

**ESTIMATES OF CONSUMPTIVE USE AND GROUND-WATER RETURN FLOW  
USING WATER BUDGETS IN PALO VERDE VALLEY, CALIFORNIA**

By Sandra J. Owen-Joyce and Steven L. Kimsey

---

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 87-4070

Prepared in cooperation with the  
U.S. BUREAU OF RECLAMATION



Tucson, Arizona  
December 1987

DEPARTMENT OF THE INTERIOR  
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY  
Dallas L. Peck, Director

---

For additional information  
write to:

District Chief  
U.S. Geological Survey  
Box FB-44  
Federal Building  
300 West Congress Street  
Tucson, Arizona 85701-1393

Copies of this report can  
be purchased from:

U.S. Geological Survey  
Books and Open-File  
Reports Section  
Federal Center, Bldg. 810  
Box 25425  
Denver, CO 80225

#### IV

Figures	6-9. Graphs showing:	Page
6.	Diversions, surface-water return flows, and cultivated area in Palo Verde Valley, California, 1960-84.....	11
7.	Daily mean flow in the Colorado River at Palo Verde Dam, 1980-84.....	12
8.	Daily mean gage height of the Colorado River at Cibola Cross Section No. 28, 1981-84.....	12
9.	Annual precipitation at Blythe, California, 1917-84.....	13
10-16.	Maps showing:	
10.	Average water-table altitude in Palo Verde Valley, California, 1982.....	16
11.	Average water-table altitude in Palo Verde Valley, California, 1983.....	18
12.	Average water-table altitude in Palo Verde Valley, California, 1984.....	20
13.	Change in annual average ground-water levels in Palo Verde Valley, California, 1980-81.....	24
14.	Change in annual average ground-water levels in Palo Verde Valley, California, 1981-82.....	26
15.	Change in annual average ground-water levels in Palo Verde Valley, California, 1982-83.....	28
16.	Change in annual average ground-water levels in Palo Verde Valley, California, 1983-84.....	30
17.	Graph showing:	
17.	Water levels in selected wells in Palo Verde Valley, California, 1980-84.....	32

## CONTENTS

---

	Page
Abstract.....	1
Introduction.....	2
Physical setting.....	3
Acknowledgments.....	6
Hydrologic system.....	6
Colorado River.....	9
Precipitation.....	13
Ground water.....	15
Areal changes in ground-water levels.....	15
Change in storage.....	33
Consumptive use.....	34
Ground-water return flow.....	42
Diversions minus return flows.....	45
Comparison of consumptive-use estimates.....	46
Summary.....	47
Selected references.....	49

---

## ILLUSTRATIONS

---

	Page
Figures 1-2. Maps showing:	
1. Area of report.....	3
2. Palo Verde Valley and location of streamflow-gaging stations and surface-water measurement sites.....	4
3-5. Graphs showing:	
3. Acreages by crop type, cultivated area, and total crops in Palo Verde Valley, California, 1980-84.....	7
4. Diversions, applied water, return flows, and total cropped area in Palo Verde Valley, California, 1981-84.....	8
5. Flow in the Colorado River, 1960-85.....	10
	III

# VI

Tables	8-11.—Continued	Page
8.	Estimates of consumptive use by vegetation in Palo Verde Valley, California, 1981-84.....	39
9.	Evapotranspiration per unit area by vegetation in Palo Verde Valley, California, 1981-84.....	39
10.	Primary variables used in the computation of consumptive use by vegetation and ground-water return flow in Palo Verde Valley, California, and sensitivity of results to a change in specified value.....	40
11.	Water budgets for the area drained by the Colorado River in Palo Verde Valley, California, 1981-84.....	44

Figures 18-20. Graphs showing:	Page
18. Comparison of consumptive use by vegetation and evapotranspiration in Palo Verde Valley, California, 1981-84.....	42
19. Comparison of consumptive use by vegetation and evapotranspiration per unit vegetated area in Palo Verde Valley, California, 1981-84.....	43
20. Comparison of consumptive use by vegetation determined from a water budget and consumptive use of river water determined from diversions minus return flows in Palo Verde Valley, California, 1981-84.....	46

---

TABLES

---

	Page
Table 1. Estimates of surface-water return flows to the Colorado River in Palo Verde Valley, California, 1981-84.....	14
2. Annual precipitation for Blythe, California, 1980-84.....	15
3. Annual water-level changes in Palo Verde Valley, California.....	22
4. Change in storage for Palo Verde Valley, California, 1981-84.....	33
5. Water budgets for the area drained by drainage ditches in Palo Verde Valley, California, 1981-84.....	35
6. Estimates of surface-water diversions to irrigated land in Palo Verde Valley, California, 1981-84.....	36
7. Estimates of irrigation requirements and evapotranspiration by vegetation in Palo Verde Valley, California, 1981-84.....	38

## CONVERSION FACTORS

For readers who prefer to use metric (International System) units rather than inch-pound units, the conversion factors for the terms used in this report are listed below:

<u>Multiply inch-pound unit</u>	<u>By</u>	<u>To obtain metric unit</u>
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi <sup>2</sup> )	2.590	square kilometer (km <sup>2</sup> )
foot per mile (m/km)	0.1894	meter per kilometer (ft/mi)
foot squared per day (ft <sup>2</sup> /d)	0.0929	meter squared per day (m <sup>2</sup> /d)
cubic foot per second (ft <sup>3</sup> /s)	0.02832	cubic meter per second (m <sup>3</sup> /s)
acre	0.4047	square hectometer (hm <sup>2</sup> )
acre-foot (acre-ft)	0.001233	cubic hectometer (hm <sup>3</sup> )
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm <sup>3</sup> /yr)
acre-foot per square mile (acre-ft/mi <sup>2</sup> )	0.000476	cubic hectometer per square kilometer (hm <sup>3</sup> /km <sup>2</sup> )

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 "Mean Sea Level of 1929."

# ESTIMATES OF CONSUMPTIVE USE AND GROUND-WATER RETURN FLOW USING WATER BUDGETS IN PALO VERDE VALLEY, CALIFORNIA

By

Sandra J. Owen-Joyce

and

Steven L. Kimsey

---

## ABSTRACT

Palo Verde Valley, California, is an agricultural area on the flood plain of the Colorado River where irrigation water is diverted from the river and ground water is discharged to a network of drainage ditches and (or) the river. Consumptive use by vegetation and ground-water return flow were calculated using water budgets. Consumptive use by vegetation was 484,000 acre-feet in 1981, 453,600 acre-feet in 1982, 364,400 acre-feet in 1983, and 374,300 acre-feet in 1984. The consumptive-use estimates are most sensitive to two measured components of the water budget—the diversion at Palo Verde Dam and the discharge from drainage ditches to the river. Ground-water return flow was 31,700 acre-feet in 1981, 24,000 acre-feet in 1982, 2,500 acre-feet in 1983, and 7,900 acre-feet in 1984. The return-flow estimates are most sensitive to discharge from drainage ditches; various irrigation requirements and crop areas, particularly alfalfa; the diversion at Palo Verde Dam; and the estimate of consumptive use. During increasing flows in the river, the estimate of ground-water return flow is sensitive also to change in ground-water storage.

Change in ground-water storage was estimated to be -5,700 acre-feet in 1981, -12,600 acre-feet in 1982, 5,200 acre-feet in 1983, and 11,600 acre-feet in 1984. Change in storage can be a significant component in the water budget used to estimate ground-water return flow but is negligible in the water budget used to estimate consumptive use. Change in storage was 1 to 3 percent of annual consumptive use. Change in storage for the area drained by the river ranged from 7 to 96 percent of annual ground-water return flow during the 4 years studied.

Consumptive use calculated as diversions minus return flows was consistently lower than consumptive use calculated in a water budget. Water-budget estimates of consumptive use account for variations in precipitation, tributary inflow, river stage, and ground-water storage. The calculations for diversions minus return flows do not account for these



components, which can be large enough to affect the estimates of consumptive use.

## INTRODUCTION

A decree by the U.S. Supreme Court (1964) apportions the waters of the lower Colorado River to the States of California, Arizona, and Nevada in terms of consumptive use, which is defined in the decree as "\* \* \*diversions from the stream less such return flow thereto as is available for consumptive use\* \* \*." The decree requires that, for each diverter, the quantities of diversion and consumptive use be published annually.

Ground-water return flow is estimated in order to credit the States with total return flows from their diversions. The quantity of ground-water return flow is needed in order to estimate consumptive use as defined by the decree. Consumptive use of lower Colorado River water is estimated as diversions minus surface-water and ground-water return flows. Diversions and surface-water return flows are measured. Ground-water return flow cannot be measured but is estimated with a water budget for part of the area in Palo Verde Valley, California (Owen-Joyce, 1984) and Parker Valley, Arizona (Leake, 1984).

The method to estimate ground-water return flow requires that consumptive use by vegetation be estimated as the residual term in a ground-water budget for that part of the shallow alluvial aquifer drained by drainage ditches. Consumptive use by vegetation is water lost through evapotranspiration and evaporation from bare-soil (non-vegetated) and open-water surfaces. Evapotranspiration refers to the loss of water from a land area through transpiration by vegetation and evaporation from the soil surface under the vegetation. Evapotranspiration calculated as the product of areas by vegetation types determined from Landsat digital-image analysis and predetermined water-use rates was tested as a method of approximating consumptive use along the lower Colorado River (Raymond and Rezin, 1986). Evapotranspiration estimates were within  $\pm 3$  percent of evapotranspiration calculated from crop maps (Raymond and Rezin, 1986, p. 30), which were within 12 to 17 percent of consumptive use by vegetation (Owen-Joyce, 1984, p. 29; Leake, 1984, p. 25).

Palo Verde Valley, California (fig. 1), was chosen as a test area to compare estimates of consumptive use by vegetation and estimates of evapotranspiration calculated using the methods described above. The study was divided into two parts, each of which is documented in a separate report. This report describes the estimation of consumptive use by vegetation using water budgets. Estimates of evapotranspiration using Landsat digital-image data and the comparison of evapotranspiration to consumptive use are found in Raymond and Owen-Joyce (1987).

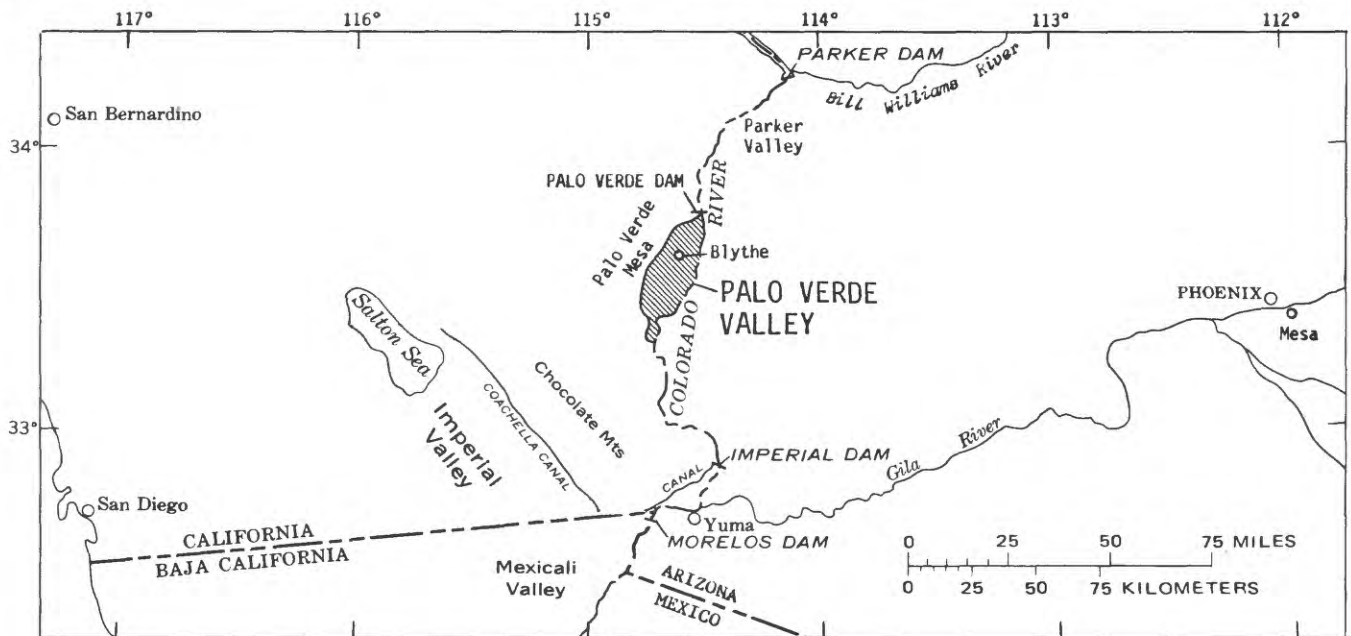


Figure 1.--Area of report (shaded).

This report describes the calculation of consumptive use by vegetation for 1981, 1982, 1983, and 1984. Multiple years of data allowed for the testing of the assumption made in the methodology report (Owen-Joyce, 1984) that change in ground-water storage was small and therefore negligible in the water-budget calculations. This report includes a brief description of the hydrologic system, estimates of consumptive use by vegetation determined by using water budgets, estimates of change in ground-water storage, estimates of ground-water return flow, estimates of consumptive use calculated as diversions minus return flows, and a comparison of estimates of consumptive use by vegetation to estimates of consumptive use as diversions minus return flows.

### Physical Setting

Palo Verde Valley contains about 175 mi<sup>2</sup> of flood plain along the Colorado River in eastern Riverside and Imperial Counties, California, adjacent to the boundary with Arizona (fig. 1). Palo Verde Valley is bounded on the west by the edge of the flood plain and on the east by the Colorado River. The main population center is Blythe (fig. 2). Most of the flood plain is used for agriculture. About 93,000 acres are cultivated. Many fields are double- or triple-cropped annually.

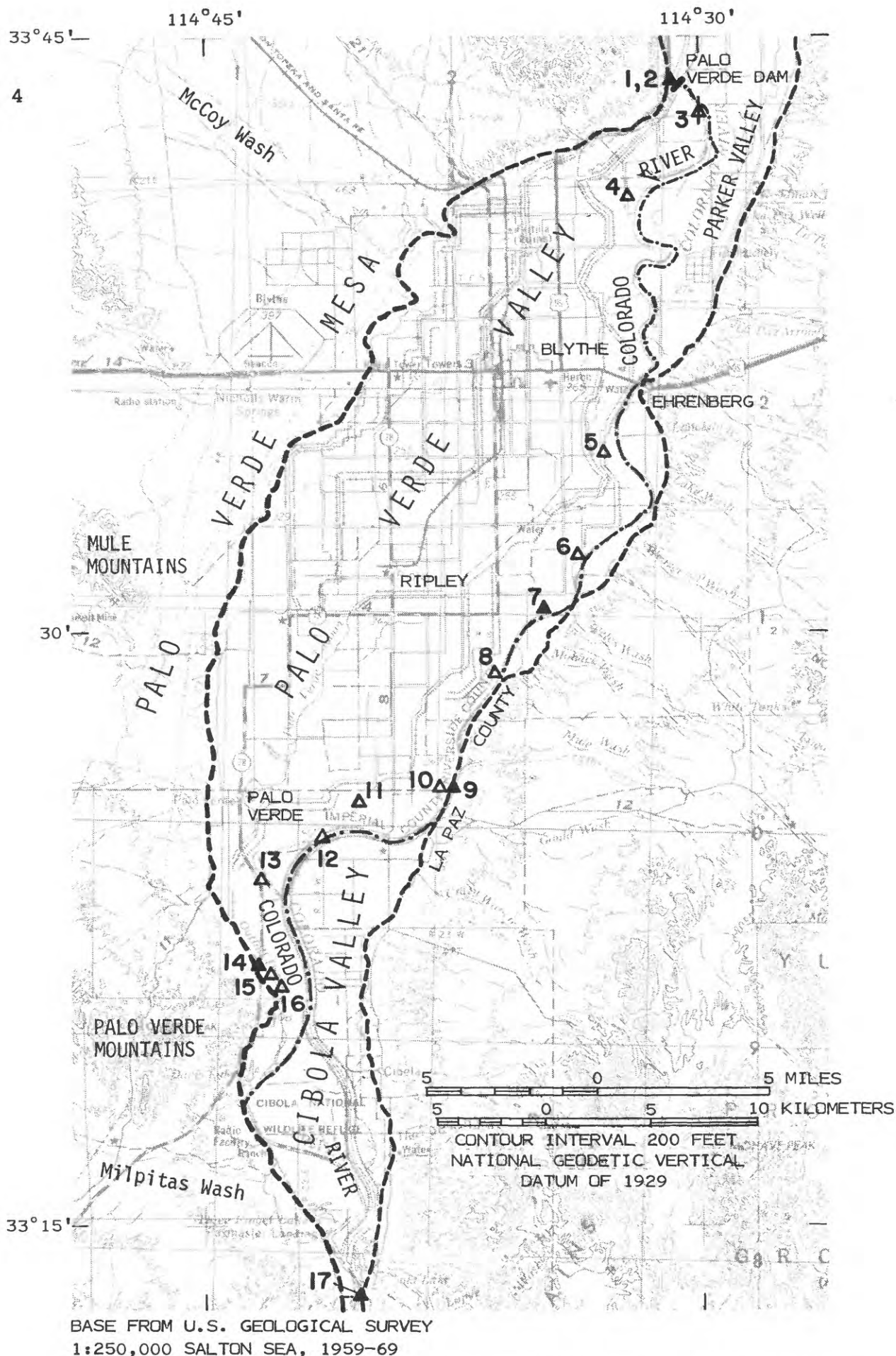


Figure 2.--Palo Verde Valley and location of streamflow-gaging stations and surface-water measurement sites.

### EXPLANATION

- ▲<sub>2</sub> CONTINUOUS-RECORD STREAMFLOW-GAGING STATION—Number, 2, corresponds to station names listed below
- Δ<sub>4</sub> MEASUREMENT SITE—Number, 4, corresponds to site names listed below
- ♠<sub>3</sub> DISCONTINUED STREAMFLOW-GAGING STATION—Number, 3, corresponds to station names listed below

----- COLORADO RIVER FLOOD-PLAIN BOUNDARY

— . — . — . — . — . — . BOUNDARY OF PALO VERDE VALLEY WHERE THE FLOOD-PLAIN  
AQUIFER IS CONTINUOUS

### Index of gaging stations and measurement sites

1. Palo Verde Canal near Blythe.
2. Colorado River at Palo Verde Dam.
3. Colorado River below Palo Verde Dam.
4. Olive Lake drain near Blythe.
5. F-canal spill near Blythe.
6. D-10-11-2 spill near Blythe.
7. D-10-11-5 spill near Blythe.
8. D-23 spill near Blythe.
9. Colorado River at Taylor Ferry near Blythe.
10. D-23-1 spill near Blythe.
11. C-canal spill near Blythe.
12. Colorado River at Cibola Cross Section No. 28.
13. C-28 upper spill near Blythe.
14. Palo Verde Outfall drain near Palo Verde.
15. Anderson drain near Palo Verde.
16. C-28 lower spill near Blythe.
17. Colorado River below Cibola Valley.

Figure 2

All crops are irrigated because the mean annual precipitation of 3.91 in. (California Department of Water Resources, 1981, p. 671) is insufficient for growing crops. About 6,900 acres are covered with phreatophytes.

River stage, the mixture of crops grown, and diversions to Palo Verde Valley changed from 1980 to 1984. Flow in the river exceeded downstream requirements for part of 1980 and for 1983 and 1984. The largest change in the crop mixture occurred during 1983 (fig. 3) when the Federal government instituted the PIK (Payment-In-Kind) program in which cotton growers were subsidized for not planting as much as half of their usual cotton acreage. About 11,000 acres of land were removed from crop production in 1983 (fig. 3) because of the PIK program (Palo Verde Irrigation District, written commun., 1984). Many of the fields left fallow were irrigated and cultivated to preserve soil structure. Volunteer vegetation grew in response to the irrigation and cultivation. In 1984 some of the fields remained fallow but most were planted with crops. Diversions to the valley and applied water varied from year to year and followed the same trend as the total cropped area (fig. 4).

#### Acknowledgments

Roger E. Henning and Jerry Wolford, Jr., of Palo Verde Irrigation District, provided irrigation and agricultural data. Hydrologic and crop data were collected by Palo Verde Irrigation District (PVID) and included monthly and annual average water levels in wells, monthly stage measurements in the drainage ditches, spillage from canals, flow in Olive Lake and Anderson drains, and crop type and acreage for each field in the valley. These data were used to calculate water budgets and change in ground-water storage. H. C. Millsaps of the U.S. Soil Conservation Service provided evapotranspiration values for alfalfa, cotton, and grains determined from soil-moisture studies in Parker Valley. D. M. Clay, D. J. Bivens, and G. R. Scarbrough of the U.S. Geological Survey collected and processed many of the water-level data used for this study.

#### **HYDROLOGIC SYSTEM**

In Palo Verde Valley the hydrologic system includes the highly regulated Colorado River and a shallow alluvial aquifer that underlies the flood plain. River water is diverted into a system of canals for distribution to fields on the flood plain, and ground water discharges to a network of drainage ditches and the river. The drainage ditches lower the water table beneath cropland and maintain it at sufficient depths to reduce waterlogging and damage to crops. The Colorado River and the drainage ditches are in hydraulic connection with ground water in the shallow alluvial aquifer. Depth to water in the

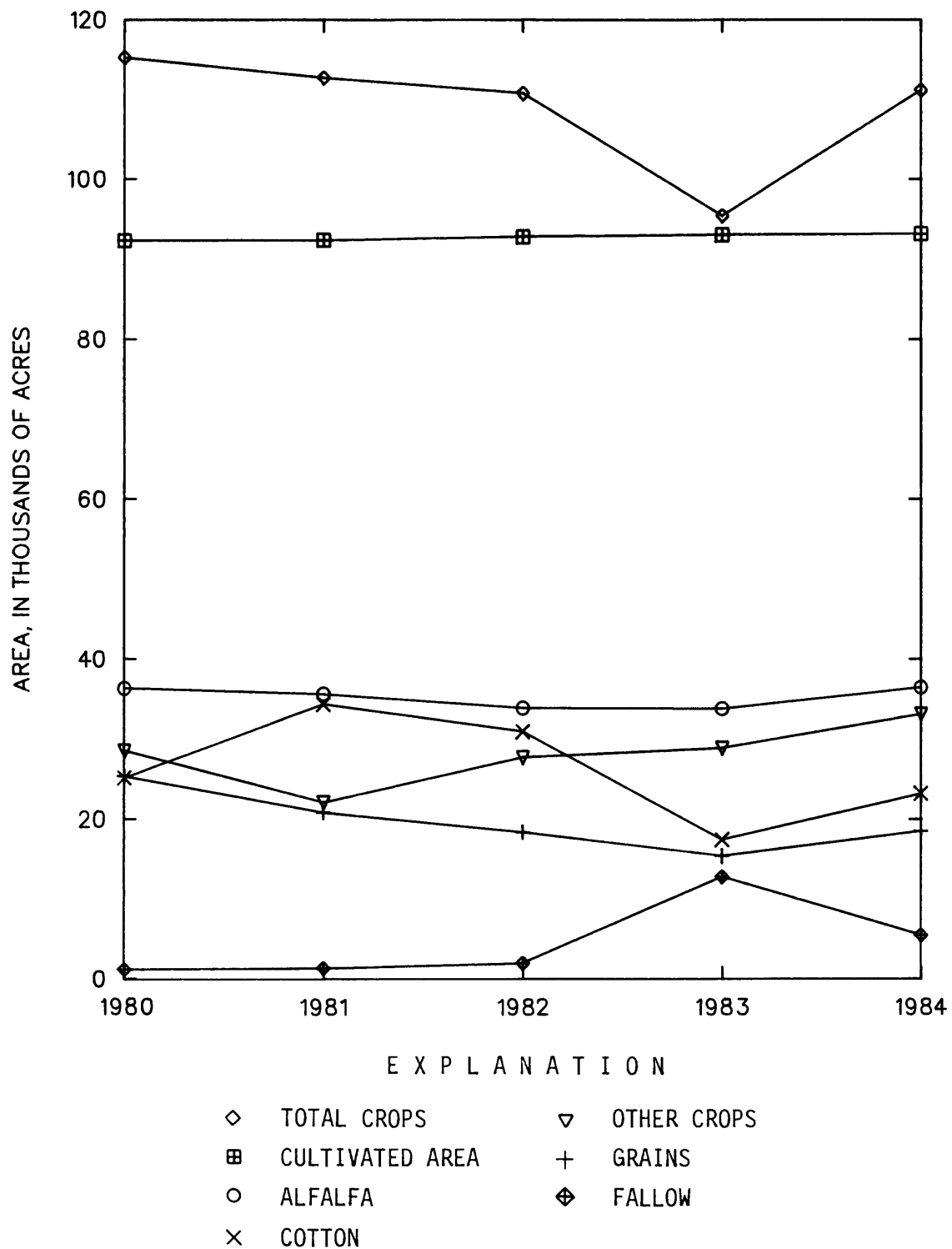
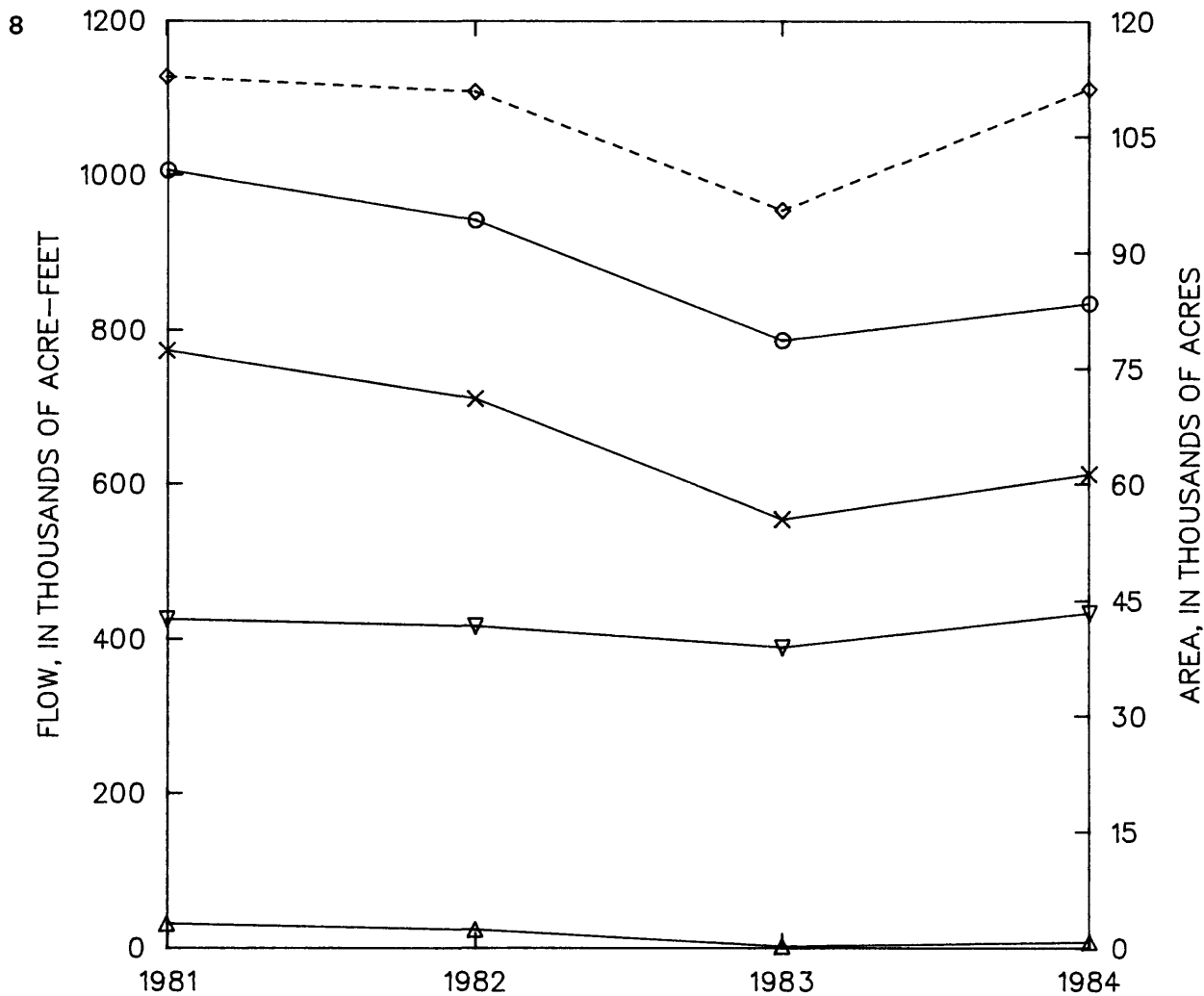


Figure 3.--Acreages by crop type, cultivated area, and total crops in Palo Verde Valley, California, 1980-84.



#### EXPLANATION

##### AREA

◇-----◇ Total crops

##### FLOW

○-----○ Diverted irrigation water

×-----× Applied irrigation water

▽-----▽ Surface-water return flow

△-----△ Ground-water return flow

Figure 4.--Diversion, applied water, return flows, and total cropped area in Palo Verde Valley, California, 1981-84.

aquifer is less than 25 ft. When releases from the reservoirs satisfy downstream water requirements, most reaches of the river adjacent to the irrigated areas gain water from the aquifer. Some reaches of the river adjacent to areas of phreatophytes lose water to the aquifer. When the annual average river stage rises, some of the gaining reaches of the river can become losing reaches, particularly where the ground-water divide is close to the river.

When flow in the river is regulated to meet downstream water requirements, drainage ditches and the application of irrigation water to fields control saturated thickness in the aquifer and direction of ground-water movement through the aquifer. Water is diverted from the river into canals from which some water spills back to the river or into drainage ditches (irrigation district regulatory waste), some enters the aquifer because of canal seepage, some evaporates, and the rest is applied to fields. Applied water is consumptively used by crops or recharges the aquifer through deep percolation. Deep percolation of irrigation water causes mounding of the water table under the fields and creates shallow ground-water divides between drainage ditches and between the easternmost drainage ditch and the river. In the area drained by drainage ditches, ground water discharges into drainage ditches and flows to the Colorado River as surface-water return flow. In the area drained by the river, ground water discharges to the river as ground-water return flow. Some ground water is intercepted and consumed by phreatophytes—mainly saltcedar, arrowweed, and mesquite—and some is pumped for municipal and domestic use. In addition to applied irrigation water, other sources of recharge to the aquifer are ground-water inflow from areas that border the flood plain and infiltration of runoff from tributary areas. Along some reaches, the river loses water to the aquifer through seepage and ground water moves away from the river. In places, ground water flows out of the flood plain into bordering areas. The hydrologic system is described in detail by Owen-Joyce (1984).

## COLORADO RIVER

Flow in the Colorado River is controlled by a series of dams upstream from Palo Verde Valley. Releases from Parker Dam, which is about 58 mi upstream from the north end of Palo Verde Valley (fig. 1), satisfy most downstream water and flood-control requirements. Annual releases from Parker Dam from 1960 to 1984 ranged from 6.3 to 20.5 million acre-ft (fig. 5). Flows in 1980, 1983, and 1984 exceeded downstream requirements because water was released for flood control. Palo Verde Dam is a diversion structure for irrigation water (fig. 2). The annual diversion of water at Palo Verde Dam ranged from 775,300 to 1,006,000 acre-ft between 1960 and 1984 (fig. 6). From 1960 to 1984, annual flow in the Colorado River below Palo Verde Dam ranged from 5.1 to 18.3 million acre-ft



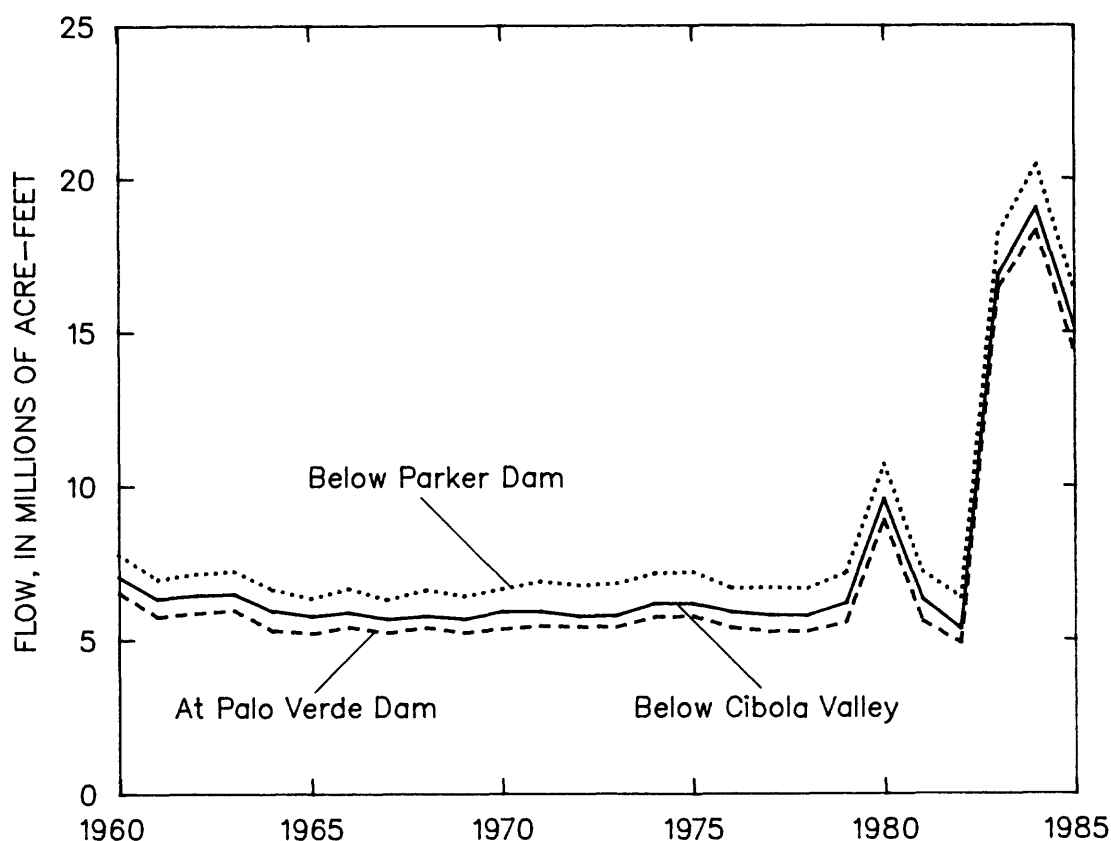


Figure 5.--Flow in the Colorado River, 1960-85.

(fig. 5). Annual flow in the Colorado River below Cibola Valley (fig. 2, site 17) ranged from 5.5 to 19.1 million acre-ft from 1960 to 1984 (fig. 5). The increase in flow between the gages is from surface-water and ground-water return flows.

Flow in the Colorado River varies daily, seasonally, yearly, and from place to place along the river. Diversions, evapotranspiration, spillage from canals, return flows to the river, and releases of water for irrigation and power generation all contribute to daily fluctuations in flow. Seasonal variations occur because releases from Parker Dam are highest in summer when the irrigation needs are greatest as shown in 1981 and 1982 (fig. 7). During the latter half of 1980 and in 1983 and 1984, flood-control releases dominated and the seasonal variations did not exist.

Changes in flow in the Colorado River correlate with changes in river stage. Changes in river stage cause fluctuations in ground-water levels beneath the flood plain and in the amount of ground water in storage because the river is hydraulically connected to ground water in the alluvium. River stage was from 5 to 10 ft higher in 1983 and 1984 than it was in 1982 (fig. 8).

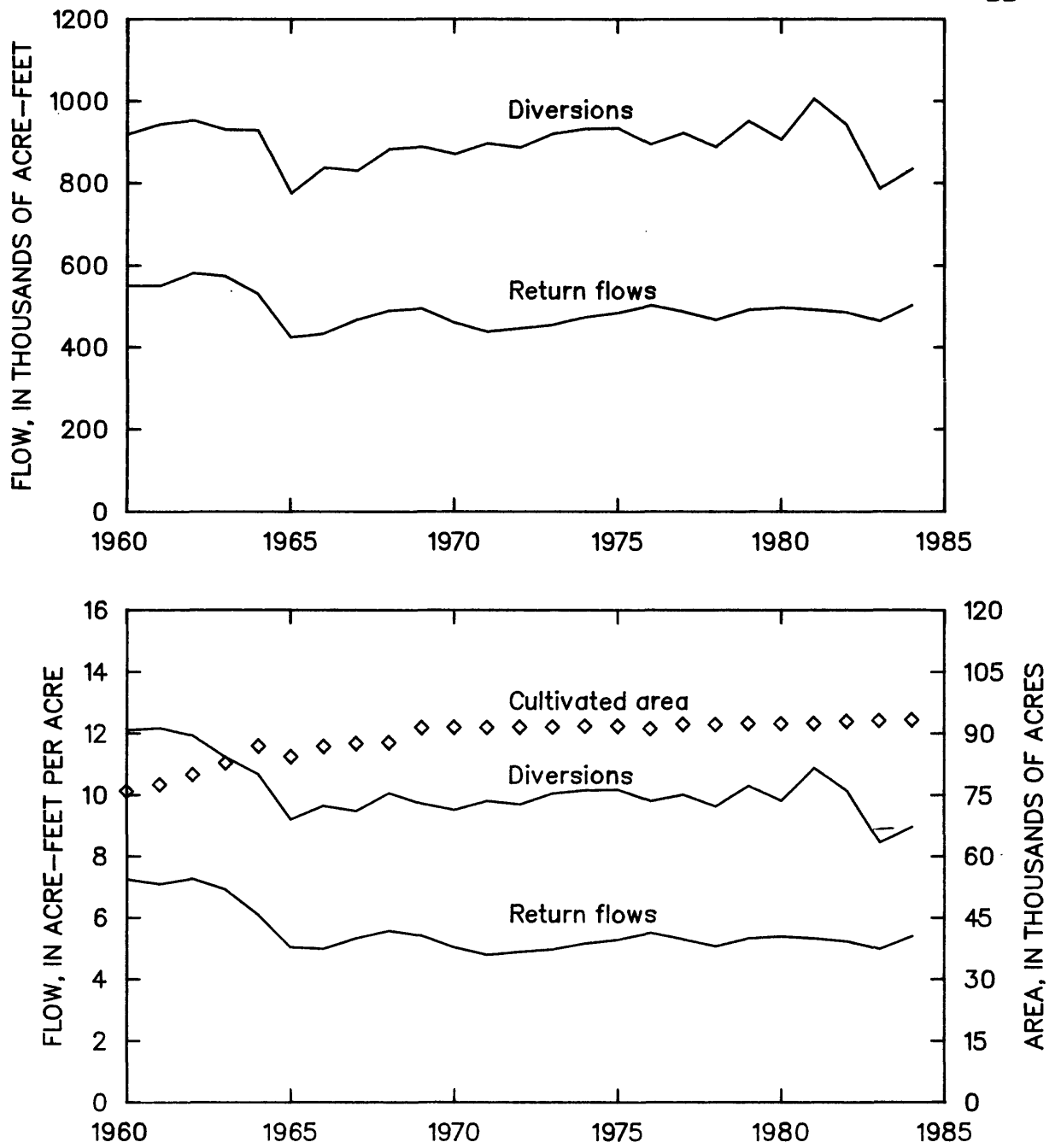


Figure 6.--Diversions, surface-water return flows, and cultivated area in Palo Verde Valley, California, 1960-84.

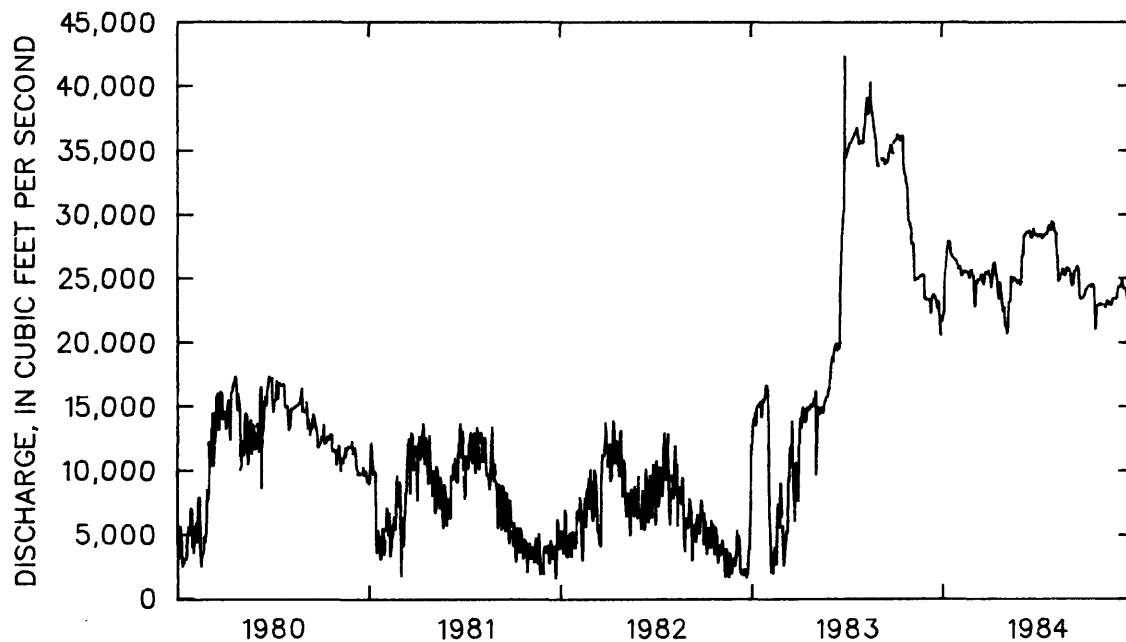


Figure 7.--Daily mean flow in the Colorado River at Palo Verde Dam, 1980-84.

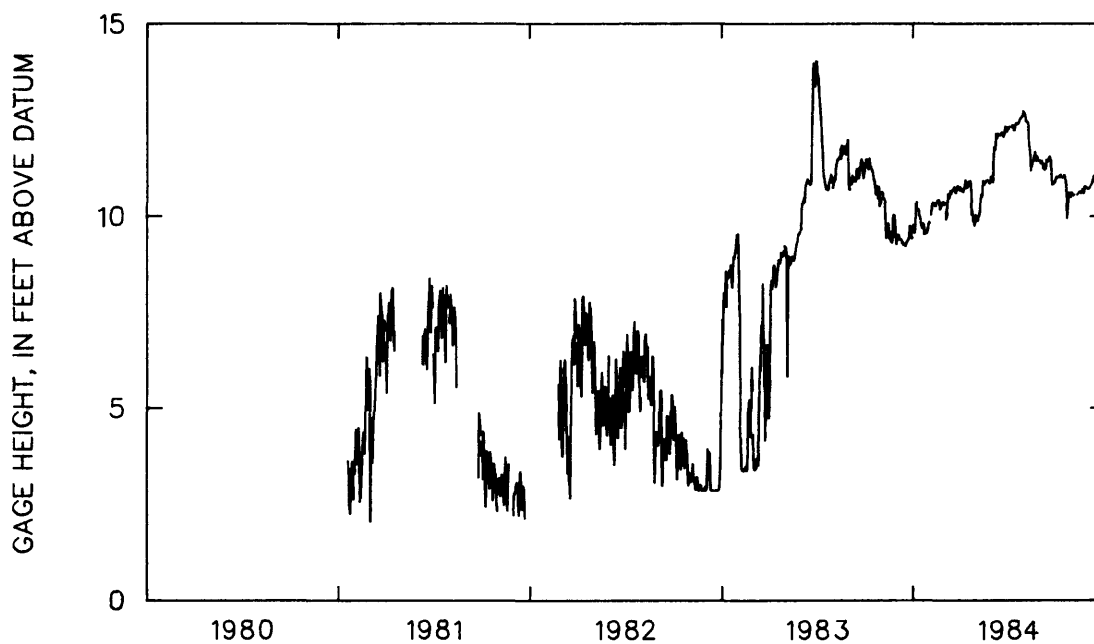


Figure 8.--Daily mean gage height of the Colorado River at Cibola Cross Section No. 28, 1981-84.

Diverted water that returns to the river as surface water was computed at eight spillways and three drainage ditches (table 1). Surface-water return flows include water that spills from canals, laterals, and wasteways and ground water that drains into about 152 mi of open-channel drainage ditches. As of June 1984, the gage on Anderson drain had been removed and the drain filled in (fig. 2, site 15).

### PRECIPITATION

Precipitation provides a small quantity of water, some of which is available for consumptive use by vegetation. Precipitation is considered to be a source of recharge to the aquifer when the mean annual precipitation exceeds 8 in. (Metzger and Loeltz, 1973, p. 35). Annual precipitation at Blythe, California, ranged from 0.48 to 8.74 in. between 1917 and 1984 (fig. 9), and mean annual precipitation was 3.88 in. About one-third of the precipitation occurs from May to September.

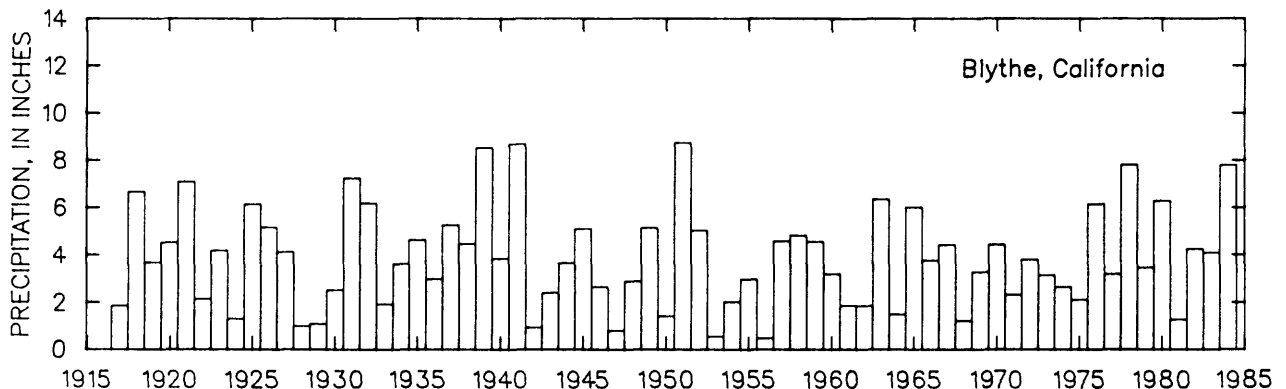


Figure 9.--Annual precipitation at Blythe, California, 1917-84.

Effective precipitation was used as a measure of the quantity of precipitation available for consumptive use by vegetation for input into the water budgets. Effective precipitation was calculated by multiplying the sum of the cropped cultivated area and area of phreatophytes each year by the annual effective precipitation (table 2). Annual effective-precipitation estimates were made by summing rainfall that was in excess of 0.25 in. per storm (U.S. Bureau of Reclamation, Lower Colorado River Region, Yuma Project Office, oral commun., 1986) to determine the amount of precipitation available to vegetation that could affect the consumptive use of Colorado River water. Annual effective precipitation from 1980 to 1984 (table 2) was computed from weather records for Blythe, California (National Climate Data Center, 1980-84).

Table 1.--Estimates of surface-water return flows to the Colorado River in Palo Verde Valley, California, 1981-84, in acre-feet per year

Site number <sup>1</sup>	Site number	1981	1982	1983	1984
5	F-canal spill	9,880	10,960	13,330	12,240
6	D-10-11-2 spill	946	822	1,860	1,370
7	D-10-11-5 spill	6,130	7,020	6,490	5,510
8	D-23 spill	10,020	10,530	14,530	14,620
10	D-23-1 spill	3,290	2,840	3,350	6,090
11	C-canal spill	25,910	24,050	24,270	19,070
13	C-28 upper spill	1,900	1,990	537	187
16	C-28 lower spill	<u>7,480</u>	<u>9,940</u>	<u>10,160</u>	<u>9,900</u>
Subtotal of surface-water return flows that spill from canals (rounded)		<u>65,600</u>	<u>68,200</u>	<u>74,500</u>	<u>69,000</u>
4	Olive Lake drain <sup>2</sup>	6,370	8,810	7,510	7,710
14	Palo Verde Outfall drain <sup>3</sup>	419,400	407,900	381,500	426,200
15	Anderson drain <sup>3</sup>	<u>110</u>	<u>274</u>	<u>362</u>	<u>152</u>
Subtotal of surface-water return flows from the drainage system (rounded)		<u>425,900</u>	<u>417,000</u>	<u>389,400</u>	<u>434,100</u>
Total surface-water return flows (rounded)		491,500	485,200	463,900	503,100

<sup>1</sup> Site number corresponds to locations shown on figure 2.

<sup>2</sup> Located in the area drained by the river.

<sup>3</sup> Located in the area drained by drainage ditches.

Table 2.--Annual precipitation for Blythe, California, 1980-84, in inches

Year	Precipitation	
	Effective	Total
1980	3.66	5.61
1981	0.41	1.24
1982	2.15	4.24
1983	1.51	4.08
1984	5.08	7.76

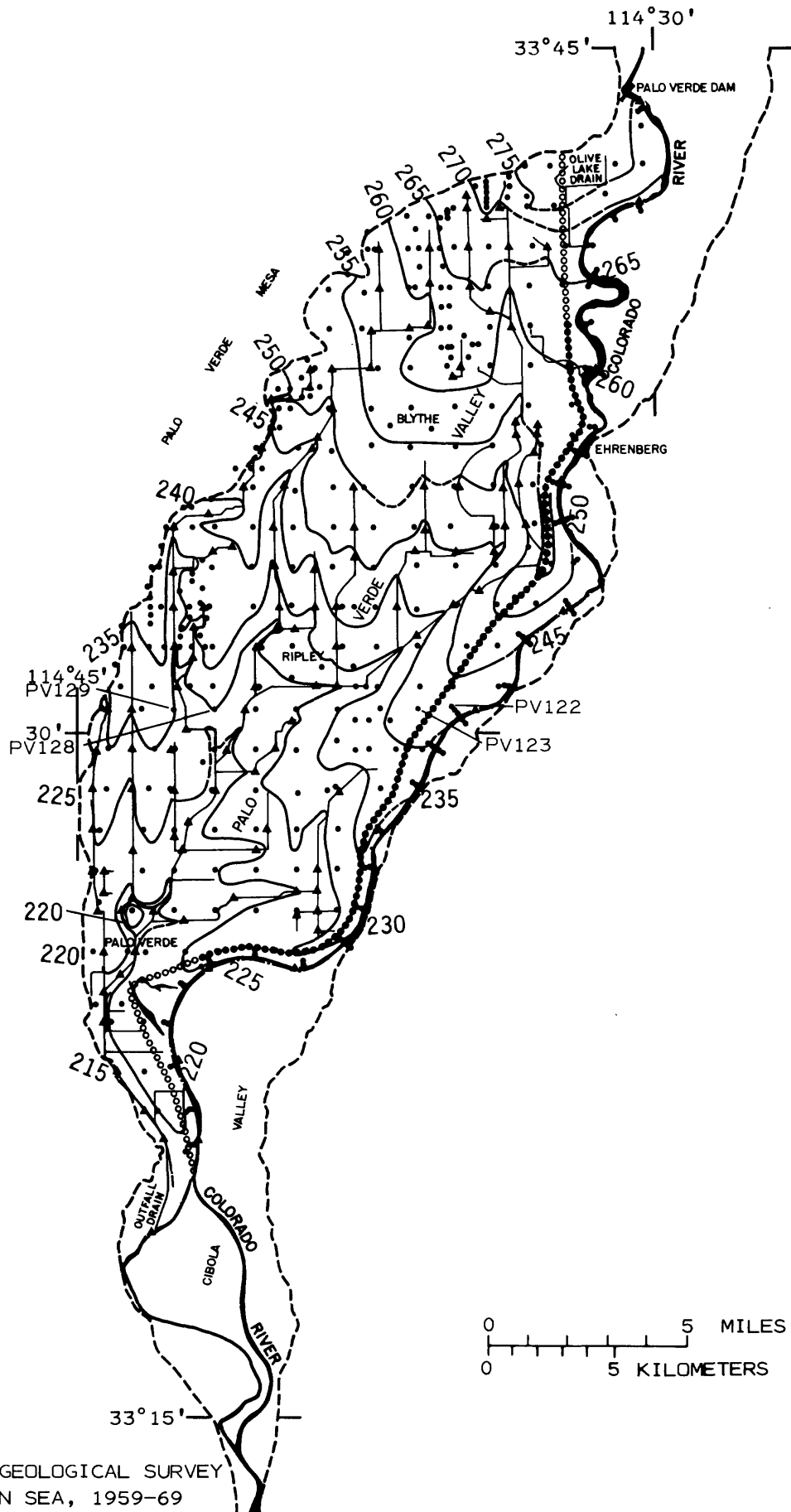
### GROUND WATER

Palo Verde Valley was divided into two ground-water drainage areas using contours of annual average water-table altitude to determine the location of the ground-water divide between the river and the easternmost drainage ditch (Owen-Joyce, 1984, p. 19). Ground water east of the divide drains to the river, and that west of the divide drains to the drainage ditches. Annual average water-table altitudes were determined by averaging monthly water levels in wells, monthly stage measurements in the drainage ditches, and monthly water levels in piezometers installed along the river.

Water-table contours indicate that the ground-water divide moves from year to year and that the location of the gaining and losing reaches varies along the river. In 1981, the river gained ground-water inflow from Palo Verde Valley except along a 0.6-mile losing reach north of Ehrenberg (Owen-Joyce, 1984, fig. 9). In 1982, the reaches adjacent to the valley gained water from the aquifer (fig. 10). In 1983, most of the river was losing water to the aquifer except at the north end of the valley and for a short reach south of Ehrenberg (fig. 11). In 1984, most of the river north of Cibola Valley gained water from the aquifer except at the bend in the river south of Olive Lake drain. The reach of the river adjacent to Cibola Valley lost water to the aquifer (fig. 12).

### Areal Changes in Ground-Water Levels

Ground-water levels vary from year to year and from place to place in Palo Verde Valley. The most significant changes occur along the river. Changes in annual average water levels were determined by subtracting the annual average



BASE FROM U.S. GEOLOGICAL SURVEY  
1:250,000 SALTON SEA, 1959-69

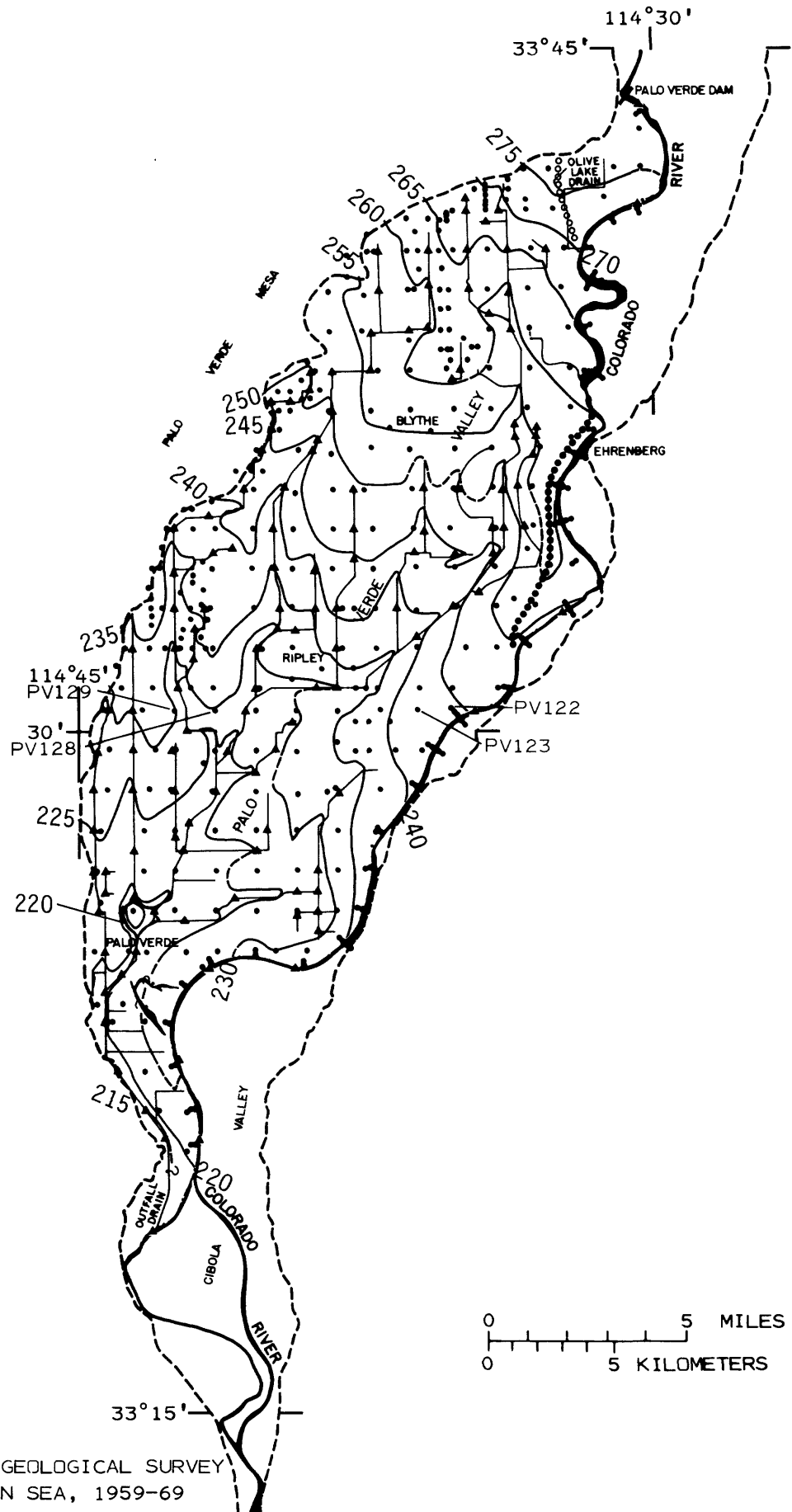
**Figure 10.--Average water-table altitude in Palo Verde Valley, California, 1982.**

## E X P L A N A T I O N

- 255 ——— WATER-TABLE CONTOUR—Shows average altitude of water table, 1982. Dashed where approximately located. Contour interval 5 feet. Datum is sea level
- PV128 • SHALLOW OBSERVATION WELL OR PIEZOMETER—Number, PV128, is a well number that corresponds to the hydrographs on figure 17
- ▲ STAFF GAGE
- DRAINAGE DITCH
- ..... GROUND-WATER DIVIDE BETWEEN THE COLORADO RIVER AND DRAINAGE DITCHES—Open symbol where approximately located
- COLORADO RIVER FLOOD-PLAIN BOUNDARY
- ..... BOUNDARY OF PALO VERDE VALLEY WHERE THE FLOOD-PLAIN AQUIFER IS CONTINUOUS

Figure 10





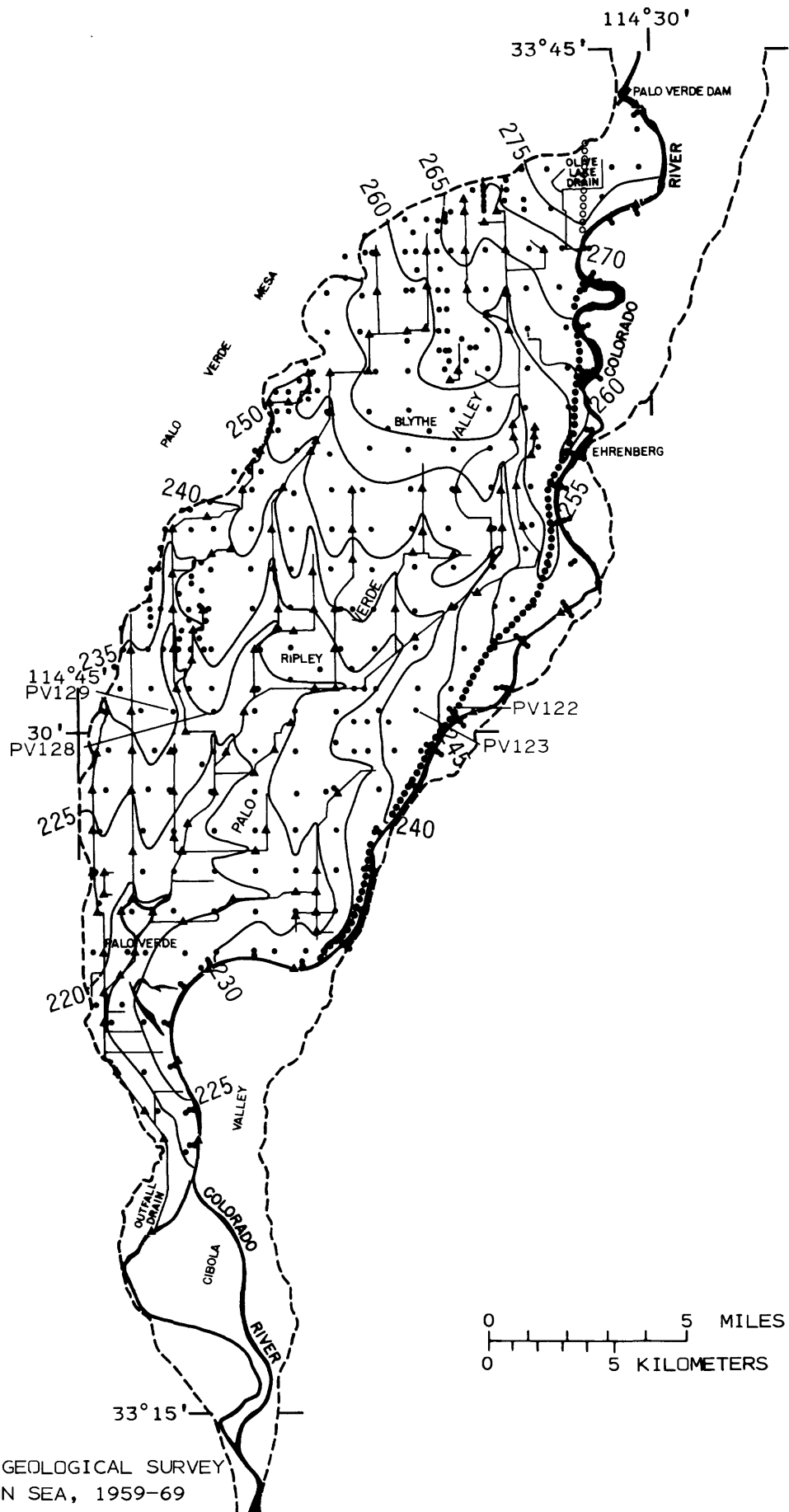
BASE FROM U.S. GEOLOGICAL SURVEY  
1:250,000 SALTON SEA, 1959-69

Figure 11.--Average water-table altitude in Palo Verde Valley,  
California, 1983.

## E X P L A N A T I O N

- 225 ———?— WATER-TABLE CONTOUR—Shows average altitude of water table, 1983. Dashed where approximately located, queried where uncertain. Contour interval 5 feet. Datum is sea level
- PV128 • SHALLOW OBSERVATION WELL OR PIEZOMETER—Number, PV128, is a well number that corresponds to the hydrographs on figure 17
- ▲ STAFF GAGE
- DRAINAGE DITCH
- ..... GROUND-WATER DIVIDE BETWEEN THE COLORADO RIVER AND DRAINAGE DITCHES—Open symbol where approximately located
- COLORADO RIVER FLOOD-PLAIN BOUNDARY
- ..... BOUNDARY OF PALO VERDE VALLEY WHERE THE FLOOD-PLAIN AQUIFER IS CONTINUOUS

Figure 11



BASE FROM U.S. GEOLOGICAL SURVEY  
1:250,000 SALTON SEA, 1959-69

**Figure 12.--Average water-table altitude in Palo Verde Valley, California, 1984.**

## E X P L A N A T I O N

- 240 ——— WATER-TABLE CONTOUR—Shows average altitude of water table, 1984. Dashed where approximately located. Contour interval 5 feet. Datum is sea level
- PV128 • SHALLOW OBSERVATION WELL OR PIEZOMETER—Number, PV128, is a well number that corresponds to the hydrographs on figure 17
- ▲ STAFF GAGE
- DRAINAGE DITCH
- ..... GROUND-WATER DIVIDE BETWEEN THE COLORADO RIVER AND DRAINAGE DITCHES—Open symbol where approximately located
- COLORADO RIVER FLOOD-PLAIN BOUNDARY
- ..... BOUNDARY OF PALO VERDE VALLEY WHERE THE FLOOD-PLAIN AQUIFER IS CONTINUOUS

Figure 12

water-table altitude of one year from that of the following year. Maps were prepared using a 1-foot contour interval (figs. 13-16) to illustrate the magnitude and extent of the annual changes in average water levels. Annual average water-level changes are listed in table 3. Water-level changes are caused by changes in river stage and in the amount of applied irrigation water.

Table 3.--Annual water-level changes in Palo Verde Valley, California, in feet

Year	Maximum decline	Maximum rise	Average water-level change		
			Area east of divide	Area west of divide	Palo Verde Valley
1980-81	-5.88	1.58	-1.32	-0.01	-0.16
1981-82	-6.08	4.83	-0.43	-0.35	-0.37
1982-83	-4.58	4.62	1.45	0.09	0.15
1983-84	-3.36	5.06	0.67	0.30	0.33

Year-to-year changes in average annual water levels were grouped by area. Two areas were identified—the area between the river and easternmost drainage ditch and the rest of the valley. Water levels within about a mile of the river declined as much as 3 ft from 1980 to 1981. Throughout the rest of the valley, water levels rose and declined as much as 2 ft (fig. 13). From 1981 to 1982, water levels declined from 0 to 1 ft over most of the valley. Water levels rose and declined as much as 3 ft in local areas south of Blythe. North of Blythe, water levels rose as much as 2 ft (fig. 14). Water levels from 1982 to 1983 rose from 0 to more than 4 ft within 1.5 mi of the river. In the rest of the valley, except near drainage ditches, water levels declined 1 ft, with some local declines of 1 to 3 ft. Within 0.4 mi of many of the drainage ditches, water levels rose about 1 ft (fig. 15). From 1983 to 1984, most of the water levels rose from 0 to 1 ft. In the area north of Ripley, however, water levels declined as much as 2 ft. Water levels rose from 1 to 2 ft along the river in the area adjacent to Cibola Valley and in other local areas throughout the valley (fig. 16).

In the area between the river and easternmost drainage ditch, changes in annual average water levels correlate with changes in river stage, whereas in the rest of the valley the changes correlate with variations in the quantity of applied irrigation water. The quantity of applied irrigation water is proportional to the quantity of water diverted from the river (fig. 4). Flow in the river was lower in 1981 than in 1980 (fig. 7) and water levels declined in the aquifer along the river in 1981 as bank storage returned to the river (fig. 13).

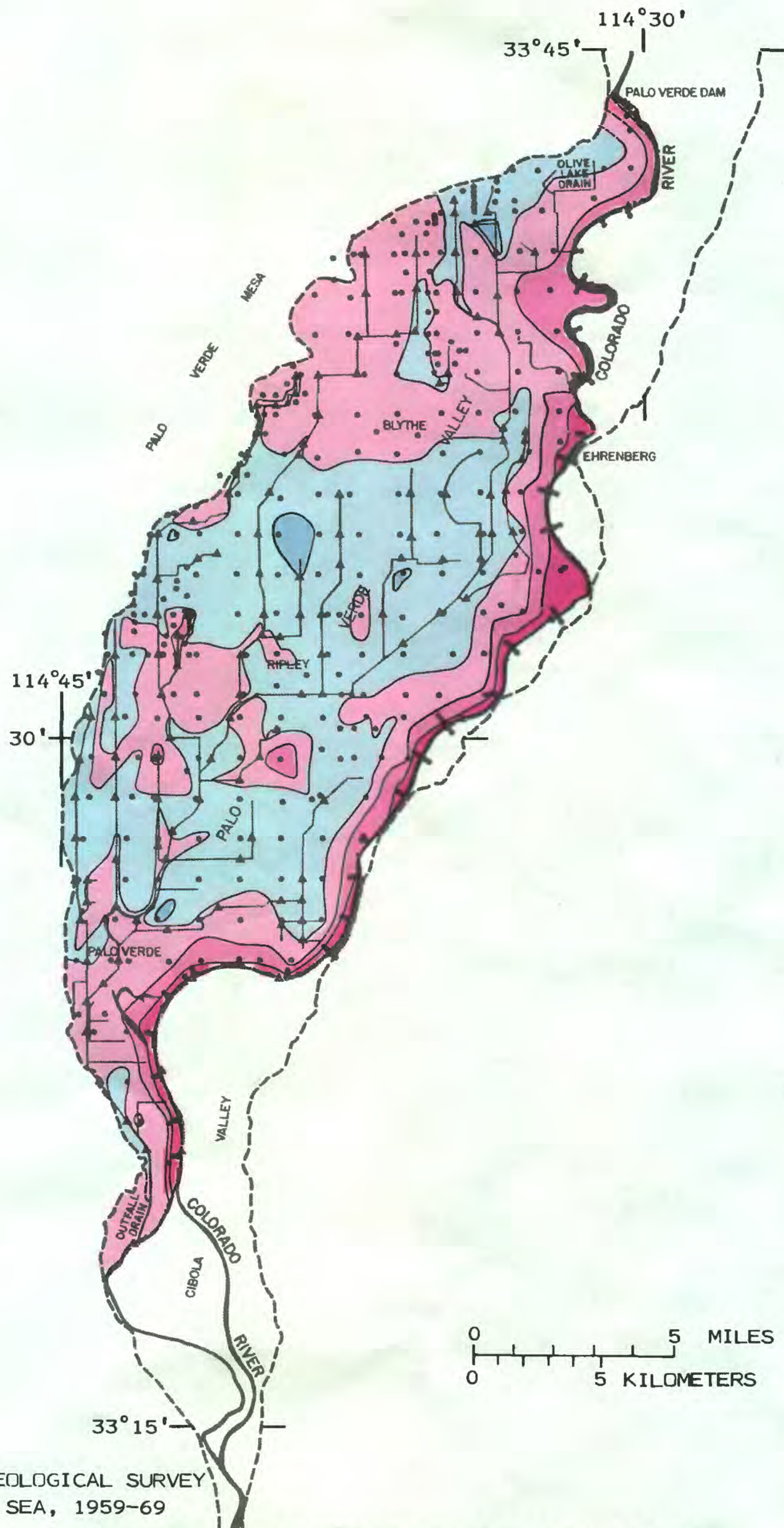


The quantity of water diverted and therefore the quantity of applied water throughout the valley was greater in 1981 than in 1980 (fig. 6). This greater quantity of applied water caused water levels in the aquifer to rise in 1981 in the area west of the easternmost drainage ditch (fig. 13). From 1981 to 1982, water levels declined in the entire valley (fig. 14) because the quantity of water applied was less in 1982 (fig. 4). Water levels along the river changed less than 1 ft because river stage had the same seasonal variation throughout 1981 and 1982 (fig. 8). Water levels along the river rose from 1982 to 1983 (fig. 15) because river stage was higher in 1983 (fig. 8). High river stage caused a backwater in tributary drainage ditches, which in turn caused a backwater effect on ground-water inflow and increased the water levels along the ditches (fig. 15). Decreased applications in 1983 because of the PIK program (fig. 4) resulted in water-level declines (fig. 15). From 1983 to 1984, water levels rose in most of the area (fig. 16) because part of that acreage was again in production and irrigated (fig. 3). Overall, water levels along the river changed less than 1 ft from 1983 to 1984 owing to changes in river stage because the average river stage did not change significantly between 1983 and 1984 (fig. 8).

Localized changes in average annual water levels occurred from year to year between 1980 and 1984. Maps showing change in annual average water levels were overlaid on crop maps, and many of the localized water-level changes corresponded to variations in the types of crops grown, especially where fields were left fallow. In several local areas from 1982 to 1983, water levels declined (fig. 15). Several of these areas had crops in 1982 followed by fallow fields in 1983. Many fields throughout the valley were fallow because of the PIK program. Water levels declined as much as 3 ft in many areas where fields were fallow in 1983 because less water was applied to those areas. Water levels rose as much as 2 ft in localized areas from 1983 to 1984 (fig. 16). Many of the areas that had a rise in water level were areas that were fallow in 1983 and had crops in 1984. The rise in water level was caused by water being applied to those areas in 1984.

Hydrographs for selected wells in Palo Verde Valley show water-level changes from 1980 to 1984 and show the relation between location and water-level changes (fig. 17). The hydrograph for well PV122, which is 0.34 mi from the river, illustrates how water levels in wells close to the river follow changes in river stage (fig. 8). High river stage results in higher water levels in the aquifer near the river. Well PV123 is 1.3 mi from the river and water-level changes follow the same trend as PV122. Well PV128 is 6.4 mi from the river between two drainage ditches where changes in water levels correspond to seasonal irrigation applications. The water level rises in summer when the irrigation application is high and declines during winter when less irrigation water is applied. Other wells between drainage ditches show the same trend. Well PV129 is 7.4 mi from the river and adjacent to a drainage ditch.





BASE FROM U.S. GEOLOGICAL SURVEY  
1:250,000 SALTON SEA, 1959-69

Figure 13.--Change in annual average ground-water levels in Palo Verde Valley, California, 1980-81.



## E X P L A N A T I O N

## ANNUAL AVERAGE WATER-LEVEL CHANGE, IN FEET



1 to less than 2



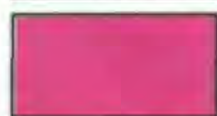
0 to less than 1



-1 to less than 0



-2 to less than -1



-3 to less than -2



SHALLOW OBSERVATION WELL OR PIEZOMETER



STAFF GAGE AND CONTINUOUS-RECORD GAGING STATION



DRAINAGE DITCH

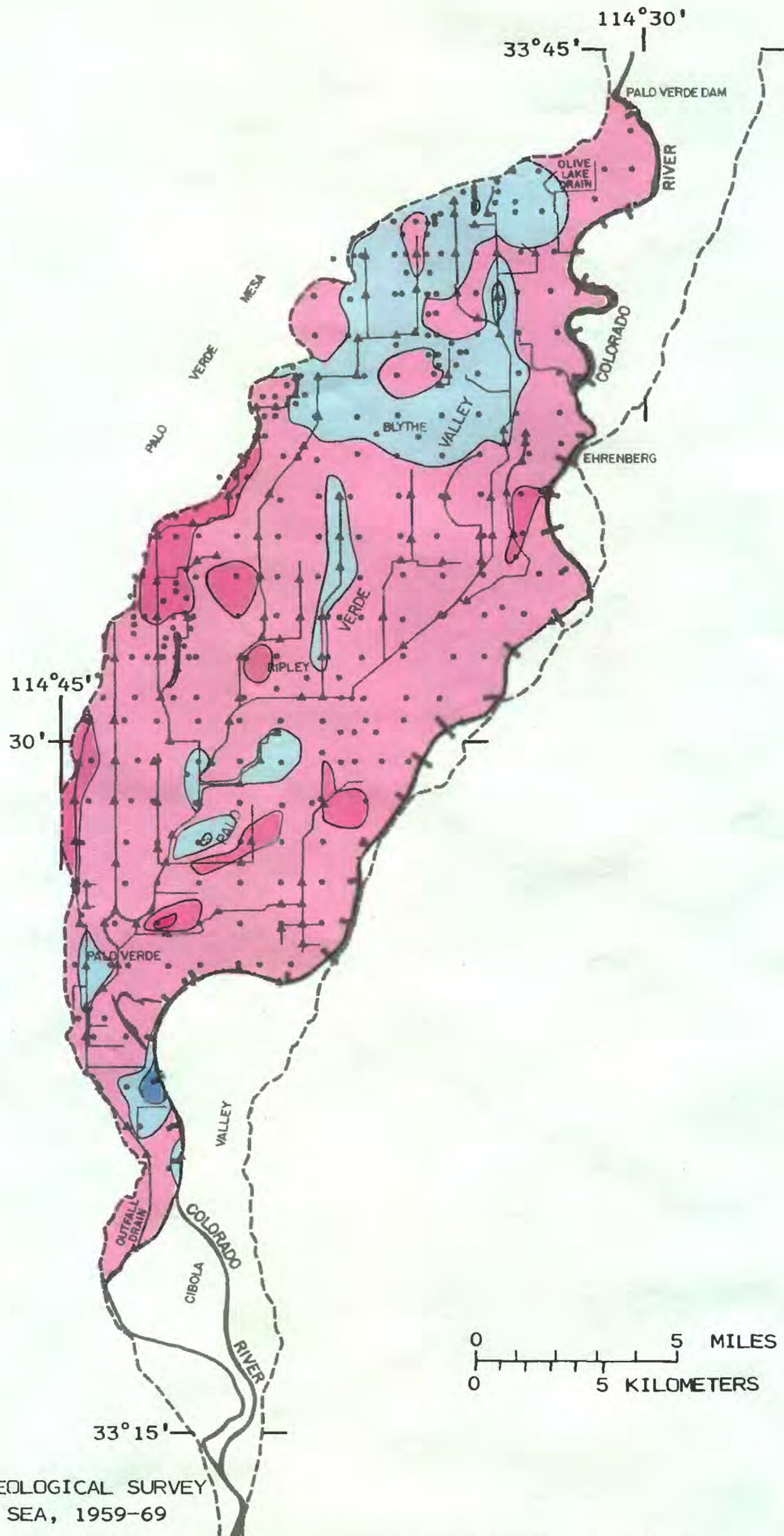


COLORADO RIVER FLOOD-PLAIN BOUNDARY

BOUNDARY OF PALO VERDE VALLEY WHERE THE  
FLOOD-PLAIN AQUIFER IS CONTINUOUS

Figure 13





BASE FROM U.S. GEOLOGICAL SURVEY  
1:250,000 SALTON SEA, 1959-69

Figure 14.--Change in annual average ground-water levels in  
Palo Verde Valley, California, 1981-82.



## E X P L A N A T I O N

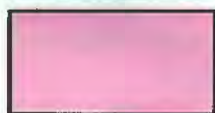
## ANNUAL AVERAGE WATER-LEVEL CHANGE, IN FEET



1 to less than 2



0 to less than 1



-1 to less than 0



-2 to less than -1



-3 to less than -2



SHALLOW OBSERVATION WELL OR PIEZOMETER



STAFF GAGE AND CONTINUOUS-RECORD GAGING STATION



DRAINAGE DITCH

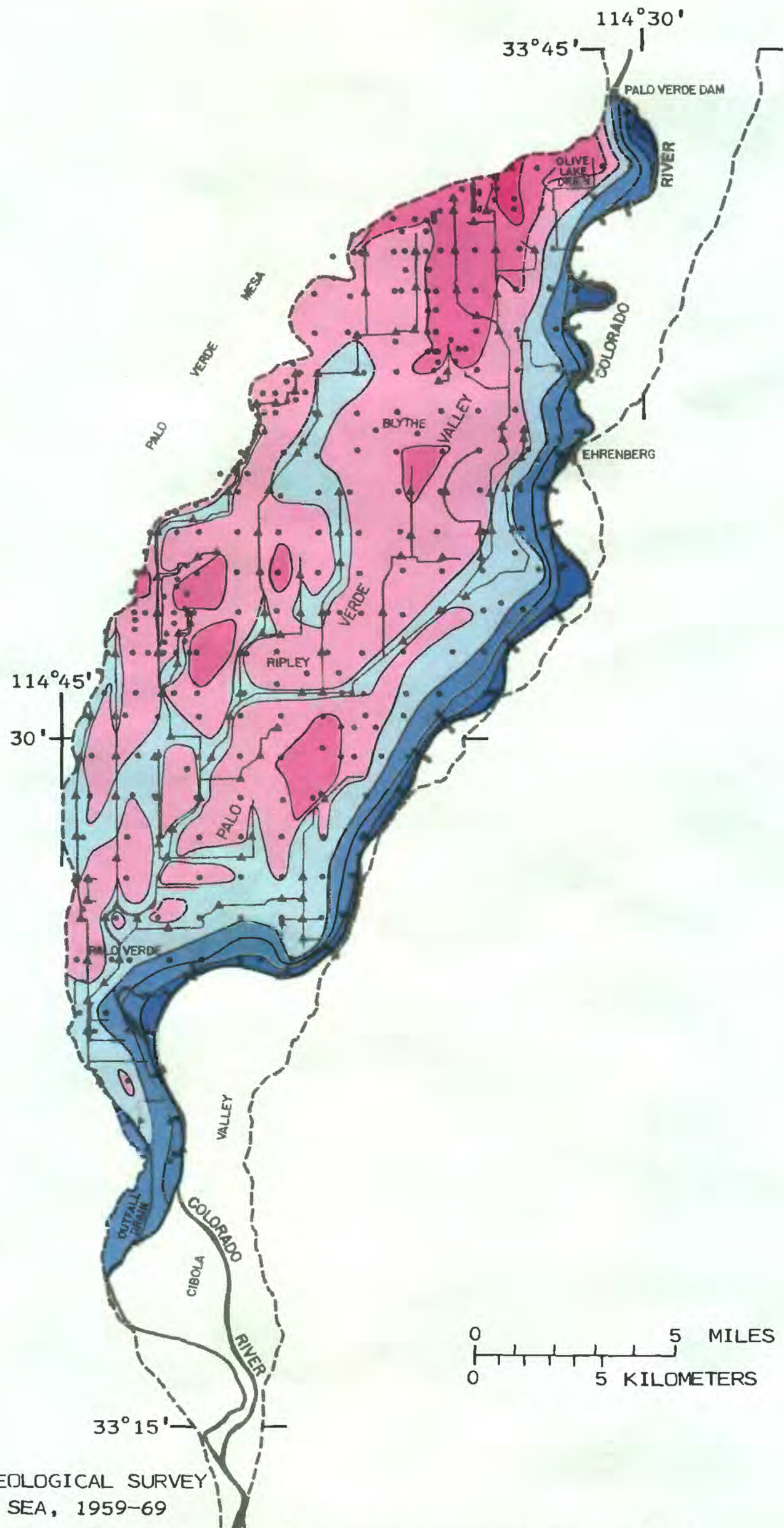


COLORADO RIVER FLOOD-PLAIN BOUNDARY

BOUNDARY OF PALO VERDE VALLEY WHERE THE  
FLOOD-PLAIN AQUIFER IS CONTINUOUS

Figure 14





BASE FROM U.S. GEOLOGICAL SURVEY  
1:250,000 SALTON SEA, 1959-69

Figure 15.--Change in annual average ground-water levels in Palo Verde Valley, California, 1982-83.



## E X P L A N A T I O N

## ANNUAL AVERAGE WATER-LEVEL CHANGE, IN FEET



More than 4

3 to less than 4

2 to less than 3

1 to less than 2

0 to less than 1

-1 to less than 0

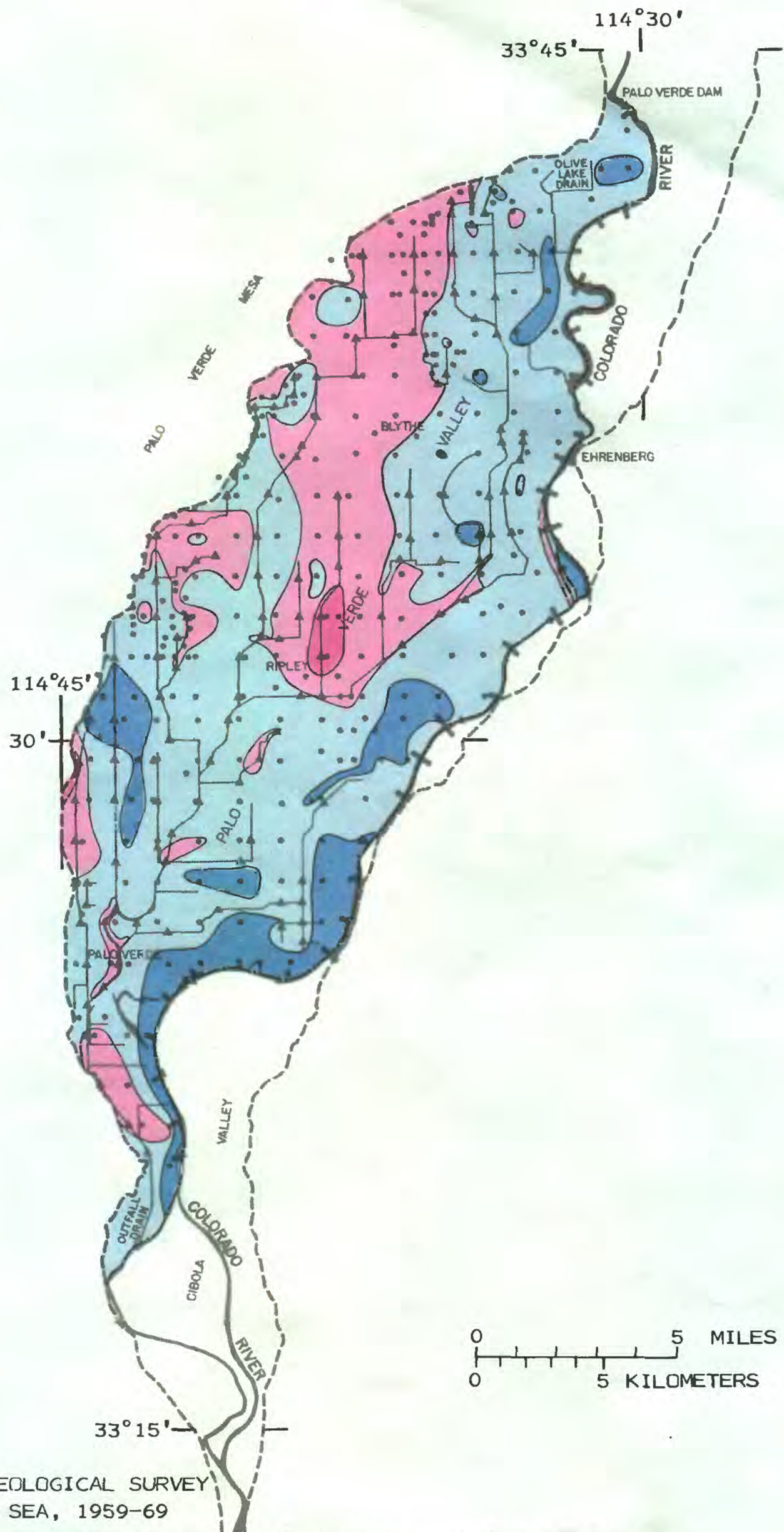
-2 to less than -1

-3 to less than -2

- SHALLOW OBSERVATION WELL OR PIEZOMETER
- ▲ STAFF GAGE AND CONTINUOUS-RECORD GAGING STATION
- DRAINAGE DITCH
- COLORADO RIVER FLOOD-PLAIN BOUNDARY
- · - · - · - BOUNDARY OF PALO VERDE VALLEY WHERE THE FLOOD-PLAIN AQUIFER IS CONTINUOUS

Figure 15





BASE FROM U.S. GEOLOGICAL SURVEY  
1:250,000 SALTON SEA, 1959-69

Figure 16.--Change in annual average ground-water levels in  
Palo Verde Valley, California, 1983-84.



## E X P L A N A T I O N

ANNUAL AVERAGE WATER-LEVEL CHANGE, IN FEET



2 to less than 3



1 to less than 2



0 to less than 1



-1 to less than 0



-2 to less than -1



SHALLOW OBSERVATION WELL OR PIEZOMETER



STAFF GAGE AND CONTINUOUS-RECORD GAGING STATION



DRAINAGE DITCH



COLORADO RIVER FLOOD-PLAIN BOUNDARY

BOUNDARY OF PALO VERDE VALLEY WHERE THE  
FLOOD-PLAIN AQUIFER IS CONTINUOUS

Figure 16

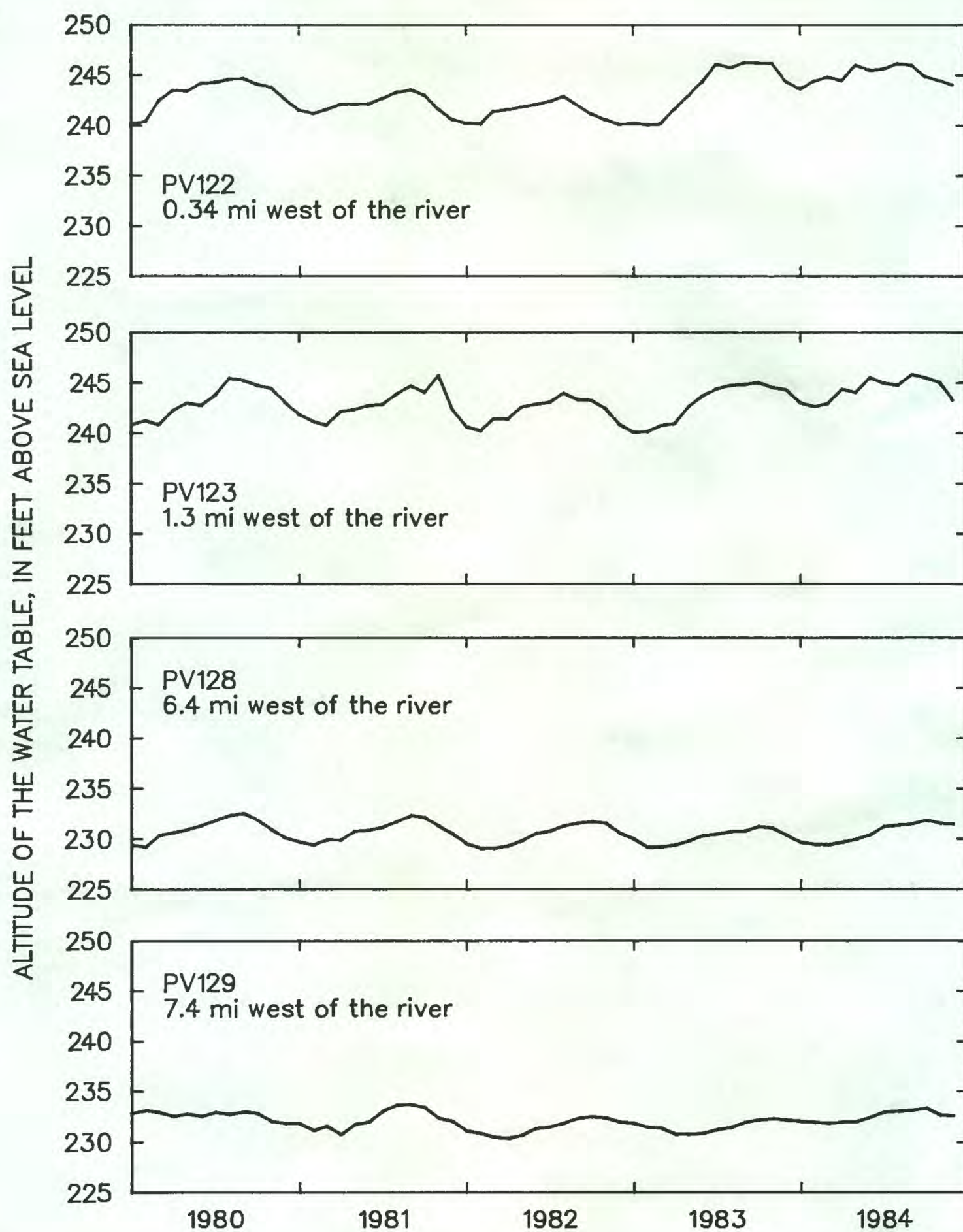


Figure 17.--Water levels in selected wells in Palo Verde Valley, California, 1980-84.



Water-level changes near drainage ditches follow the same trend associated with irrigation, but the amount of change is less than for areas between drainage ditches.

#### Change in Storage

Change in ground-water storage was calculated for each of the two drainage areas (table 4) as the product of changes in ground-water levels, areas of change, and specific yield. Change in storage for Palo Verde Valley was calculated as the sum of the changes in the two drainage areas. Changes in ground-water levels were estimated as the differences between the annual average water levels to approximate the net change in ground-water storage. Annual average water levels provide the best defined surfaces of the water table from year to year. Areas of change were determined by integrating the areas between the contours on figures 13-16. Metzger and others (1973, p. 72) measured a specific yield of 0.32 for sediments in Palo Verde Valley above the water table, which was used for calculating changes in storage. Specific yield was calculated from soil-moisture studies using a neutron moisture probe at 16 sites throughout the flood plain.

Table 4.--Change in storage for Palo Verde Valley, California, 1981-84, in acre-feet

	1981	1982	1983	1984
Area drained by drainage ditches	-400	-10,900	2,900	10,200
Area drained by the river	-5,300	-1,700	2,300	1,400
Total for Palo Verde Valley	-5,700	-12,600	5,200	11,600

The estimates of change in storage are small relative to the estimates of consumptive use by vegetation and consumptive use of river water. Therefore, the accuracy with which change in storage is estimated does not significantly affect either the estimates of consumptive use by vegetation calculated in a water budget or the estimates of consumptive use of Colorado River water calculated as measured diversions minus return flows. The accuracy with which change in storage is estimated does significantly affect the estimate of ground-water return flow calculated in a water budget because change in storage is of the same magnitude as the estimates of ground-water return flow.



### CONSUMPTIVE USE

Consumptive use by vegetation for the area drained by drainage ditches was calculated as the residual in a water budget (table 5) that accounted for inflow as (1) water diverted from the river for application to fields, (2) effective precipitation, (3) ground-water inflow and tributary runoff from the area west of the flood plain, and (4) seepage from the Colorado River. Outflow occurred as (1) surface-water discharge to the river from the drainage ditches, (2) consumptive use by vegetation, (3) ground-water outflow to the area west of the flood plain, and (4) pumpage. Diversions and surface-water return flows, the largest components in the budget, are measured. Change in ground-water storage was calculated as the product of annual average changes in ground-water levels, areas of change, and specific yield. Consumptive use per unit vegetated area from the area drained by drainage ditches was used to estimate consumptive use by vegetation for the area drained by the river. The vegetated area consists of cropped areas, including multiple cropping, and areas of phreatophytes (table 7). Total consumptive use by vegetation for Palo Verde Valley is the sum of consumptive use from both ground-water drainage areas.

The surface-water diversion to the area drained by drainage ditches was calculated by determining the quantity of water diverted from the river at Palo Verde Dam that (1) was applied to fields, (2) seeped from the canals, (3) spilled to the river, (4) was wasted to drainage ditches, (5) evaporated from canals, and (6) was diverted out of the flood plain to Palo Verde Mesa and by summing the proportion of each component that occurred in the drainage area (table 6). The applied water was apportioned between the two drainage areas using the percentages determined from irrigation requirements (table 7)—the volume of water per unit area required to grow each crop—in order to account for the effect of areal cropping distributions on the areal distribution of applied water (Owen-Joyce, 1984, p. 27). Canal seepage and evaporation were apportioned by canal length (Owen-Joyce, 1984, p. 29). The quantities of water spilled to the river and diverted to the mesa were measured by Palo Verde Irrigation District.

Ground-water inflow to and outflow from, tributary runoff from the area west of the flood plain, and ground-water pumpage were estimated in previous studies. Ground-water inflow was estimated to be 9,500 acre-ft/yr, and ground-water outflow was estimated to be 4,700 acre-ft/yr (Owen-Joyce, 1984, p. 15-16). Tributary runoff, some of which recharges the aquifer and some of which is consumed by phreatophytes, was estimated to be 3,200 acre-ft/yr (Metzger and others, 1973). Ground-water pumpage consumptively used for domestic, municipal, and industrial purposes was estimated to be 2,000 acre-ft/yr (Bookman-Edmonston Engineering, Inc., 1976, p. 37).

Table 5.--Water budgets for the area drained by drainage ditches in Palo Verde Valley, California, 1981-84, in acre-feet per year

	1981	1982	1983	1984
Inflow:				
Surface-water diversion...	836,000	777,000	668,700	715,400
Effective precipitation...	3,100	16,200	10,600	39,400
Ground-water inflow from the area west of the flood plain.....	9,500	9,500	9,500	9,500
Tributary runoff.....	3,200	3,200	3,200	3,200
Seepage from the Colorado River.....	<u>3,100</u>	<u>0</u>	<u>45,400</u>	<u>27,000</u>
Total.....	<u>854,900</u>	<u>805,900</u>	<u>737,400</u>	<u>794,500</u>
Outflow:				
Surface-water discharge to Colorado River from drainage ditches...	419,500	408,200	381,900	426,400
Consumptive use by vege- tation <sup>1</sup> .....	429,100	401,900	345,900	351,200
Ground-water outflow to the area west of the flood plain.....	4,700	4,700	4,700	4,700
Pumpage.....	<u>2,000</u>	<u>2,000</u>	<u>2,000</u>	<u>2,000</u>
Total.....	<u>855,300</u>	<u>816,800</u>	<u>734,500</u>	<u>784,300</u>
Change in storage:	-400	-10,900	2,900	10,200

<sup>1</sup> Consumptive use calculated as inflow minus outflow minus change in storage.

Table 6.--Estimates of surface-water diversions to irrigated land in Palo Verde Valley, California, 1981-84, in acre-feet per year

	1981	1982	1983	1984
Diversions to Palo Verde Valley:				
Surface-water diversion at Palo Verde Dam <sup>1</sup>	<u>1,006,000</u>	<u>942,000</u>	<u>786,700</u>	<u>834,900</u>
Canal seepage <sup>2</sup>	125,000	125,000	125,000	125,000
Spills to river <sup>3</sup>	65,600	68,200	74,500	69,000
Regulatory waste to drainage ditches <sup>4</sup>	22,300	17,200	14,200	10,300
Diversions to Palo Verde Mesa <sup>4</sup>	17,100	15,900	13,200	12,800
Evaporation from canals <sup>5</sup>	<u>5,000</u>	<u>5,000</u>	<u>5,000</u>	<u>5,000</u>
Subtotal of water loss	<u>235,000</u>	<u>231,300</u>	<u>231,900</u>	<u>222,100</u>
Net water applied to irrigated land	771,000	710,700	554,800	612,800
Diversions to area west of divide:				
Surface water applied to irrigated land	696,984	641,762	529,834	580,322
Regulatory waste to drainage ditches	22,300	17,200	14,200	10,300
Canal seepage	112,250	113,500	119,875	120,000
Evaporation from canals	<u>4,490</u>	<u>4,540</u>	<u>4,795</u>	<u>4,800</u>
Total diversion (rounded)	836,000	777,000	668,700	715,400

Table 6.--Estimates of surface-water diversions to irrigated land in Palo Verde Valley, California, 1981-84, in acre-feet per year--Continued

	1981	1982	1983	1984
Diversions to area east of divide:				
Surface water applied to irrigated land	74,016	68,938	24,966	32,478
Regulatory waste to drainage ditches	0	0	0	0
Canal seepage	12,750	11,500	5,125	5,000
Evaporation from canals	<u>510</u>	<u>460</u>	<u>205</u>	<u>200</u>
Total diversion (rounded)	87,300	80,900	30,300	37,700

<sup>1</sup> Gaged by the U.S. Geological Survey, Palo Verde Canal near Blythe.

<sup>2</sup> Estimated by Bookman-Edmonston Engineering, Inc. (1976, p. 35).

<sup>3</sup> Measured and computed by the U.S. Geological Survey (see table 1).

<sup>4</sup> Measured by Palo Verde Irrigation District (R. E. Henning, written commun., 1983-85).

<sup>5</sup> Estimated by Bookman-Edmonston Engineering, Inc. (1976, p. 36).

Seepage from the Colorado River occurred along some reaches of the river where the ground-water divide and the river coexist. In 1981, seepage was estimated to be 3,100 acre-ft (Owen-Joyce, 1984, p. 16). In 1982, seepage did not occur along reaches adjacent to Palo Verde Valley. In 1983, seepage occurred along 19.9 mi of the river and was estimated to be 45,400 acre-ft. Ground-water gradients ranged from 1.7 to 13.2 ft/mi in the losing reaches. In 1984, seepage occurred along 9.9 mi of river and ground-water gradients ranged from 4.5 to 11.1 ft/mi; seepage was estimated to be 27,000 acre-ft. A transmissivity of 53,000 ft<sup>2</sup>/d (Metzger and others, 1973, p. 68) was used to estimate the seepage in all reaches.

**Table 7.--Estimates of irrigation requirements and evapotranspiration  
by vegetation in Palo Verde Valley, California, 1981-84**

Year	Vegetation type	Irrigation requirement, in feet	Evapotranspiration, in feet	Area, in acres			Irrigation requirement, in acre-feet			Evapotranspiration, in acre-feet		
				West of divide	East of divide	Total	West of divide	East of divide	Total	West of divide	East of divide	Total
1981	Crops											
	Alfalfa	19.5	25.3	31,003	4,574	35,577	294,529	43,453	337,982	164,316	24,242	188,558
	Cotton	15.7	23.2	32,198	2,090	34,288	183,529	11,913	195,442	103,034	6,688	109,722
	Grain	13.3	21.9	19,199	1,600	20,799	63,357	5,280	68,637	36,478	3,040	39,518
	Other	4.0	31.9	20,700	1,406	22,106	82,800	5,624	88,424	39,330	2,671	42,001
	Subtotal			103,100	9,670	112,770	624,215	66,270	690,485	343,158	36,641	379,799
	Phreatophytes	----	43.4	4,239	2,697	6,936	-----	-----	-----	14,413	9,170	23,583
	Total			107,339	12,367	119,706	624,215	66,270	690,485	357,571	45,811	403,382
1982	Crops											
	Alfalfa	19.5	25.3	30,008	3,817	33,825	285,076	36,262	321,338	159,042	20,230	179,272
	Cotton	15.7	23.2	28,221	2,685	30,906	160,860	15,304	176,164	90,307	8,592	98,899
	Grain	13.3	21.9	17,375	1,002	18,377	57,337	3,307	60,644	33,012	1,904	34,916
	Other	4.0	31.9	25,229	2,491	27,720	100,916	9,964	110,880	47,935	4,733	52,668
	Subtotal			100,833	9,995	110,828	604,189	64,837	669,026	330,296	35,459	365,755
	Phreatophytes	----	43.4	4,285	2,651	6,936	-----	-----	-----	14,569	9,013	23,582
	Total			105,118	12,646	117,764	604,189	64,837	669,026	344,865	44,472	389,337
1983	Crops											
	Alfalfa	19.5	25.3	31,614	2,145	33,759	300,333	20,378	320,711	167,554	11,369	178,923
	Cotton	15.7	23.2	16,889	556	17,445	96,267	3,169	99,436	54,045	1,779	55,824
	Grain	13.3	21.9	15,060	330	15,390	49,698	1,089	50,787	28,614	627	29,241
	Other	4.0	31.7	28,387	511	28,898	113,548	2,044	115,592	48,258	869	49,127
	Subtotal			91,950	3,542	95,492	559,846	26,680	586,526	298,471	14,644	313,115
	Phreatophytes	----	43.4	6,202	734	6,936	-----	-----	-----	21,087	2,496	23,583
	Total			98,152	4,276	102,428	559,846	26,680	586,526	319,558	17,140	336,698
1984	Crops											
	Alfalfa	19.5	25.3	34,073	2,354	36,427	323,694	22,363	346,057	180,587	12,476	193,063
	Cotton	15.7	23.2	22,049	1,122	23,171	125,679	6,395	132,074	70,557	3,590	74,147
	Grain	13.3	21.9	18,025	497	18,522	59,483	1,640	61,123	34,248	944	35,192
	Other	4.0	31.8	31,778	1,303	33,081	127,112	5,212	132,324	57,200	2,345	59,545
	Subtotal			105,925	5,276	111,201	635,968	35,610	671,578	342,592	19,355	361,947
	Phreatophytes	----	43.4	5,679	1,257	6,936	-----	-----	-----	19,309	4,274	23,583
	Total			111,604	6,533	118,137	635,968	35,610	671,578	361,901	23,629	385,530

<sup>1</sup>S. H. Stipe (U.S. Economic Research Service, written commun., 1983).

<sup>2</sup>Determined by U.S. Soil Conservation Service on the basis of soil-moisture depletion studies in Parker Valley (H. C. Millsaps, oral commun., 1983).

<sup>3</sup>Calculated as area-weighted average of empirically determined evapotranspiration for other crops.

<sup>4</sup>Boyle Engineering Corp. (1976, p. 11-7).

Consumptive use by vegetation for the area drained by the river (table 8) was estimated using the consumptive use per unit vegetated area determined for the area drained by drainage ditches (table 8) multiplied by the vegetated area in the area drained by the river (table 7) and adjusted for the unequal distribution of vegetation types in the two drainage areas (table 9). An analysis of evapotranspiration by vegetation types using empirically determined evapotranspiration (table 7) indicated that evapotranspiration per unit vegetated area was higher in the area drained by the river than in the area drained by the drainage ditches (table 9). The percent difference in evapotranspiration between the two drainage areas was used to adjust consumptive use for the unequal distribution of vegetation types. The higher evapotranspiration per unit vegetated area is caused by a greater percentage of the cultivated area planted with alfalfa and more phreatophytes per

Table 8.--Estimates of consumptive use by vegetation in Palo Verde Valley, California, 1981-84

	Consumptive use, in acre-feet				Consumptive use, in feet <sup>1</sup>			
	1981	1982	1983	1984	1981	1982	1983	1984
Area drained by drainage ditches.....	429,100	401,900	345,900	351,200	4.00	3.82	3.52	3.15
Area drained by the river..	<u>54,900</u>	<u>51,700</u>	<u>18,500</u>	<u>23,100</u>	4.44	4.09	4.33	3.53
Palo Verde Valley.....	484,000	453,600	364,400	374,300	4.04	3.85	3.56	3.17

<sup>1</sup>Calculated as consumptive use per unit vegetated area (table 7)—the area of crops plus phreatophytes.

Table 9.--Evapotranspiration per unit area by vegetation in Palo Verde Valley, California, 1981-84

Year	Evapotranspiration, in feet		Percent difference
	Area drained by drainage ditches	Area drained by the river	
1981	3.33	3.70	11
1982	3.28	3.52	7
1983	3.28	4.01	23
1984	3.24	3.62	12

unit area. Consumptive use for Palo Verde Valley is the sum of consumptive use for the two ground-water drainage areas (table 8).

A sensitivity analysis was done to determine the change in computed consumptive use by vegetation for a specified change of a primary variable. The sensitivity values for consumptive use in table 10 indicate that consumptive use is most sensitive to the diversion at Palo Verde Dam and the discharge from drainage ditches to the river from the area west of the divide; both variables are measured quantities. The movement of the ground-water divide from year to year and the change in storage do not significantly affect the computation of

**Table 10.--Primary variables used in the computation of consumptive use by vegetation and ground-water return flow in Palo Verde Valley, California, and sensitivity of results to a change in specified value**

[Source: M, measured; E, estimated. East area is drained by the Colorado River, west area is drained by drainage ditches. Sensitivity: Percentage change in computed consumptive use or ground-water return flow for a +10 percent change in value of the primary variable]

Variable	Source	Value				Units	Consumptive use sensitivity				Ground-water return flow sensitivity			
		1981	1982	1983	1984		1981	1982	1983	1984	1981	1982	1983	1984
Diversions at Palo Verde Dam	M	1,006,000	942,000	786,700	834,900	acre-ft	-21.1	-21.2	-21.7	-22.5	6.2	7.6	19.7	9.6
Canal seepage	E	125,000	125,000	125,000	125,000	acre-ft	0.0	0.0	0.0	0.0	-0.3	0.3	2.1	2.2
Spills to the river	M	65,600	68,200	74,500	69,000	acre-ft	1.4	1.5	2.1	1.9	-0.4	-0.5	-1.9	-0.8
Regulatory waste to ditches	E	22,300	17,200	14,200	10,300	acre-ft	0.0	0.0	0.0	0.0	0.8	0.8	2.7	0.7
Diversion to Palo Verde Mesa	E	17,100	15,900	13,200	12,800	acre-ft	0.4	0.4	0.4	0.3	-0.1	-0.1	-0.3	-0.1
Evaporation from canals	E	5,000	5,000	5,000	5,000	acre-ft	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Length of canals in east area	M	25.8	23.4	10.4	10.0	miles	0.3	0.3	0.2	0.1	-4.2	-5.5	-22.3	-5.2
Length of canals in west area	M	226.9	229.6	242.6	243.0	miles	-0.2	-0.2	-0.1	-0.1	3.7	4.3	16.7	7.0
Areas of vegetation in east area:														
Alfalfa	M	4,574	3,817	2,145	2,354	acres	-0.6	-0.6	-0.3	-0.3	9.6	10.7	50.6	13.1
Cotton	M	2,090	2,685	556	1,122	acres	-0.2	-0.2	-0.1	0.0	2.9	4.6	9.8	2.3
Grain	M	1,600	1,002	330	497	acres	-0.1	-0.1	0.0	0.0	2.2	1.7	5.8	-0.4
Other crops	M	1,406	2,491	511	1,303	acres	-0.1	-0.1	0.0	0.0	2.0	2.2	2.8	0.5
Phreatophytes	M	2,697	2,651	734	1,257	acres	-0.2	-0.2	-0.1	-0.1	3.8	4.5	12.9	2.9
Areas of vegetation in west area:														
Alfalfa	M	31,003	30,008	31,614	34,073	acres	0.5	0.5	0.2	0.3	-7.9	-9.9	-35.4	-16.1
Cotton	M	32,198	28,221	16,889	22,049	acres	0.3	0.3	0.1	0.1	-5.0	-5.6	-12.7	-5.6
Grain	M	19,199	17,375	15,060	18,025	acres	0.1	0.1	0.0	0.1	-1.5	-1.5	-5.4	-4.6
Other crops	M	20,700	25,229	28,387	31,778	acres	0.1	0.2	0.1	0.1	-1.7	-3.1	-9.3	-5.5
Phreatophytes	M	4,239	4,285	6,202	5,679	acres	0.0	0.0	0.0	0.0	-0.7	-0.9	-4.7	-1.5
Irrigation requirement in east area:														
Alfalfa	E	43,453	36,262	20,378	22,363	acre-ft	1.1	0.9	0.6	0.5	-16.5	-16.7	-95.0	-24.7
Cotton	E	11,913	15,305	3,169	6,395	acre-ft	0.4	0.4	0.2	0.2	-5.5	-6.7	-23.8	-8.2
Grain	E	5,280	3,307	1,089	1,640	acre-ft	0.2	0.0	0.0	0.0	-2.7	0.0	-23.8	0.0
Other crops	E	5,624	9,964	2,044	5,212	acre-ft	0.2	0.2	0.2	0.2	-2.7	-3.3	-23.8	-8.2
Irrigation requirement in west area:														
Alfalfa	E	294,529	285,076	300,333	323,694	acre-ft	-0.7	-0.7	-0.3	-0.3	11.0	13.4	47.5	16.4
Cotton	E	183,529	160,860	96,267	125,679	acre-ft	-0.5	-0.4	0.0	0.0	-0.2	8.2	6.7	0.0
Grain	E	63,357	57,337	49,698	59,483	acre-ft	-0.2	-0.2	0.0	0.0	2.7	3.3	0.0	0.0
Other crops	E	82,800	100,916	113,548	127,112	acre-ft	-0.2	-0.4	0.0	-0.2	2.7	6.7	0.0	8.2
Evapotranspiration:														
Alfalfa	E	5.3	5.3	5.3	5.3	feet	-0.1	0.0	-0.1	0.0	1.6	0.0	12.2	0.0
Cotton	E	3.2	3.2	3.2	3.2	feet	0.1	0.1	0.0	0.1	-1.6	-2.0	-6.1	-2.6
Grain	E	1.9	1.9	1.9	1.9	feet	0.0	0.0	0.0	0.1	0.0	0.0	-6.1	-2.6
Other crops	E	1.9	1.9	1.7	1.8	feet	0.0	0.0	0.0	0.0	0.0	0.0	-6.1	-2.6
Phreatophytes	E	3.4	3.4	3.4	3.4	feet	-0.2	-0.2	0.0	-0.1	3.1	4.0	6.1	2.6
Effective precipitation in:														
West area	E	3,100	16,200	10,600	39,400	acre-ft	-0.1	-0.4	-0.3	-1.1	0.1	0.9	2.3	3.3
East area	E	380	1,900	510	2,400	acre-ft	0.0	0.0	0.0	0.0	-0.1	-0.8	-2.1	-3.0
Inflow from west side of valley	E	9,500	9,500	9,500	9,500	acre-ft	-0.2	-0.2	-0.3	-0.3	0.4	0.5	2.1	0.8
Tributary runoff from west side of valley	E	3,200	3,200	3,200	3,200	acre-ft	-0.1	-0.1	-0.1	-0.1	0.1	0.2	0.7	0.3
Inflow from river seepage	E	3,100	0	45,400	27,000	acre-ft	-0.1	0.0	-1.3	-0.8	0.1	0.0	9.9	2.2
Discharge from drains to river from:														
West area	M	419,500	408,200	381,900	426,400	acre-ft	9.8	10.2	11.0	12.1	-16.9	-21.9	-83.2	-35.2
East area	M	6,370	8,810	7,510	7,710	acre-ft	0.0	0.0	0.0	0.0	2.0	3.7	30.5	9.7
Outflow to west from valley	E	4,700	4,700	4,700	4,700	acre-ft	0.1	0.1	0.1	0.1	-0.2	-0.3	-1.0	-0.4
Pumpage	E	2,000	2,000	2,000	2,000	acre-ft	0.0	0.0	0.1	0.1	-0.1	-0.1	-0.4	-0.2
Change in storage in:														
West area	E	-400	-10,900	2,900	10,200	acre-ft	0.0	-0.3	0.1	0.3	0.0	0.6	-0.6	-0.8
East area	E	-5,300	-1,700	2,300	1,400	acre-ft	0.0	0.0	0.0	0.0	-1.7	-0.7	9.3	1.8

consumptive use by vegetation. Change in storage from 1981 to 1984 was 1 to 3 percent of consumptive use by vegetation for each year. For a valley drained by a network of drainage ditches with one point of diversion, the estimate of consumptive use by vegetation depends mostly on the accuracy with which the diversion and surface-water return flows are measured.

Comparisons were made using the values of consumptive use by vegetation and evapotranspiration for Palo Verde Valley and also using the values per unit vegetated area. Evapotranspiration is the major part of consumptive use by vegetation and, during 1981 and 1982, evapotranspiration was less than consumptive use by vegetation; in 1983 and 1984 that relation reversed (fig. 18). The only major difference between the two time periods, 1981-82 and 1983-84, was the rise in river stage from flood-control releases at Parker Dam. The reverse relation between consumptive use and evapotranspiration in 1983-84 may indicate that the amount of seepage from the river was underestimated. In a comparison of the two values per unit vegetated area, the reverse relation does not appear until 1984 (fig. 19). Both values consistently decrease from 1981 to 1984, but the difference between the two values decreases each year until they reverse in 1983 or 1984.

Consumptive use by vegetation in Palo Verde Valley decreases with decreases in the quantity of water diverted but consumptive use per unit vegetated area does not follow the same trend. Consumptive use by vegetation decreased from 1981 to 1983 (fig. 18; table 8) and correlates with decreasing vegetated area (table 7). In 1984, however, when the vegetated area increased to an amount between the 1981 and 1982 areas, consumptive use by vegetation increased slightly but remained far less than consumptive use by vegetation in 1981 and 1982. Consumptive use per unit area consistently decreased from 1981 to 1984 (fig. 19; table 8). The decrease does not correlate with changes in any one component and probably is the combined effect from changes in a number of the components. Changes from higher water-use crops—alfalfa and cotton—to lower water-use crops—grains and other crops—(fig. 3) could account for some, but not all, of the difference. The quantity of water diverted from the river each year has decreased; this decrease may indicate a change in irrigation practices that reduce consumptive use by vegetation.

The estimate of each component for input into the water budget affects the overall calculation of consumptive use by vegetation, and knowing the limitations of those estimates can help in analyzing the year-to-year variations. In 1984 effective precipitation was substantially higher than that in preceding years (table 5) and therefore could account for a lower consumptive use by vegetation of Colorado River water but does not account for the total difference. Higher rainfall in 1984 may have increased tributary runoff above the average value used in the water budget, but data are not available on the



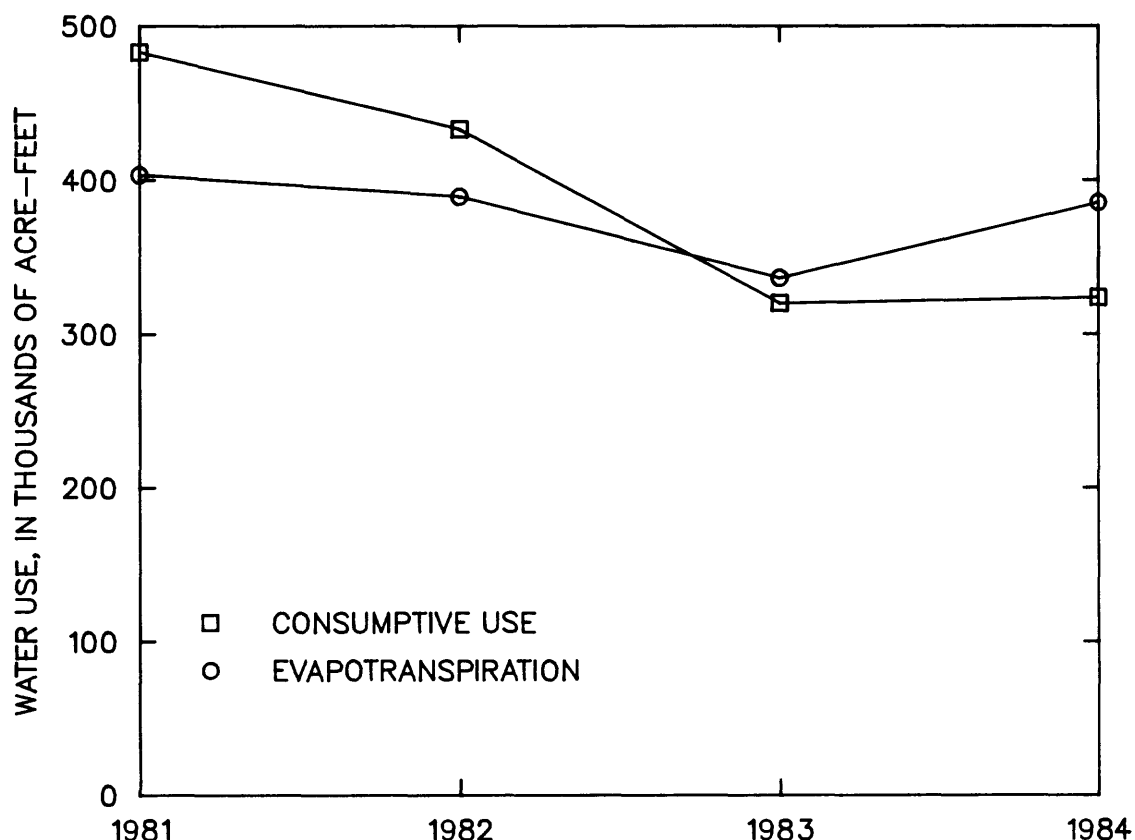


Figure 18.--Comparison of consumptive use by vegetation and evapotranspiration in Palo Verde Valley, California, 1981-84.

quantity of runoff in 1984. An increase in the tributary runoff component in the water budget would increase consumptive use by vegetation. Variations from year to year in other climatic factors such as solar radiation, wind, and minimum and maximum air and soil temperatures could also contribute to variations in evapotranspiration. Sustained high river stage in 1984 caused water to be retained in the aquifer and caused backwater in the network of drainage ditches; therefore, a large quantity of water in the aquifer originated directly from infiltration from the river rather than from applied irrigation water. The differences in consumptive use by vegetation from year to year could be an indication that the estimate of transmissivity used to compute seepage from the river is too small.

#### GROUND-WATER RETURN FLOW

Annual ground-water return flow to the river for 1981 to 1984 was computed using water budgets (table 11). Annual

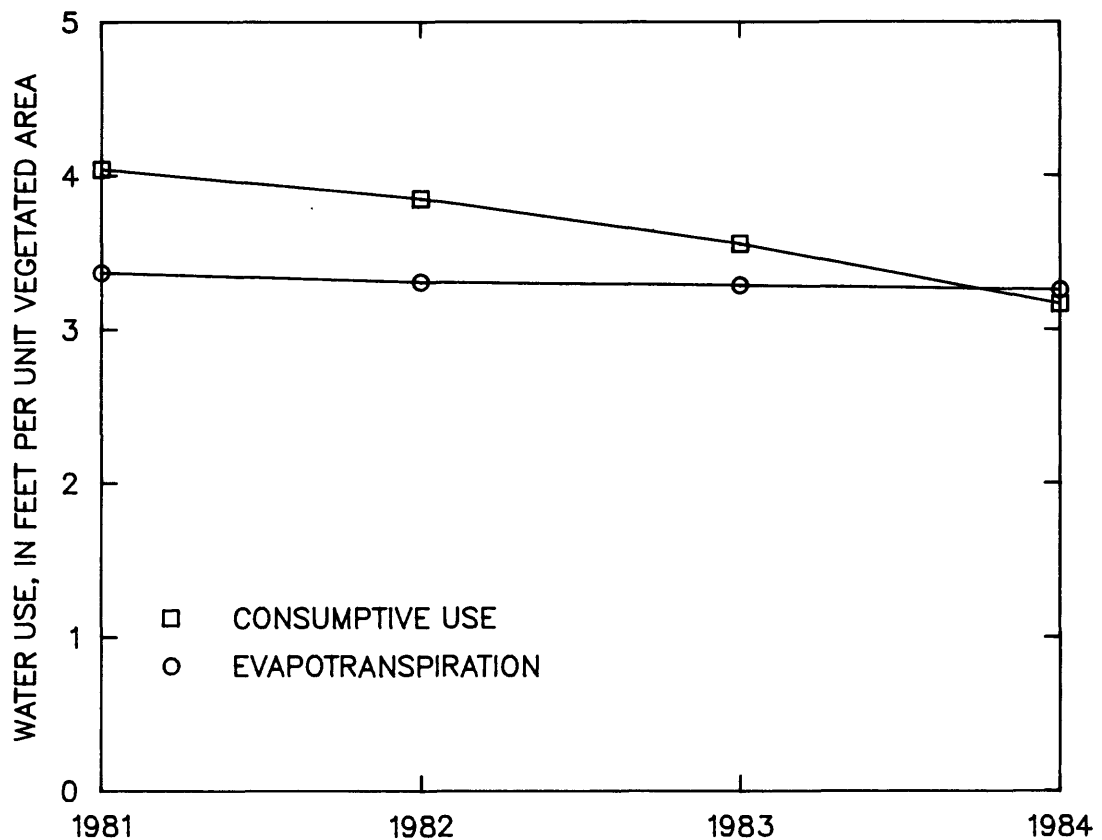


Figure 19.--Comparison of consumptive use by vegetation and evapotranspiration per unit vegetated area in Palo Verde Valley, California, 1981-84.

diversions to the area drained by the river were estimated as shown in table 6. Consumptive use by vegetation was estimated using the consumptive use per unit area determined for the area drained by drainage ditches multiplied by the vegetated area in the area drained by the river and adjusted for the unequal distribution of vegetation types in the drainage areas as described in the section entitled "Consumptive Use."

A sensitivity analysis was done to determine the change in computed ground-water return flow for a specified change in the value of a primary variable. The sensitivity values for ground-water return flow in table 10 indicate that ground-water return flow is most sensitive to discharge from drainage ditches to the river; various irrigation requirements, particularly for alfalfa; various crop areas, particularly those of alfalfa; and the diversion at Palo Verde Dam. All these components are significant in calculating consumptive use by vegetation; therefore, the estimate of ground-water return flow is most sensitive to consumptive use by vegetation and the

Table 11.--Water budgets for the area drained by the Colorado River in Palo Verde Valley, California, 1981-84, in acre-feet per year

	1981	1982	1983	1984
<b>Inflow:</b>				
Surface-water diversion...	87,300	80,900	30,300	37,700
Effective precipitation...	<u>380</u>	<u>1,900</u>	<u>510</u>	<u>2,400</u>
Total (rounded)...	<u>87,700</u>	<u>82,800</u>	<u>30,800</u>	<u>40,100</u>
<b>Outflow:</b>				
Surface-water discharge to Colorado River from Olive Lake drain (measured).....	6,370	8,810	7,510	7,710
Consumptive use by vegetation.....	54,900	51,700	18,500	23,100
Unmeasured ground-water return flow to the river <sup>1</sup> .....	<u>31,700</u>	<u>24,000</u>	<u>2,500</u>	<u>7,900</u>
Total (rounded)...	<u>93,000</u>	<u>84,500</u>	<u>28,500</u>	<u>38,700</u>
Change in storage:	-5,300	-1,700	2,300	1,400

<sup>1</sup>Unmeasured ground-water return flow to the river was calculated as inflow minus other outflows minus change in storage.

measured components—discharge from drainage ditches to the river and the diversion at Palo Verde Dam.

From year to year, the position of the ground-water divide moves. The total vegetated area east of the divide in 1982 was about 300 acres larger than in 1981; the major difference was that seepage from the river did not occur in 1982. The sensitivity values for ground-water return flow (table 10) increased slightly from 1981 to 1982. The total vegetated area east of the divide in 1983 was, on the average, about 8,200 acres less than in 1981 or 1982. The sensitivity values increased greatly and indicate that ground-water return

flow is most sensitive to some additional variables—the length of canals and change in storage in the area east of the divide. Change in storage for the area drained by the river ranged from 7 to 96 percent of ground-water return flow. In 1984, the total vegetated area east of the divide was about 2,300 acres more than in 1983 and about half the vegetated area in 1981 and 1982. The sensitivity values correlate more closely with the values and relations stated for 1981 and 1982. The higher sensitivity values in 1983 are related to the overall change in hydrologic conditions in the valley. River stage rose throughout the year. In response to the rise in river stage, the ground-water divide moved to the river in some places and decreased the area drained by the river. The crop types changed because of the PIK program; some fields were fallow and more lower water-use crops were grown in 1983.

### DIVERSIONS MINUS RETURN FLOWS

In a decree by the U.S. Supreme Court (1964), the United States is required to account for the consumptive use of lower Colorado River water on a calendar-year basis. The quantity of water diverted from the river at Palo Verde Dam is gaged. Surface-water return flows are computed from measurements and (or) gaging-station records, and ground-water return flows are estimated by using the water-budget method described by Owen-Joyce (1984). The method to estimate consumptive use of river water as diversions minus return flows assumes that the source of all flow in the drainage ditches is the measured diversion at Palo Verde Dam. Agriculture is the primary use of Colorado River water in Palo Verde Valley but some return flows moving through the alluvium are intercepted by domestic pumping and phreatophytes. Quantities of measured diversions, return flows, and consumptive use of river water calculated as diversions minus return flows for 1981 to 1984 are itemized in the following list:

	<u>Quantity, in acre-feet</u>			
	<u>1981</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>
Surface-water diversion....	1,006,000	942,000	786,700	834,900
Surface-water return flow..	491,500	485,200	463,900	503,100
Ground-water return flow...	31,700	24,000	2,500	7,900
Consumptive use (diversions minus return flows).....	482,800	432,800	320,300	323,900

Consumptive use as diversions minus return flows was consistently lower than consumptive use by vegetation estimated using water budgets during the 4 years studied (fig. 20). The difference between the two estimates varied year to year from 1,200 to 50,400 acre-ft and was greatest during the years of high flow in the river.

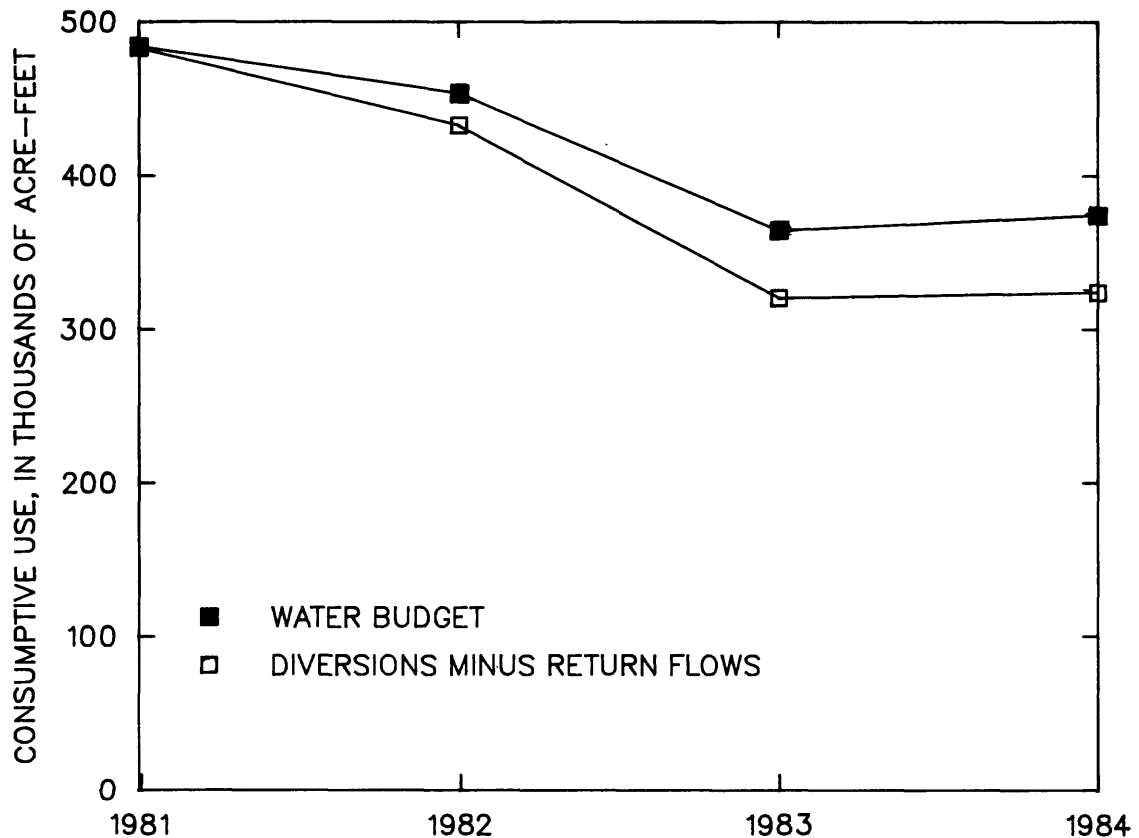


Figure 20.--Comparison of consumptive use by vegetation determined from a water budget and consumptive use of river water determined from diversions minus return flows in Palo Verde Valley, California, 1981-84.

#### COMPARISON OF CONSUMPTIVE-USE ESTIMATES

The comparison of consumptive use by vegetation calculated with a water budget to consumptive use of river water calculated as diversions minus return flows helps to show that the method using measured diversions minus return flows does not result in an estimate of the total consumptive use of river water in Palo Verde Valley. Consumptive use by vegetation calculated with a water budget is not equivalent to consumptive

use of river water calculated as diversions minus return flows. Consumptive use by vegetation is a major part of the consumptive use of river water, but consumptive use by vegetation on the flood plain does not include the quantity of ground water pumped from the shallow alluvial aquifer or the quantity of the diversion of Colorado River water to Palo Verde Mesa that is consumed. If the pumpage and the total diversion to the mesa are consumed, the water-budget estimate of consumptive use would increase by the sum of the pumpage and the mesa diversion. The difference between the two estimates of consumptive use also would increase by that quantity.

The estimate of consumptive use of Colorado River water using diversions minus return flows is much lower than the estimate of consumptive use by vegetation. The differences are greatest during years of high flow in the river, suggesting a connection to the increase in river seepage, which moves through the alluvium and into the drainage ditches. Other sources of water to the drainage ditches are tributary runoff and ground-water inflows, which may account for the differences in years when flow in the river is regulated to meet downstream requirements.

Consumptive use of Colorado River water is underestimated when calculated as measured diversions minus return flows because this method does not include the effects caused by variations in precipitation, tributary inflow, or river stage. In years of above-average precipitation that generate above-average tributary runoff, the tributary runoff flows into the drainage ditches and is measured and credited as surface-water return flows. Tributary ground-water inflow also is captured in drainage ditches and measured as surface-water return flows. Changes in river stage affect the quantity of water moving through the aquifer that originates as seepage from the river. During periods of high river stage, larger quantities of river seepage result in increased bank storage, increased captured river seepage in the drainage ditches, and a backwater effect on irrigation return flow in the aquifer along drainage ditches. Captured river seepage in the drainage ditches is not accounted for in the diversion of Colorado River water but is measured and credited as surface-water return flows from that diversion. Overestimating surface-water return flows results in underestimating the consumptive use of river water. The response time to changes in river stage that occur late in the year may be significant in delaying part of the effects into the next calendar year. These changes in ground-water storage are not accounted for in the calculation of diversions minus return flows.

#### SUMMARY

Palo Verde Valley is on the flood plain of the Colorado River and is used mostly for agriculture. The valley

is underlain by a shallow alluvial aquifer that is in hydraulic connection with the Colorado River and a network of drainage ditches. Precipitation is insufficient for growing crops. Palo Verde Dam diverts water from the Colorado River into a system of irrigation canals. Drainage ditches are used to reduce damage to crops from shallow ground water. Application of irrigation water and the network of drainage ditches control the direction of ground-water movement and the saturated thickness in the shallow aquifer. The diversion at Palo Verde Dam and the surface-water return flows to the river are measured. The valley is divided into two ground-water drainage areas by a ground-water divide, which is determined from contours of annual average water-table altitudes. Areas east of the divide drain to the Colorado River and areas west of the divide drain to drainage ditches. The location of the ground-water divide shifts from year to year and is controlled mainly by river stage and the amount of irrigation, both of which change the location of gaining and losing reaches along the river.

Annual water budgets were used to determine consumptive use by vegetation and ground-water return flow from 1981 to 1984. Consumptive use by vegetation in Palo Verde Valley was 484,000 acre-ft in 1981, 453,600 acre-ft in 1982, 364,400 acre-ft in 1983, and 374,300 acre-ft in 1984. Sensitivity analyses of the primary variables used in the computation of consumptive use by vegetation show that variations in computed consumptive use are most sensitive to two measured components—the diversion at Palo Verde Dam and the discharge from drainage ditches to the river. The movement of the ground-water divide and the changes in ground-water storage do not significantly affect the computation of consumptive use by vegetation. Ground-water return flow was estimated to be 31,700 acre-ft in 1981, 24,000 acre-ft in 1982, 2,500 acre-ft in 1983, and 7,900 acre-ft in 1984. Sensitivity analyses indicate that variations in computed ground-water return flow are most sensitive to discharge from drainage ditches to the river; various irrigation requirements, particularly for alfalfa; various crop areas, particularly those of alfalfa; and the diversion at Palo Verde Dam. During years when flow in the river increases, variations in computed ground-water return flow are sensitive also to change in ground-water storage and the length of canals in the area drained by the river. Year-to-year variations in the ground-water return flow sensitivity of the primary variables indicate that (1) rising river stage within a year causes the ground-water divide to move toward the river and, thus decreases the area drained by the river and (2) changes in crop types from year to year, especially when fields are left fallow, cause the largest changes in the ground-water return flow sensitivity values for all the variables.

Maps that show change in annual average ground-water level were used to calculate change in ground-water storage. Water-level changes were caused by change in river stage adjacent to the river and variations in the amounts of irrigation in the area west of the easternmost drainage ditch.

From 1981 to 1984, local changes in water levels ranged from -6.08 to 5.06 ft, and average water-level changes ranged from -0.37 to 0.33 ft. Annual change in ground-water storage from 1981 to 1984 ranged from -12,600 to 11,600 acre-ft and was 1 to 3 percent of consumptive use for each year. The change in storage for the area drained by the river ranged from -5,300 to 2,300 acre-ft and was 7 to 96 percent of unmeasured ground-water return flow. Change in ground-water storage can be a significant component in a water budget to estimate ground-water return flow.

Estimates of average consumptive use per unit vegetated area for the area drained by the drainage ditches were within 1 percent of the consumptive use per unit vegetated area for Palo Verde Valley. Therefore, consumptive use per unit area for the area drained by drainage ditches can be used as an estimate of the consumptive use per unit area for Palo Verde Valley. Consumptive use of Colorado River water calculated by diversions minus return flows was consistently less than consumptive use by vegetation determined by the water-budget method because the effects caused by variations in precipitation, tributary inflow, and river stage are not considered in the calculation of diversions minus return flows. Water-budget estimates of consumptive use account for changes in these components and include change in ground-water storage.

#### SELECTED REFERENCES

- Bookman-Edmonston Engineering, Inc., 1976, Reduction of salt loading to the Colorado River from Palo Verde Irrigation District: Glendale, California, Report prepared for U.S. Bureau of Reclamation, 75 p.
- Boyle Engineering Corporation, 1976, Salinity control and irrigation system analysis, Colorado River Indian Reservation, Yuma County, Arizona: Phoenix, Report prepared for U.S. Bureau of Reclamation, 267 p.
- California Department of Water Resources, 1981, Index to sources of hydrologic data: California Department of Water Resources Bulletin 230-81, 696 p.
- Metzger, D. G., and Loeltz, O. J., 1973, Geohydrology of the Needles area, Arizona, California, and Nevada: U.S. Geological Survey Professional Paper 486-J, 54 p.
- Metzger, D. G., Loeltz, O. J., and Ireland, Burdige, 1973, Geohydrology of the Parker-Blythe-Cibola area, Arizona and California: U.S. Geological Survey Professional Paper 486-G, 130 p.



- National Climatic Data Center, 1980-84, Climatological Data California: U.S. Department of Commerce (published monthly).
- Owen-Joyce, S. J., 1984, A method for estimating ground-water return flow to the Colorado River in the Palo Verde-Cibola area, California and Arizona: U.S. Geological Survey Water-Resources Investigations Report 84-4236, 48 p.
- Raymond, L. H., and Owen-Joyce, S. J., 1986, Estimates of consumptive use and evapotranspiration in Palo Verde Valley, 1981 and 1983, in Johnson, A. I., and Rango, A., eds., Remote Sensing Applications for Consumptive Use (Evapotranspiration): American Water Resources Association Monograph Series No. 6, p. 25-34.
- 
- \_\_\_\_\_1987, Comparison of estimates of evapotranspiration and consumptive use in Palo Verde Valley, California: U.S. Geological Survey Water-Resources Investigations Report 87-4071, 27 p.
- Raymond, L. H., and Rezin, K. V., 1986, Evapotranspiration estimates using remote-sensing data, Parker and Palo Verde Valleys, Arizona and California: U.S. Geological Survey Open-File Report 86-67, 33 p.
- U.S. Supreme Court, 1964, State of Arizona, plaintiff v. State of California, et al., defendants: Decree--March 9, 1964, no. 8, original, 14 p.