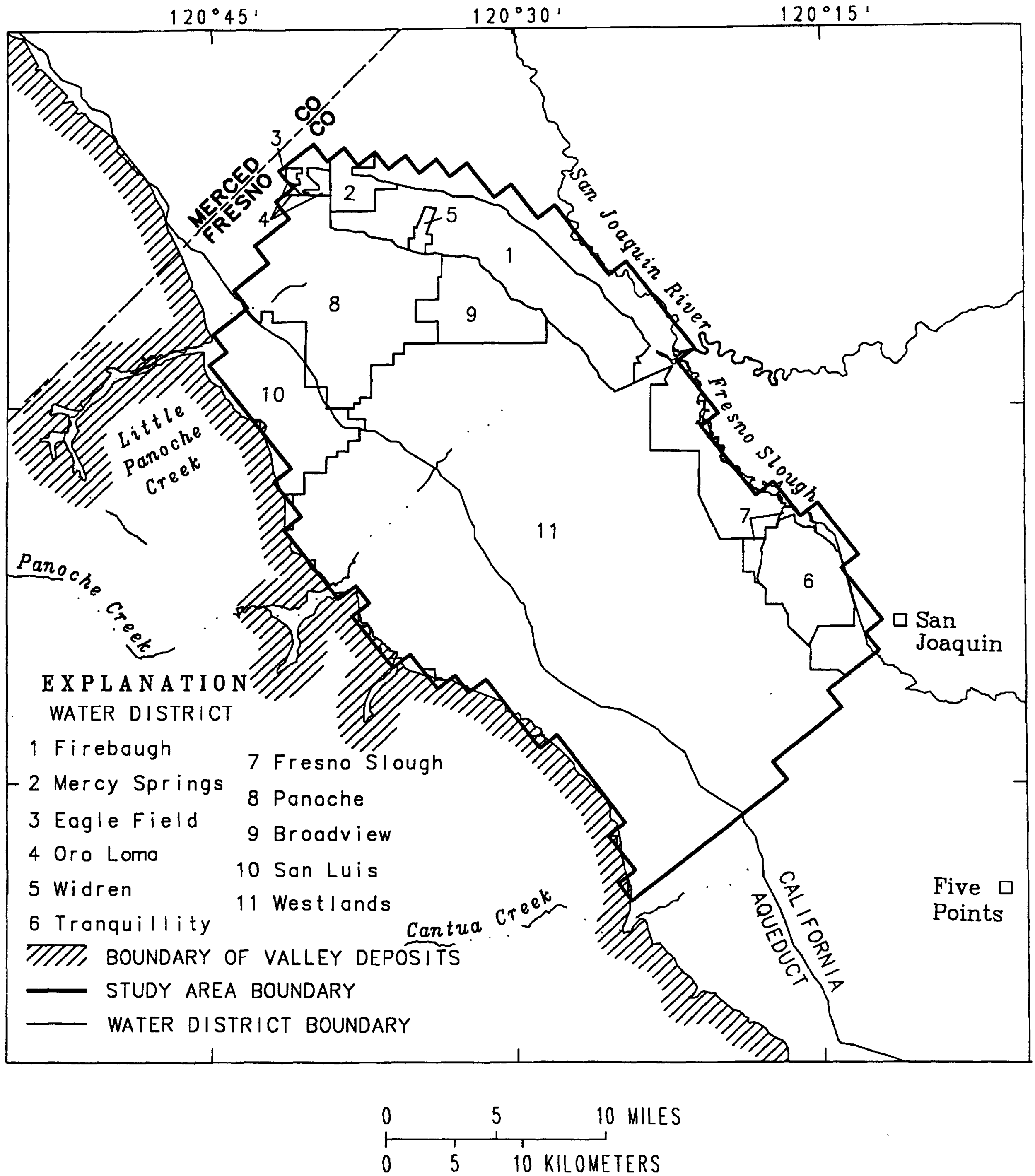

Figure 2. Water-district boundaries in the study area.

Panoche Water District, which now services Mercy Springs, Eagle Field and Oro Loma Water Districts, received its first Central Valley Project water in 1947. Broadview Water District received CVP water in the early 1950's. Tranquillity and Westlands Water Districts entered into long-term contract to receive CVP water in 1963. San Luis Water District also receives CVP water.

As surface water became the primary source of irrigation, the total quantity of applied water increased; however, the quantity of water removed from the system (through pumping) decreased. As a result, the potentiometric surface of the confined zone rose by as much as 200 to 300 ft between 1967 and 1984 in some parts of the study area. Similarly, the water-table altitude has risen over much of the valley. In 1984, about 50 percent of the western part of the central San Joaquin Valley was characterized by a water table within 20 ft of land surface, as compared with less than 10 percent in 1952. In 1988, about 50 percent of the western part of the central San Joaquin Valley was characterized by a water table within 10 feet of land surface.

The study area can be characterized by three areas on the basis of depth to the water table less than or equal to 10 ft, greater than 10 and less than or equal to 20 ft, and greater than 20 ft. Areas where the water table is within 10 ft of the land surface are relatively low topographically and are subject to drainage problems and bare-soil evaporation. Areas where the water table is more than 20 ft below land surface have greater relief and elevation and are not presently subject to drainage problems. Areas where the depth to the water table is between 10 and 20 ft are areas with potential for developing drainage problems in the future.

DATA ACQUISITION

CROP-WATER REQUIREMENT

Crop-water requirement is the depth of water per unit area that needs to be applied to a specific crop for maximum yield and is calculated from consumptive use and effective precipitation values for each crop. Consumptive use is the depth of water (acre-feet per acre, or feet) transpired by a specific crop, retained in plant tissue, and evaporated from adjacent soil surfaces during the growing season. Effective precipitation is that part of consumptive use satisfied by rainfall. Crop-water requirement is the difference between consumptive use and effective precipitation.

Estimates of consumptive use and effective precipitation for specific crops grown in the study area are available from the Westlands Water District (Byron Steinert, written commun., 1987) and the California Department of Water Resources (1975). Consumptive use and effective precipitation are estimated by the Westlands Water District on a yearly basis using three climatic stations in and near the study area. Westlands Water District uses a modified Penman equation to calculate consumptive use. Estimates by the California Department of Water Resources are based on climatic data collected from stations selected to be representative of the San Joaquin Valley. California Department of Water Resources uses the Blaney-Criddle equation to calculate consumptive use coupled with an evaporation index to extrapolate to specific regions. Where available, estimates from Westlands Water District were used (table 1).

W.E. Templin (U.S. Geological Survey, written commun., 1989) compiled crop type and acreage for each water district. These data were provided by the individual water districts; but, in a few cases, were extracted from the U.S. Bureau of Reclamation (1981a, 1985a). Crop-acreage data for the Firebaugh, Mercy Springs, Eagle Field, Widren, Tranquillity, Panoche, Broadview, San Luis, and Westlands Water Districts are provided on a section basis; crop-acreage data for Oro Loma and Fresno Slough Water Districts are provided for the entire water district only. The crop-acreage data and total water district area are summarized in table 2.

SURFACE-WATER DELIVERY

Surface-water delivery data were obtained from the U.S. Bureau of Reclamation (1981b, 1985b) and W.E. Templin (U.S. Geological Survey, written commun., 1989). The Bureau of Reclamation reports surface water in acre-feet delivered to a water district. Although W.E. Templin (U.S. Geological Survey, written commun., 1989) presents surface-water delivery in acre-feet per section for each water district, only Broadview, San Luis, and Westlands Water Districts were metered at their delivery point. Values for the other water districts were extrapolated using various methods from the information provided by the individual water districts and, in some cases, data from the U.S. Bureau of Reclamation (1981b, 1985b). W.E. Templin (U.S. Geological Survey, written commun., 1989) describes the methods used to incorporate the information into a common data base and also reports problems associated with the data. For example, some reported surface-water delivery also could include surface water from other water districts or reclaimed water. The Bureau of Reclamation values were used except where section data were needed or where surface water was transferred between water districts and not accounted for in the Bureau of Reclamation values.

Table 1. Consumptive use and effective precipitation

[Data from Byron Steinert, Westlands Water District, written commun., 1987. ft, foot]

Crop type	1980		1984	
	Consumptive use (ft)	Effective precipitation (ft)	Consumptive use (ft)	Effective precipitation (ft)
Alfalfa				
Hay	4.40	0.60	4.70	0.40
Seed	3.78	.30	3.93	.20
Almonds	2.64	.15	2.87	.10
Barley	1.13	.45	1.23	.30
Beans	1.88	.00	1.97	.00
Cantaloupes	.93	.00	.94	.00
Cotton	2.17	.00	2.38	.00
Garlic	1.10	.15	1.10	.10
Grapes	1.85	.15	2.08	.10
Lettuce				
Spring	.80	.30	.80	.20
Autumn	.70	.00	.70	.00
Onions	1.83	.15	1.60	.10
Safflower	2.63	.15	2.70	.10
Sugar beets	3.04	.30	3.19	.20
Tomatoes	1.86	.00	1.91	.00
Wheat	1.49	.45	1.58	.30
Field crops, misc.	2.00	.00	2.00	.00
Truck crops, misc.	1.50	.00	1.50	.00
Trees/vines, misc.	2.50	.00	2.50	.00
Fallow	.00	.00	.00	.00
Rice[1]	3.80	.30	3.80	.10
Pasture[1]	3.70	.40	3.70	.20

[1]Data from California Department of Water Resources (1975).

GROUND-WATER PUMPAGE

Ground-water pumpage is not directly measured in the central part of the western San Joaquin Valley. Diamond and Williamson (1983) used electrical usage data to estimate ground-water pumpage for 1961-77. Those data were reported on a township basis (36 mi^2). In this study area, pumpage estimates from all or part of 26 townships were used to extrapolate ground-water pumpage to the nine subareas.

Diamond and Williamson (1983) do not provide estimates of ground-water pumpage after 1977. Therefore, as an indicator of ground-water pumpage for 1980 and 1984, the average of their 1974, 1975, and 1976 estimates were used. This assumption is reasonable because pumpage since 1974, with the exception of the drought year of 1977, has been relatively constant.

Table 2. Crop-acreage data

[Values in acres. Total area represents acres in Water District. Location of water districts shown in figure 2. --, no data; ft, foot]

Crop type	Crop-acreage data 1980	Crop-acreage data 1984
Firebaugh, Mercy Springs, Eagle Field, Oro Loma, Widren Water Districts (Total area, 31,766)		
Alfalfa		
Hay	1,149	1,514
Seed	765	--
Barley	404	357
Beans	120	120
Cotton	10,003	12,442
Garlic	15	--
Sugar beets	2,257	2,245
Tomatoes	139	883
Wheat	5,164	1,772
Field crops, miscellaneous	515	868
Truck crops, miscellaneous	325	507
Fallow	--	773
Rice	4,664	3,743
Pasture	289	108
Tranquillity, Fresno Slough Water Districts (Total area, 11,882)		
Alfalfa		
Hay	271	118
Seed	2,111	2,253
Barley	1,950	1,849
Cantaloupes	--	199
Cotton	4,895	4,901
Sugar beets	960	386
Wheat	346	123
Truck crops, miscellaneous	34	410
Pasture	23	20
Panoche Water District (Total area, 39,424)		
Alfalfa		
Hay	753	1,543
Seed	312	--
Almonds	176	174
Barley	1,050	230
Beans	971	1,690
Cantaloupes	261	819
Cotton	14,778	15,813
Garlic	150	--
Lettuce	263	176
Onions	78	--
Safflower	692	156
Sugar beets	550	826
Panoche Water District--*Continued*		
Tomatoes	3,008	3,804
Wheat	2,932	2,823
Field crops, miscellaneous	2,849	770
Truck crops, miscellaneous	1,668	528
Trees/vines, miscellaneous	127	377
Fallow	1,513	1,064
Pasture	10	--
Broadview Water District (Total area, 9,711)		
Alfalfa		
Hay	--	160
Seed	925	560
Barley	465	190
Beans	635	300
Cantaloupes	150	--
Cotton	5,272	4,905
Sugar beets	297	1,355
Tomatoes	150	150
Wheat	700	900
Field crops, miscellaneous	--	140
Truck crops, miscellaneous	--	300
Fallow	--	95
Rice	277	--
San Luis Water District[1] (Total area, 21,120)		
Alfalfa		
Hay	80	424
Seed	--	230
Almonds	1,252	290
Beans	881	--
Cantaloupes	2,440	1,425
Cotton	7,908	7,713
Garlic	845	--
Lettuce	--	300
Onions	115	156
Sugar beets	718	160
Tomatoes	1,222	2,630
Wheat	200	563
Field crops, miscellaneous	--	1,335
Truck crops, miscellaneous	622	877
Trees/vines, miscellaneous	31	230
Fallow	556	661

Footnotes at end of table.

Table 2. Crop-acreage data--*Continued*

Crop type	Crop-acreage data 1980	Crop-acreage data 1984
Westlands Water District[1]		
(Depth to water table less than or equal to 10 ft)		
Total area[2]	69,760	69,760
Alfalfa		
Hay	2,748	2,978
Seed	3,505	2,295
Almonds	1,029	307
Barley	10,150	2,696
Beans	363	154
Cantaloupes	2,943	2,795
Cotton	30,247	34,809
Garlic	318	502
Grapes	39	--
Onions	341	321
Safflower	850	643
Sugar beets	3,543	1,983
Tomatoes	1,307	4,543
Wheat	7,007	2,959
Field crops, miscellaneous	978	1,651
Truck crops, miscellaneous	252	736
Trees/vines, miscellaneous	472	415
Fallow	343	929
Rice	180	110
Pasture	96	73
(Depth to water table greater than 10 ft and less than or equal to 20 ft)		
Total area	33,920	33,920
Alfalfa		
Hay	976	364
Seed	2,673	1,112
Barley	2,565	604
Beans	224	--
Cantaloupes	1,352	1,759
Cotton	15,859	16,065
Garlic	327	500
Grapes	112	223
Onions	366	577
Safflower	999	186
Sugar beets	1,055	1,191
Tomatoes	1,413	3,570
Wheat	3,978	625
Field crops, miscellaneous	183	1,684
Truck crops, miscellaneous	152	319
Trees/vines, miscellaneous	37	33
Fallow	38	292
Rice	--	40
Pasture	--	4
Westlands Water District--*Continued*		
(Depth to water table greater than 20 ft, with surface-water delivery)		
Total area	91,520	102,400
Alfalfa		
Hay	2,498	2,581
Seed	2,652	1,092
Almonds	1,547	2,378
Barley	6,755	5,474
Beans	2,220	1,333
Cantaloupes	6,004	6,373
Cotton	37,450	42,260
Garlic	267	1,706
Grapes	1,424	2,636
Lettuce	422	340
Onions	252	1,727
Safflower	912	247
Sugar beets	2,055	1,204
Tomatoes	7,772	16,198
Wheat	7,227	5,859
Field crops, miscellaneous	2,271	904
Truck crops, miscellaneous	895	2,827
Trees/vines, miscellaneous	332	380
Fallow	2,213	1,292
Rice	198	152
Pasture	80	119
(Depth to water table greater than 20 ft, without surface-water delivery)		
Total area	23,680	12,800
Alfalfa		
Hay	159	--
Seed	1,201	149
Barley	3,088	409
Cantaloupes	478	250
Cotton	12,544	6,081
Garlic	303	--
Onions	--	147
Tomatoes	11	449
Wheat	2,830	3,224
Truck crops, miscellaneous	--	267
Fallow	1,500	445

[1]Data within study area only.
[2]Calculated from number of sections within study area (number of sections × 640 acres).

WATER-BUDGET ANALYSIS

A water-budget approach was applied to determine estimates of ground-water recharge and pumpage. This approach requires an accounting of water coming into and going out of a defined system. In this study, the top of the system is the land surface, and the bottom of the system is defined by the depth of the crop roots. Water entering the top of the system is accounted for by surface-water delivery and irrigation by ground-water pumpage; water leaving the system is accounted for by crop evapotranspiration and recharge to the water table (ground-water recharge). Although some of the rain that falls on the valley floor contributes to fulfilling crop evapotranspiration, Davis and Poland (1957) and subsequent workers assumed that rainfall was an insignificant mechanism for recharging the system under natural conditions. Although these components displayed seasonal variation, the primary purpose of the model was to simulate long-term trends, and yearly time steps were used in the model. Therefore, water-budget components were based on average values for the designated years. This approach is used to estimate recharge from irrigation of agricultural lands, which results from percolation of irrigation water beyond the root zone and from seepage losses from unlined ditches within the fields. Recharge from major canals, such as the California Aqueduct, is not addressed here.

Initial and revised water budgets were calculated for the study area. The initial water budget used the available surface-water and crop-acreage data, along with the ground-water pumpage estimates of Diamond and Williamson (1983), to estimate ground-water recharge and irrigation efficiency. The revised water budget used the available surface-water and crop-acreage data, along with estimated irrigation efficiencies, to estimate ground-water recharge and ground-water pumpage.

Water budgets were prepared for 1980 and 1984. These years are within the period of relatively steady ground-water use and fluctuating surface-water deliveries (1974 to present), which are representative of present practices--1980 is an average year in terms of weather, crops planted, and surface-water delivered; 1984 has a higher than average crop-water requirement and higher than average surface-water delivery. These two years correspond to two of the three time periods used in the preliminary steady-state modeling by Phillips and Belitz (1991).

For the purposes of analysis, the study area was organized into nine water-budget subareas: Firebaugh, Tranquillity, Panoche, Broadview, San Luis, Westlands a, Westlands b, Westlands c, and Westlands d (fig. 3). Subarea boundaries do not coincide with water-district boundaries, but are the closest approximation of the boundaries within the constraints of the data and the model cell locations. Information from Firebaugh, Mercy Springs, Eagle Field, Oro Loma, and Widren Water Districts were aggregated to calculate water-budget components for the Firebaugh subarea. Similarly, Tranquillity and Fresno Slough Water Districts were aggregated to calculate water-budget components for the Tranquillity subarea. More than one-half of San Luis and Westlands Water Districts lie outside the study area. To focus the analysis on the study area, only section data from San Luis and Westlands Water Districts representative of the study area were used. (The data are geographically referenced to the rectangular system for the subdivision of public land, the Public Land Survey System.)

The four areas within the Westlands Water District are characterized by depth to water table of less than or equal to 10 ft; greater than 10 ft and less than or equal to 20 ft; greater than 20 ft with surface-water delivery; and greater than 20 ft without surface-water delivery. These areas are consistent with the areas of shallow ground water which is of concern to the San Joaquin Valley Drainage Program. The designation of areas with and without surface-water delivery is based on the observation that areas without surface-water delivery are planted with crops with lower crop-water requirement.

In order to use the compiled data in the water-budget analysis and ultimately in the ground-water model, the data need to be converted into a consistent and transferable form. For this study, a representative depth (feet) of crop-water requirement, surface-water delivery, ground-water pumpage, and ground-water recharge is calculated for each subarea. Because the extent of the subareas differs from the extent of the water districts, or parts of the water districts they represent, the volume of the water-budget components are summarized for the water districts and then are normalized by the area of the water districts. This value is then assigned to the subarea.

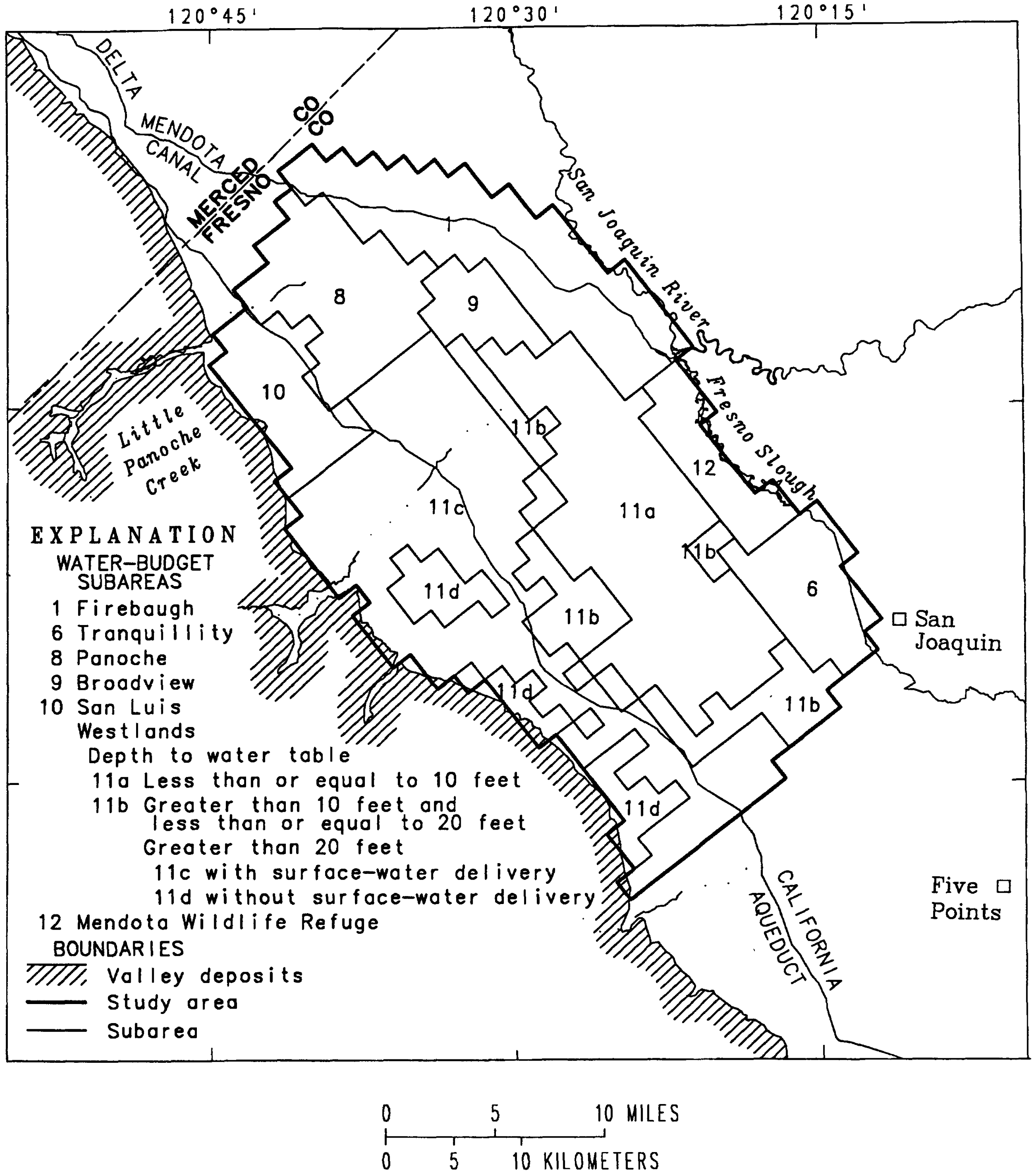

Figure 3. Water-budget subareas.

This process is best illustrated by following the explanation for the Firebaugh subarea, which is made up of the Firebaugh, Mercy Springs, Eagle Field, Oro Loma, and Widren Water Districts. To calculate crop-water requirement, the crop-water requirement (feet) for each crop (from table 1) was multiplied by the crop acreage (acre) planted in that crop (table 2). The volume crop-water requirement (acre-feet) for each crop type was then summed for these water districts. The total volume crop-water requirement (acre-feet) was then divided by the total area (acre) of the water districts to provide an average depth of crop-water requirement (feet).

Similarly, total volume of surface-water delivery (acre-feet) is summed for these water districts. This total volume was then divided by the total area of the water districts (acre) to obtain an average depth of surface-water delivery (feet).

Ground-water pumpage is reported as volume (acre-feet) per township. Pumpage was calculated for the water districts assuming that pumpage was evenly distributed over the township. The proportion of each township that was within a given water district was then determined and that proportion of township pumpage was assigned to the water district. Pumpage from the townships and parts of townships was then aggregated for these water districts. The total pumpage was then divided by the total area of the water district acreage to derive an average depth of ground-water pumpage.

INITIAL WATER BUDGET

The objective of the initial water budget was to estimate ground-water recharge and irrigation efficiency from the components determined in the previous sections. However, during that process, analysis of the results indicated that the ground-water estimates extrapolated from Diamond and Williamson (1983) may be inappropriate for this application. At the same time, examination of the subareas in Westlands Water District suggested an inverse relation between the depth to water table and irrigation efficiency, which was used in revising the water budget.

In this study, inflow can be accounted for by surface-water delivery (*SW*) and ground-water pumpage (*GW*), and outflow can be accounted for by crop-water requirement (*CWR*) and ground-water recharge (*GWR*). Assuming no change in storage, ground-water recharge can be calculated according to the following equation:

$$GWR = (SW + GW) - CWR. \qquad (1)$$

These components also can be used to calculate irrigation efficiency (*IE*), which is the percentage of the total amount of water applied that is directly evaporated from soil and plant surfaces or retained within the root zone to be transpired at a later time:

$$IE = \frac{CWR}{(SW + GW)}. \qquad (2)$$

This value, together with recharge, is calculated as an aid to understand the system and to evaluate the quality of the ground-water pumpage estimates.

Average depth of crop-water requirement, surface-water delivery, and ground-water pumpage (Diamond and Williamson, 1983) for each subarea are given in table 3. Ground-water recharge and irrigation efficiency calculated from these components also are given. Table 3 shows that ground-water recharge ranges from -1.42 to 1.41 ft for 1980 and -1.48 to 1.35 ft for 1984. Irrigation efficiency ranges from 52 to 880 percent for 1980 and 55 to 922 percent for 1984. Negative recharge rates and irrigation efficiency values greater than 100 percent indicate subareas where applied water (surface and ground water) is not sufficient to meet crop-water requirement.

Subareas with negative recharge rates and irrigation efficiency values greater than 100 percent do not receive surface water and therefore rely entirely on ground-water pumpage (table 3). These areas are further characterized by plantings of crops with lower crop-water requirement than areas with surface-water delivery. Subareas without surface-water delivery are small, generally less than 9 mi^2, compared to the pumpage data base, which is reported on a township basis (36 mi^2). This indicates that the ground-water estimates could be in error, at least at the scale required for this study. It is also possible that these areas could represent direct evapotranspiration from the water table by the crops, but because the depth to the water table is greater than 200 ft, this is unlikely. Therefore, these estimates are poor and an alternative to this initial water budget is needed. In the revised water budget, a crop-based approach was used to estimate water-budget components. A crop-based approach requires estimates of irrigation efficiency for each of the nine subareas.

IRRIGATION EFFICIENCY

In order to proceed to the revised water budget, a method of assigning a value for irrigation efficiency to each subarea must be determined. Irrigation efficiency for the nine subareas (table 3) indicates no clear pattern in terms of the areal distribution of irrigation efficiency. Data for the four subareas within the Westlands Water District indicate an inverse relation between irrigation efficiency and the depth to water table.

Table 3. Initial water budgets for 1980 and 1984

[ft, foot]

Subarea (fig. 3)	Crop-water requirement (ft)	Surface-water delivery (ft)	Ground-water pumpage (ft)	Ground-water recharge (ft)	Irrigation efficiency (percent)
1980					
Firebaugh	1.88	2.63	0.37	1.12	63
Tranquillity	1.97	2.51	.22	.76	72
Panoche	1.52	2.48	.45	1.41	52
Broadview	1.97	2.75	.13	.91	68
San Luis[1]	1.47	1.86	.19	.58	72
Westlands[1]					
Depth to water table					
Less than or equal to 10 ft	1.84	1.90	.27	.33	85
Greater than 10 ft and less than or equal to 20 ft	1.91	2.19	.27	.55	78
Greater than 20 ft					
With surface-water delivery	1.74	2.43	.28	.97	64
Without surface-water delivery	1.60	.00	.18	-1.42	880
Study area	1.76	2.12	.28	.64	73
1984					
Firebaugh	2.02	2.76	0.37	1.11	65
Tranquillity	2.06	2.94	.22	1.10	65
Panoche	1.68	2.58	.45	1.35	55
Broadview	2.21	2.52	.13	.44	83
San Luis[1]	1.63	2.03	.17	.57	74
Westlands[1]					
Depth to water table					
Less than or equal to 10 ft	1.97	2.31	.27	.61	76
Greater than 10 ft and less than or equal to 20 ft	1.88	2.53	.27	.92	67
Greater than 20 ft					
With surface-water delivery	1.92	2.68	.27	1.03	65
Without surface-water delivery	1.66	.00	.18	-1.48	922
Study area	1.89	2.45	.28	.84	69

[1]Data within study area only.

The relation between irrigation efficiency and the depth to water table was evaluated by focusing on those sections within the Westlands Water District that receive surface-water delivery. Sections without surface-water delivery were excluded because the preliminary water budget indicated that ground-water pumpage data estimated from electrical usage data cannot be disaggregated at scales smaller than townships.

For the subareas representing each depth to the water table range, crop type and acreage, surface-water delivery data, and pumpage estimates for sections receiving surface-water delivery were aggregated to calculate irrigation efficiency. These values for 1980 and 1984 are given in table 4. These values show that as depth to the water table increases, irrigation efficiency decreases. This relation reflects the fact that areas of shallow ground water are subject to drainage problems. Farmers in these areas are encouraged to be more efficient in their irrigation practices because excess water contributes to rising water levels (Westlands Water District, written commun., 1985).

The following average values of irrigation efficiency for each range of depth to water table were used in the revised water budget:

Irrigation efficiency (percent)	Depth to water table
80	Less than or equal to 10 ft
72	Greater than 10 ft and less than or equal to 20 ft
65	Greater than 20 ft

For water-budget subareas with more than one range of depth to water table, an irrigation efficiency was calculated using an area-weighted average.

The reliability of the irrigation efficiency values based on the depth to water table can be evaluated by comparing them with other investigations of regional-scale irrigation efficiency. Burt and Katen (1988) evaluated irrigation efficiency in 83 fields (about 11,000 acres) in the central part of the western San Joaquin Valley during 1986-87. The 83 fields were planted in more than seven crop types and the depth to water table was within 10 ft of land surface in all 83 fields. Burt and Katen (1988) measured or calculated water-budget components including: applied water, beneficial use (applied water used by crops), effective precipitation, deep percolation (ground-water recharge), and evaporative and runoff losses during irrigation. For the 83 fields examined, the average amount of irrigation water applied during the 1986-87 irrigation season was 2.5 acre-ft/acre, the average irrigation efficiency was 66 percent, and deep percolation for the year was 0.8 acre-ft/acre. Evaporative and runoff losses were negligible (for example, losses were smaller than the reported level of accuracy of the study).

Table 4. Irrigation efficiencies calculated for 1980 and 1984

[ft, foot]

Irrigation efficiency (percent)		Depth to water table
1980	1984	
84	76	Less than or equal to 10 ft
76	66	Greater than 10 ft and less than or equal to 20 ft
64	65	Greater than 20 ft

The average irrigation efficiency reported by Burt and Katen (1988) is lower than the results of this investigation. In order to resolve the difference in results between Burt and Katen (1988) and this study, it is worthwhile to examine Burt and Katen's (1988) data for the 83 fields.

Examination of Burt and Katen's (1988) data for 83 fields shows that six crops in these fields are planted in a distribution similar to that in the Westlands Water District in areas where the depth to the water table is less than or equal to 10 ft. The acreage planted in these six crop types make up 70 percent of Burt and Katen's study area and 62 percent of the Westlands crop acreage. Irrigation efficiency is calculated by concentrating on the acreage planted in these six crop types. Burt and Katen's beneficial use values, which are used in calculating irrigation efficiency, differ from the crop-water requirement values provided by Westlands Water District. Although it is impossible to say which are "correct," Westlands Water District crop-water requirement values are used here for consistency. With these assumptions, the irrigation efficiency calculated for Burt and Katen's (1988) sample is 78 percent. This value is within the range of irrigation efficiency for 1980 and 1984 for areas with depth to water of less than or equal to 10 ft.

In another study of local scale, Hoffman and Steinert (U.S. Department of Agriculture, written commun., 1987) studied four fields in the study area, two in the areas of shallow water table and two upslope of this area. They calculated irrigation efficiency slightly differently, by adding effective rainfall to the crop-water requirement in the numerator, and rainfall to the applied water in the denominator. They found as in this study that the average upslope irrigation efficiency (55 percent) was lower than the average downslope irrigation efficiency (76 percent).

REVISED WATER BUDGET

The revised water budget culminates the process of quantifying recharge to the water table and ground-water pumpage for the nine subareas that represent the study area. In the revised water budget, surface-water delivery and crop-acreage data, along with the relation between irrigation efficiency and depth to water table, are used to estimate these essential components of the ground-water model. To do this, a crop-based approach is used. Irrigation requirement can be defined as the depth of water, surface water and ground water, required to meet crop-water requirement for normal crop production plus leaching requirements and losses caused by inefficiency in irrigation. Almost all fields in the Central Valley receive enough water to fulfill plant needs, which maximizes crop-water requirement. Agriculture in California tends to be oriented to maximize crop production rather than to minimize crop-water requirement (Williamson, 1982). Additionally, irrigation requirement generally exceeds crop-water requirement because of the inefficiencies in irrigation, particularly distribution nonuniformity (Burt and Katen, 1988).

Subarea crop-water requirement and irrigation efficiency values are used to calculate irrigation requirement. The irrigation requirement is then compared with surface-water delivery to determine if ground-water pumping is necessary. Ground-water recharge is evaluated by comparing crop-water requirement with applied water (for example, surface water which may or may not be supplemented with ground water).

The irrigation requirement is calculated by rearranging equation 2 for irrigation efficiency:

$$IR = SW + GW = \frac{CWR}{IE}. \qquad (3)$$

Average depth of crop-water requirement and irrigation efficiency for the nine subareas are described in previous sections of this report and are shown in table 5 for 1980 and 1984.

Irrigation requirement can be supplied by surface water, if available, and by ground-water pumpage, if needed. Although surface-water delivery data are available by section or water district for the entire study area, ground-water pumpage must be estimated. A unit value of ground-water pumpage (*GW*) for a subarea can be calculated by comparing the unit value of surface water delivered to the unit value of irrigation requirement. If surface-water delivery (*SW*) is less than the irrigation requirement (*IR*), then:

$$GW = IR - SW. \qquad (4)$$

If the surface-water delivery exceeds irrigation requirement, then:

$$GW = 0. \qquad (5)$$

In areas where the surface-water delivery exceeds irrigation requirement, the irrigation efficiency is lower than predicted by the depth to water relation. A value of irrigation efficiency based on application can be computed:

$$A\text{-}IE = \frac{CWR}{SW}. \qquad (6)$$

Irrigation requirement and surface-water delivery data for 1980 and 1984 are shown in table 5. From these data, ground-water pumpage and ground-water recharge were calculated (table 5). In addition, irrigation efficiency in subareas in which surface-water delivery exceeds irrigation requirement also were calculated (table 5).

The results of these calculations for the nine subareas for 1980 and 1984 are summarized in table 5. Recharge ranged from 0.46 to 0.96 ft in 1980 and 0.49 to 1.03 ft in 1984. Ground-water pumpage ranged from 0.25 to 2.46 ft in 1980 and 0.08 to 2.55 ft in 1984 for those subareas requiring pumpage. Three subareas, Firebaugh, Panoche, and Broadview in 1980, and Firebaugh, Tranquillity, and Panoche in 1984 did not require pumping.

The three areas not requiring ground-water pumpage (for example, surface water exceeded calculated irrigation requirement) are underlain by extensive on-farm drainage systems. In contrast, the six subareas without excess surface water are not underlain by on-farm drains.

Ground-water pumpage estimates in this report can be compared with the interviews with the individual water districts as compiled by W.E. Templin (U.S. Geological Survey, written commun., 1989). Templin reports that in general the Tranquillity and Westlands Water Districts use ground-water pumpage and the Firebaugh, Broadview, and San Luis Water Districts do not. Templin does not provide pumpage information on the Panoche Water District. Pumpage estimates for 1980 concur with the findings of Templin except for the San Luis subarea.

Table 5. Revised water budgets for 1980 and 1984

[Irrigation efficiency from worksheets. ft, foot; nc, not calculated]

Subarea (fig. 3)	Crop-water require-ment (ft)	Irrigation efficiency based on depth to water table (percent)	Irrigation require-ment (ft)	Surface-water delivery (ft)	Ground-water pumpage (ft)	Ground-water recharge (ft)	Irrigation efficiency based on application (percent)
1980							
Firebaugh	1.88	80	2.35	2.63	0	0.75	71
Tranquillity	1.97	70	2.81	2.51	.30	.84	nc
Panoche	1.52	73	2.08	2.48	0	.96	61
Broadview	1.97	79	2.49	2.75	0	.78	72
San Luis[1]	1.47	65	2.26	1.86	.40	.79	nc
Westlands[1]							
Depth to water table							
Less than or equal to 10 ft	1.84	80	2.30	1.90	.40	.46	nc
Greater than 10 ft and less than or equal to 20 ft	1.91	72	2.65	2.19	.46	.74	nc
Greater than 20 ft							
With surface-water delivery	1.74	65	2.68	2.43	.25	.94	nc
Without surface-water delivery	1.60	65	2.46	0	2.46	.86	nc
1984							
Firebaugh	2.02	80	2.53	2.76	0	0.74	73
Tranquillity	2.06	70	2.94	2.94	0	.88	70
Panoche	1.68	73	2.30	2.58	0	.90	65
Broadview	2.21	79	2.80	2.52	.28	.59	nc
San Luis[1]	1.63	65	2.51	2.03	.48	.88	nc
Westlands[1]							
Depth to water table							
Less than or equal to 10 ft	1.97	80	2.46	2.31	.15	.49	nc
Greater than 10 ft and less than or equal to 20 ft	1.88	72	2.61	2.53	.08	.73	nc
Greater than 20 ft							
With surface-water delivery	1.92	65	2.95	2.68	.27	1.03	nc
Without surface-water delivery	1.66	65	2.55	0	2.55	.89	nc

[1]Data within study area only.

For 1984, the data provided by Templin indicate that pumpage is not required for Tranquillity and is required for Broadview and San Luis Water Districts to satisfy irrigation requirement. The agreement between the 1980 results and the survey by Templin suggests that the 1980 water budget is a more reliable indicator of general conditions than the 1984 water budget.

DISTRIBUTION OF PUMPING

Estimation of a water budget for the study area indicates that ground-water pumpage is needed to supplement surface-water delivery in the four subareas within the Westlands Water District and in certain years in San Luis, Broadview, and Tranquillity Water Districts. It is also important to estimate the percentages of pumping from the confined and semiconfined zones, below and above the Corcoran Clay Member.

Several workers have reported on the distribution of pumping from the confined and semiconfined zones. Bull and Miller (1975) presented a map showing the distribution of ground-water pumping with respect to the Corcoran Clay Member. Bull and Miller's (1975) map shows a trend from predominantly confined zone pumping along the Coast Ranges to predominantly semiconfined zone pumping along the valley trough. The exceptions to these trends are areas where poor-quality ground water occurs in the semiconfined zone. Diamond and Williamson (1983) also present a map, based on well perforation data, indicating the distribution of pumping from a lower and upper aquifer (reportedly coincident with the Corcoran Clay Member in areas where the Corcoran Clay Member is present). Diamond and Williamson's (1983) map shows a distribution of pumping from the zones similar to Bull and Miller's (1975) map, but does not show lesser pumping in the upper aquifer in areas demarcated by Bull and Miller (1975) as having poor-quality ground water above the Corcoran Clay Member.

To estimate the percentage of pumping from above and below the Corcoran Clay Member, the distribution of well perforations was examined. Three maps were overlain to establish pumping subareas for analysis: water-budget subarea boundaries, presence or absence of Sierran sand, and Bull and Miller's (1975) pumping distribution. Eleven subareas were identified for analysis of pumpage (fig. 4). The Westlands Water District, Sierran sand present, north; Westlands Water District, Sierran sand present, middle; and Westlands Water District, Sierran sand present, south, were identified by Bull and Miller (1975) as having 25 to 50 percent, 0 to 25 percent, and 50 to 100 percent of pumping from above the Corcoran Clay Member. The Mendota Wildlife Refuge was assumed to have no pumping.

For each of the 10 subareas in which pumping might occur, well depth and well perforations were used to determine the percentage of perforation length within the semiconfined and confined zones. For each of the subareas, data from wells of known depth and known perforation length were divided into three categories: wells completed in the semiconfined zone only, wells completed in both the semiconfined and confined zones, and wells completed in the confined zone only. For each of the 10 subareas and for each of the three categories, the following data were compiled: total number of wells, total perforation length above Corcoran Clay Member (if appropriate), and total perforation length below Corcoran Clay Member (if appropriate). From the compiled data, the average perforation length above and below Corcoran Clay Member was calculated. The well-perforation data are presented by pumping subarea in table 6 and are used in subsequent calculations.

The distribution of pumping from the semiconfined and confined zones was evaluated from perforation length data (table 6). In areas where the Sierran sand is absent, the percentages of pumping from the semiconfined and confined zones were evaluated by assuming that the hydraulic conductivity of the Coast Ranges alluvium above the Corcoran Clay Member is the same as the hydraulic conductivity of the poorly consolidated flood-plain, deltaic, alluvial-fan, and lacustrine deposits below the Corcoran Clay Member. This assumption is made because the Coast Ranges alluvium above the Corcoran Clay Member and the poorly consolidated deposits below the Corcoran are heterogeneous. With this assumption, the percentages of pumping from the semiconfined and confined zones were calculated from the percentages of perforation length above and below the Corcoran Clay Member.

In areas where the Sierran sand is present, the analysis is somewhat more complex because the Sierran sand has a coarser texture (Laudon and Belitz, 1991) than the Coast Ranges alluvium and larger average hydraulic conductivity (Phillips and Belitz, 1991). Conversion of perforation length to percentage of pumping requires establishing a relation between a given length of perforation in the Sierran sand and the same length in the Coast Ranges alluvium.

The well-perforation data were aggregated into two groups: wells in areas where Sierran sand is present and wells in areas where Sierran sand is absent. The aggregated data were used to establish an "average" well in the two areas (table 7). The average well in areas where the Sierran sand is present has a perforation length of 108 ft above the Corcoran Clay Member and 328 ft below the Corcoran Clay Member. The average well where the Sierran sand is absent has a perforation length of 43 ft above the Corcoran Clay Member and 740 ft below the Corcoran Clay Member.

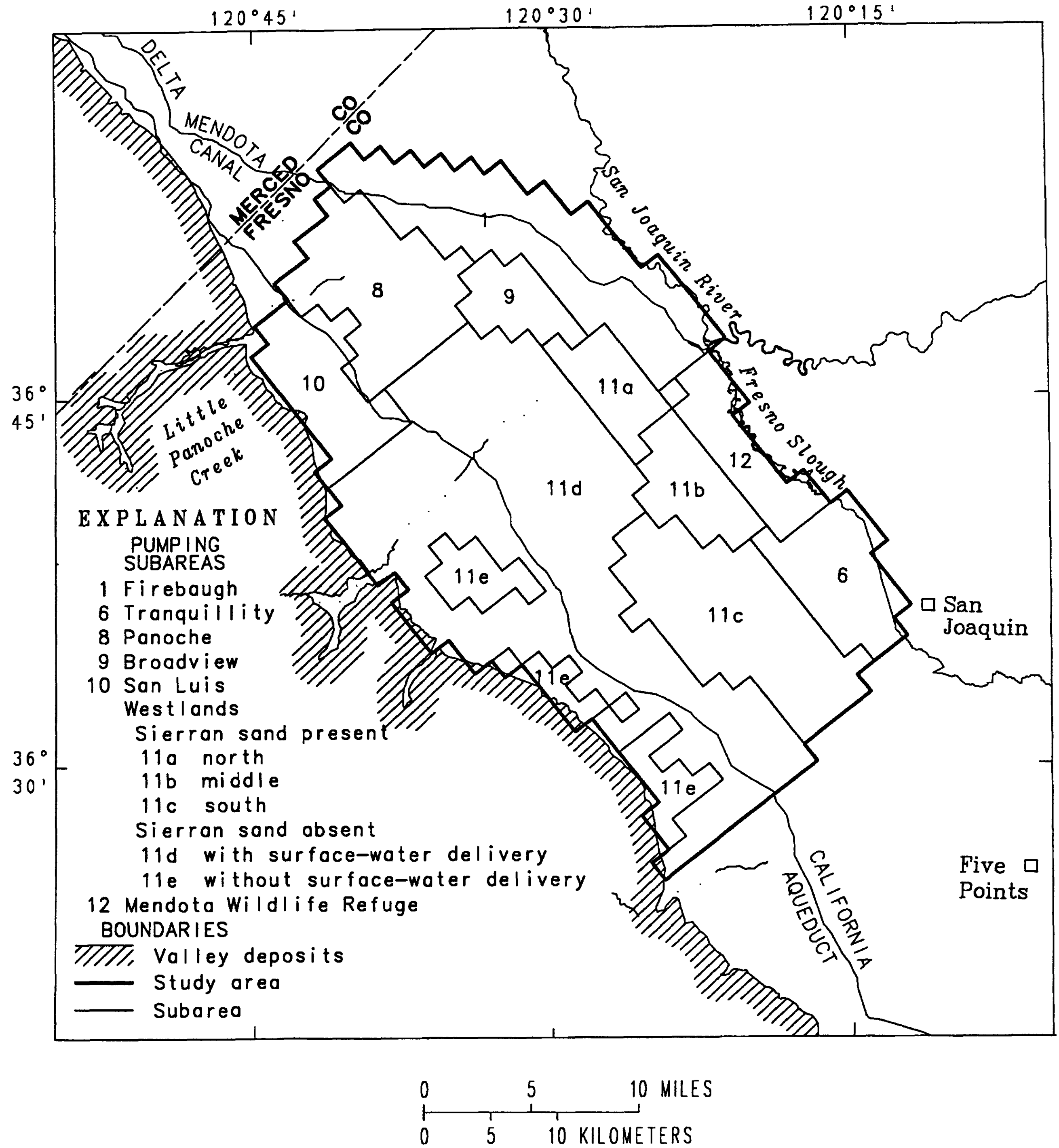

Figure 4. Pumping subareas.

Evidence indicates that the Sierran sand above the Corcoran Clay Member yields more water than the Coast Ranges alluvium. This can be shown by comparing the hydraulic conductivity and texture of Sierran sand with that of Coast Ranges alluvium. The average hydraulic conductivity of Sierran sand is 1.2×10^{-3} ft/s and the average hydraulic conductivity of Coast Ranges alluvium is 3.6×10^{-4} ft/s (Phillips and Belitz, 1991); the ratio of the hydraulic conductivity is 3.3. The texture of the Sierran sand is typically 65 percent coarse grained and the texture of the Coast Ranges alluvium is typically 35 percent (Laudon and Belitz, 1991); the ratio of the texture-weighted hydraulic conductivity is 6.2. Methods used for calculating texture-weighted hydraulic conductivity are explained by Phillips and Belitz (1991).

Table 6. Well-perforation data for subareas

[ft, foot. --, no data]

	Number of wells	Total perforation length (ft)		Average perforation length (ft)	
		Above Corcoran Clay Member	Below Corcoran Clay Member	Above Corcoran Clay Member	Below Corcoran Clay Member
Firebaugh subarea					
Semiconfined	12	1,863	--	155	--
Semiconfined and confined	1	387	130	387	130
Confined	2	--	367	--	184
Total	15	2,250	497	150	33
Tranquillity subarea					
Semiconfined	0	--	--	--	--
Semiconfined and confined	5	939	1,184	188	237
Confined	1	--	297	--	297
Total	6	939	1,481	157	247
Panoche subarea					
Semiconfined	1	150	--	150	--
Semiconfined and confined	8	350	4,992	44	624
Confined	30	--	14,955	--	499
Total	39	500	19,947	13	511
Broadview subarea					
Semiconfined	0	--	--	--	--
Semiconfined and confined	4	223	2,952	56	738
Confined	3	--	1,406	--	469
Total	7	223	4,358	32	623
San Luis subarea					
Semiconfined	5	436	--	87	--
Semiconfined and confined	1	6	486	86	486
Confined	12	--	8,820	--	735
Total	18	522	9,306	29	517
Westlands Water District, Sierran sand is present, northern subarea					
Semiconfined	2	321	--	161	--
Semiconfined and confined	4	378	2,409	95	602
Confined	5	--	3,088	--	618
Total	11	699	5,497	64	500
Westlands Water District, Sierran sand is present, middle subarea					
Semiconfined	4	500	--	125	--
Semiconfined and confined	2	246	958	123	479
Confined	14	--	6,163	--	440
Total	20	746	7,121	37	356
Westlands Water District, Sierran sand is present, southern subarea					
Semiconfined	11	2,227	--	202	--
Semiconfined and confined	28	4,800	9,578	171	342
Confined	12	--	7,575	--	631
Total	51	7,027	17,153	138	336

Table 6. Well-perforation data for subareas--*Continued*

	Number of wells	Total perforation length (ft)		Average perforation length (ft)	
		Above Corcoran Clay Member	Below Corcoran Clay Member	Above Corcoran Clay Member	Below Corcoran Clay Member
Westlands Water District, Sierran sand is absent, with surface-water delivery					
Semiconfined	25	2,398	--	96	--
Semiconfined and confined	118	11,593	92,471	98	784
Confined	148	--	131,466	--	888
Total	291	13,991	223,937	48	770
Westlands Water District, Sierran sand is absent, without surface-water delivery					
Semiconfined	5	526	--	105	--
Semiconfined and confined	9	1,056	9,484	117	1,054
Confined	20	--	1,953	--	998
Total	34	1,582	29,437	47	866

Table 7. Compilation of data for wells in areas where the Sierran sand is present or absent

[Data for wells in areas where Sierran sand is present are from Firebaugh, Tranquillity, Broadview, and Westlands subareas--north, middle, and south. Data for wells in areas where Sierran sand is absent are from Panoche, San Luis, and Westlands subareas--with and without surface-water delivery. ft, foot; --, no data]

Description of wells	Number of wells	Total perforation length (ft)		Average perforation length (ft)	
		Above Corcoran Clay Member	Below Corcoran Clay Member	Above Corcoran Clay Member	Below Corcoran Clay Member
Sierran sand is present					
Wells completed in the					
Semiconfined zone	29	4,911	--	169	--
Semiconfined and confined zones	44	6,973	17,211	158	391
Confined zone	37	--	18,896	--	511
Total	110	11,884	36,107		
Average				108	328
Sierran sand is absent					
Wells completed in the					
Semiconfined zone	36	3,510	--	98	--
Semiconfined and confined zones	136	13,085	107,433	96	790
Confined zone	210	--	175,194	--	834
Total	382	16,595	282,627		
Average				43	740

The relation between a given length of perforation in the Sierran sand and the same length in the Coast Ranges alluvium can be established using the perforation lengths with two assumptions: deposits below the Corcoran Clay Member have similar hydraulic conductivity to Coast Ranges alluvium above the Corcoran Clay Member (this assumption was made in preceding analysis of percentage of pumping in areas where the Sierran sand is absent); and the average well has equal yield independent of the presence or absence of Sierran sand. With these assumptions, the average well where Sierran sand is present can be equated to the average well where the Sierran sand is absent:

$$ax+b = c+d, \tag{7}$$

where

- a = perforation length above the Corcoran Clay Member in areas where Sierran sand is present;
- x = "worth" of Sierran sand with respect to Coast Ranges alluvium;
- b = perforation length below Corcoran Clay Member in areas where Sierran sand is present;
- c = perforation length above Corcoran Clay Member in areas where Sierran sand is absent;
- d = perforation length below Corcoran Clay Member in areas where Sierran sand is absent.

Application of equation 7 to the average well data for the model area (a=108, b=328, c=43, and d=740) indicates that x=4.21. This value is consistent with the range indicated by the hydraulic conductivity and textural data.

The percentages of pumping from the semiconfined and confined zones where the Sierran sand is present was estimated by multiplying the perforation length above Corcoran Clay Member by 4.21 to calculate a "weighted" perforation length above the Corcoran Clay Member. The perforation length below the Corcoran Clay Member is multiplied by 1. The percentage of pumping above the Corcoran Clay Member is equivalent to the ratio of the weighted perforation length above the Corcoran Clay Member to the total perforation length; the percentage of pumping below the Corcoran Clay Member is calculated in a similar manner (table 8).

Table 8. Summary of average perforation length and percentage of pumpage by subarea

Subarea (fig. 4)	Number of wells	Sierran sand	Above Corcoran Clay Member		Below Corcoran Clay Member	
			Average perforation length (ft)	Pumpage (percent)	Average perforation length (ft)	Pumpage (percent)
Firebaugh	15	Present	150	95	33	5
Tranquillity	6	Present	157	73	247	27
Panoche	39	Absent	13	2	511	98
Broadview	7	Present	32	18	623	82
San Luis[1]	18	Absent	29	5	517	95
Westlands[1]						
North	11	Present	64	35	500	65
Middle	20	Present	37	30	356	70
South	51	Present	138	63	336	37
With surface-water delivery	291	Absent	48	6	770	94
Without surface-water delivery	34	Absent	47	5	866	95

[1]Data within study area only.

SUMMARY

Quantitative estimates of ground-water recharge and ground-water pumpage are essential for developing a numerical simulation model of the regional ground-water flow system in the central part of the western San Joaquin Valley, California. An accurate model of the system requires identification of the areal distribution of recharge and the areal and vertical distribution of ground-water pumpage.

Initial and revised water budgets for nine subareas of the study area were made. The initial water budget used available surface-water delivery and crop-acreage data along with the ground-water pumpage estimates from electrical usage data to estimate ground-water recharge and irrigation efficiency. The revised water budget used the available surface-water delivery and crop-acreage data along with estimated irrigation efficiencies to estimate ground-water recharge and ground-water pumpage.

In the initial water budget, values of surface-water delivery, crop-water requirement, and ground-water pumpage were applied to the water budget. Analysis of the water budget at this stage indicated that pumpage estimates may not be reliable in areas significantly smaller than townships; in particular, weaknesses appear when examining areas without surface-water delivery. Although this analysis pointed to weaknesses in the ground-water pumpage estimates, it also indicated an inverse relation between irrigation efficiency and depth to water table. Evaluation of data from the Westlands Water District indicates the following values of irrigation efficiency: 80 percent in areas where depth to water table is less than or equal to 10 ft; 72 percent in areas where depth to water table is greater than 10 ft and less than or equal to 20 ft; and 65 percent in areas where depth to water table is greater than 20 ft.

The revised water-budget approach used the surface-water delivery and crop-acreage data as in the initial water budget, but with an estimate of ground-water pumpage based on irrigation requirement. Recharge ranged from 0.46 to 0.96 ft in 1980 and 0.49 to 1.03 ft in 1984. Ground-water pumpage ranged from 0.25 to 2.46 ft in 1980 and 0.08 to 2.55 ft in 1984.

Ground-water pumpage was distributed between the semiconfined and confined zones on the basis of an analysis of perforation lengths of wells in the study area. In areas where Sierran sand is absent, the percentage of pumping from the semiconfined and confined zones was estimated from the percentage of perforated length above and below the Corcoran Clay Member. In areas where Sierran sand is present, the same procedure is used but the part of perforation length above the Corcoran Clay Member in Sierran sand was weighted relative to the other perforated zones. In areas where Sierran sand is absent, the percentage of pumping from below the Corcoran Clay Member ranges from 94 to 98 percent. In areas where Sierran sand is present, the percentage of pumping from below the Corcoran Clay Member ranges from 5 to 82 percent.

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