COMPARISON OF ESTIMATES OF EVAPOTRANSPIRATION AND CONSUMPTIVE USE IN PALO VERDE VALLEY, CALIFORNIA

By Lee H. Raymond and Sandra J. Owen-Joyce

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CONTENTS

ILLUSTRATIONS

TABLES

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:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25,400	micrometer (m)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
acre	0.4047	square hectometer (hm^2)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
degree Fahrenheit (°F)	°C = (°F-32)/1.8	degree Celsius (°C)

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."

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ABSTRACT

Estimates of evapotranspiration and consumptive use by vegetation in Palo Verde Valley, California, were compared for calendar years 1981 to 1984. Vegetation types were classified, and the areas covered by each type were computed from Landsat satellite digital-image analysis. Evapotranspiration was calculated by multiplying the area of each vegetation type by a corresponding water-use rate adjusted for year-to-year variations in climate. The vegetation classifications slightly underestimated the total vegetated area when compared to crop reports because not all multiple cropping could be identified. The accuracy of evapotranspiration calculated from vegetation classifications depended primarily on the correct classification of alfalfa and cotton because alfalfa and cotton have larger acreages and use more water per acre than the other crops in the valley. Consumptive use was calculated using a water budget for each of the 4 years.

Estimates of evapotranspiration and consumptive use by vegetation, respectively, were: (1) 439,400 and 483,500 acre-feet in 1981, (2) 430,700 and 452,700 acre-feet in 1982, (3) 402,000 and 364,400 acre-feet in 1983, and (4) 406,700 and 373,800 acre-feet in 1984. Evapotranspiration estimates were lower than consumptive-use estimates in 1981 and 1982 and higher in 1983 and 1984. Both estimates were lower in 1983 and 1984 than in 1981 and 1982. These differences correspond most closely to significant changes in stage of the lower Colorado River caused by flood-control releases in 1983 and 1984 and to changes in cropping practices.

INTRODUCTION

Evapotranspiration and consumptive use by vegetation were compared to determine variations on a year-to-year basis in Palo Verde Valley, California (fig. 1). In a decree by the U.S. Supreme Court (1964) that apportions consumptive use of water from the lower Colorado River, consumptive use is defined as "* * *diversions from the stream less such return flow thereto as is available for consumptive use* * *." Consumptive use was calculated using a water budget that accounts for irrigation diversion, surface-water discharge from drainage ditches,

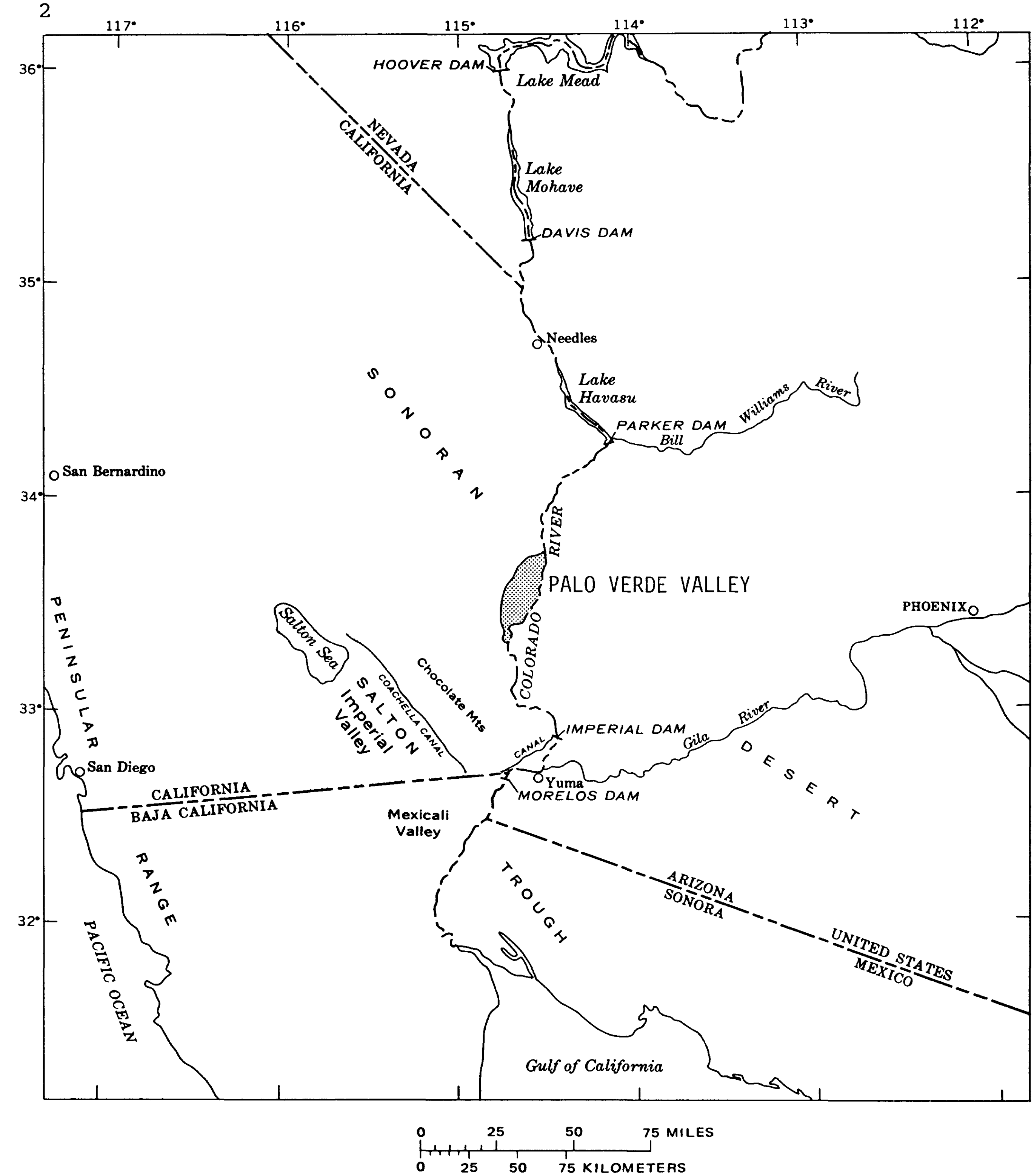

Figure 1.--Area of report.

precipitation, ground-water inflow to and outflow from the flood plain, tributary runoff, seepage from the Colorado River, ground-water pumpage, and change in ground-water storage. The water budgets are described in detail by Owen-Joyce and Kimsey (1987). In an agricultural area, total consumptive use consists of evapotranspiration, evaporation from bare-soil and open-water surfaces, and a small amount of domestic consumption. In this study, consumptive use refers to consumptive use by vegetation and is equivalent to evapotranspiration and evaporation from bare-soil and open-water surfaces. Within the context of this report, evapotranspiration is defined as the loss of water from a land area through transpiration by vegetation and evaporation from the soil surface. Evapotranspiration was calculated as the sum of the products of areas of vegetation types and water-use rates. Vegetation types and the areas covered by each type were determined from Landsat digital-image analysis. Water-use rates were adjusted for year-to-year variations in climate.

This report is the second report of the study and includes a brief description of the hydrologic system, a detailed description of the calculation of evapotranspiration, and a comparsion of annual estimates of evapotranspiration and consumptive use for the years 1981 through 1984. All annual data values given in this report are for calendar years.

Background

In a previous cooperative investigation with the U.S. Bureau of Reclamation, the U.S. Geological Survey developed methods for estimating ground-water return flow to the Colorado River (Loeltz and Leake, 1983; Leake, 1984; Owen-Joyce, 1984). The water-budget method used to estimate ground-water return flow in Parker Valley (Leake, 1984) and Palo Verde Valley (Owen-Joyce, 1984) required that consumptive use be estimated as a component for input into the water budget for the area drained by the river. Surface-water diversions and returns from the area drained by drainage ditches generally are well defined; therefore, consumptive use can be calculated directly using a water budget. Consumptive use per unit of vegetated area drained by drainage ditches can be used to estimate consumptive use for the area drained by the river.

Evapotranspiration calculated as the product of vegetation acreages from crop maps and average water-use rates was 17 percent less than consumptive use calculated by the water-budget method in Parker Valley (Leake, 1984). The difference was attributed to evaporation from bare-soil and open-water surfaces and to uncounted areas of multiple cropping that were not included in the evapotranspiration calculations. Owen-Joyce (1984) made the same comparison in Palo Verde Valley, which showed that evapotranspiration was 12 percent less than consumptive use. This difference was attributed to evaporation from water and soil surfaces not included in the evapotranspiration calculations.

Landsat digital-image analysis was used to classify vegetation types and to compute the areas covered by each vegetation type (Raymond and Rezin, 1986). Evapotranspiration was estimated using areas of vegetation classified by Landsat digital-image analysis multiplied by the corresponding water-use rates developed in the field for each vegetation type in Parker and Palo Verde Valleys and was within 3 percent of evapotranspiration calculated using crop maps.

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 include monthly water levels in wells, monthly stage measurements in the drainage ditches, 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 and to calibrate vegetation classifications from Landsat digital-image analysis.

The Arizona State Land Department, Resource Analysis Division, provided computer resources for the image analyses. The authors particularly wish to thank William H. Bayham, Director, and Steve B. Miller for their assistance and support.

PHYSICAL SETTING

Palo Verde Valley covers about 175 mi^2 of Colorado River flood plain, most of which is used for agriculture, and includes parts of Imperial and Riverside Counties, California. The main population center is Blythe (fig. 2). All crops must be irrigated because a mean annual rainfall of 3.91 in. (California Department of Water Resources, 1981, p. 671) is insufficient for growing crops. Irrigation water is diverted from the Colorado River at Palo Verde Dam (fig. 2).

Approximately 93,000 acres in Palo Verde Valley are cultivated (fig. 3). Principal crops are cotton, alfalfa, wheat, melons, and lettuce. A variety of other crops, particularly vegetables and grasses, are grown in small quantities. Many fields are double or triple cropped annually. Spring lettuce, wheat, or vegetables are most commonly followed by cotton or fall lettuce. Approximately 6,900 acres are covered with phreatophytes—mainly mesquite and saltcedar with some arrowweed, saltbush, and cattails along the drainage ditches (fig. 3). Total vegetated areas, including multiple-cropped areas, for 1981 to 1984 are listed in table 1.

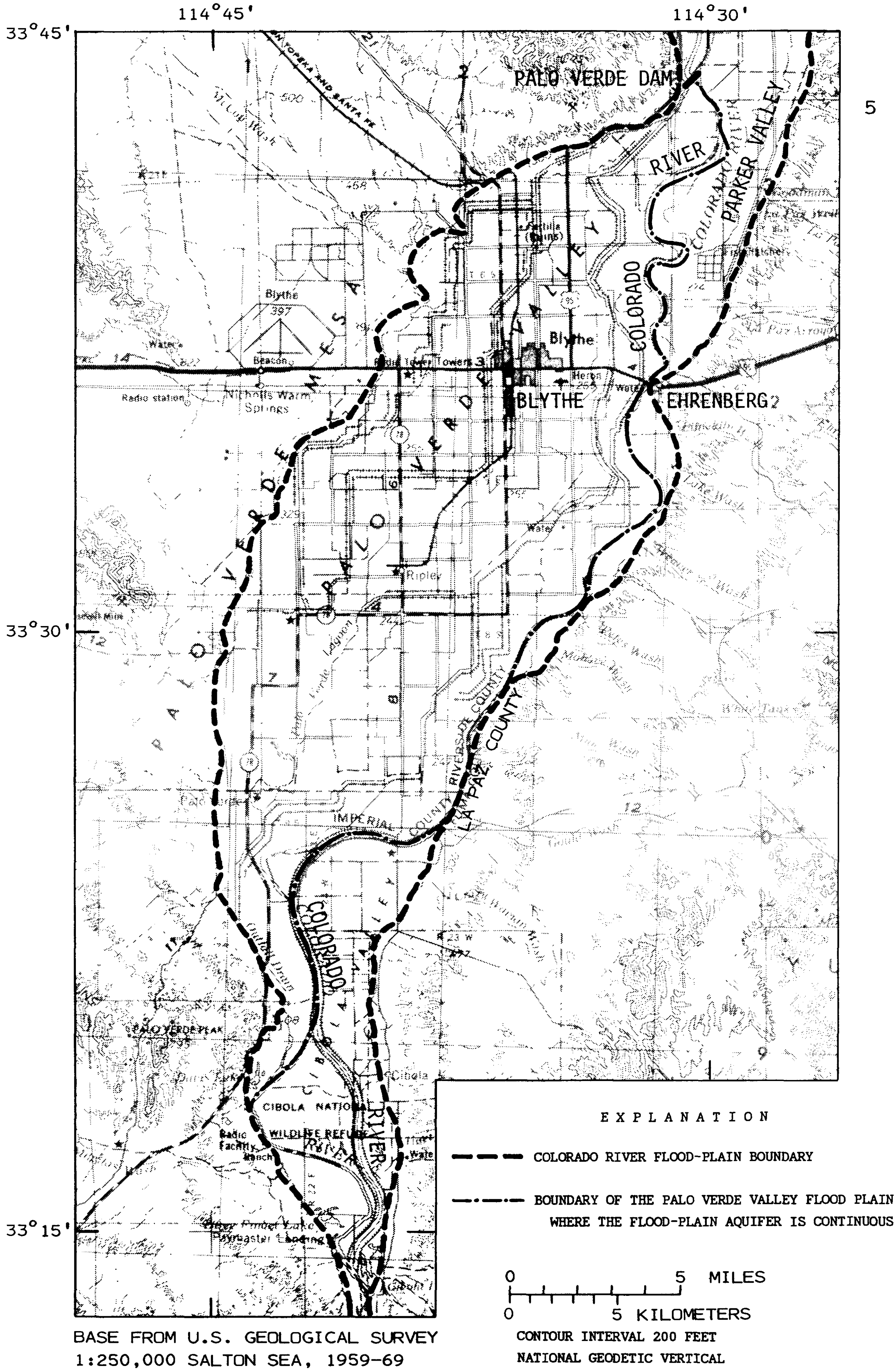

Figure 2.--Palo Verde Valley flood plain.

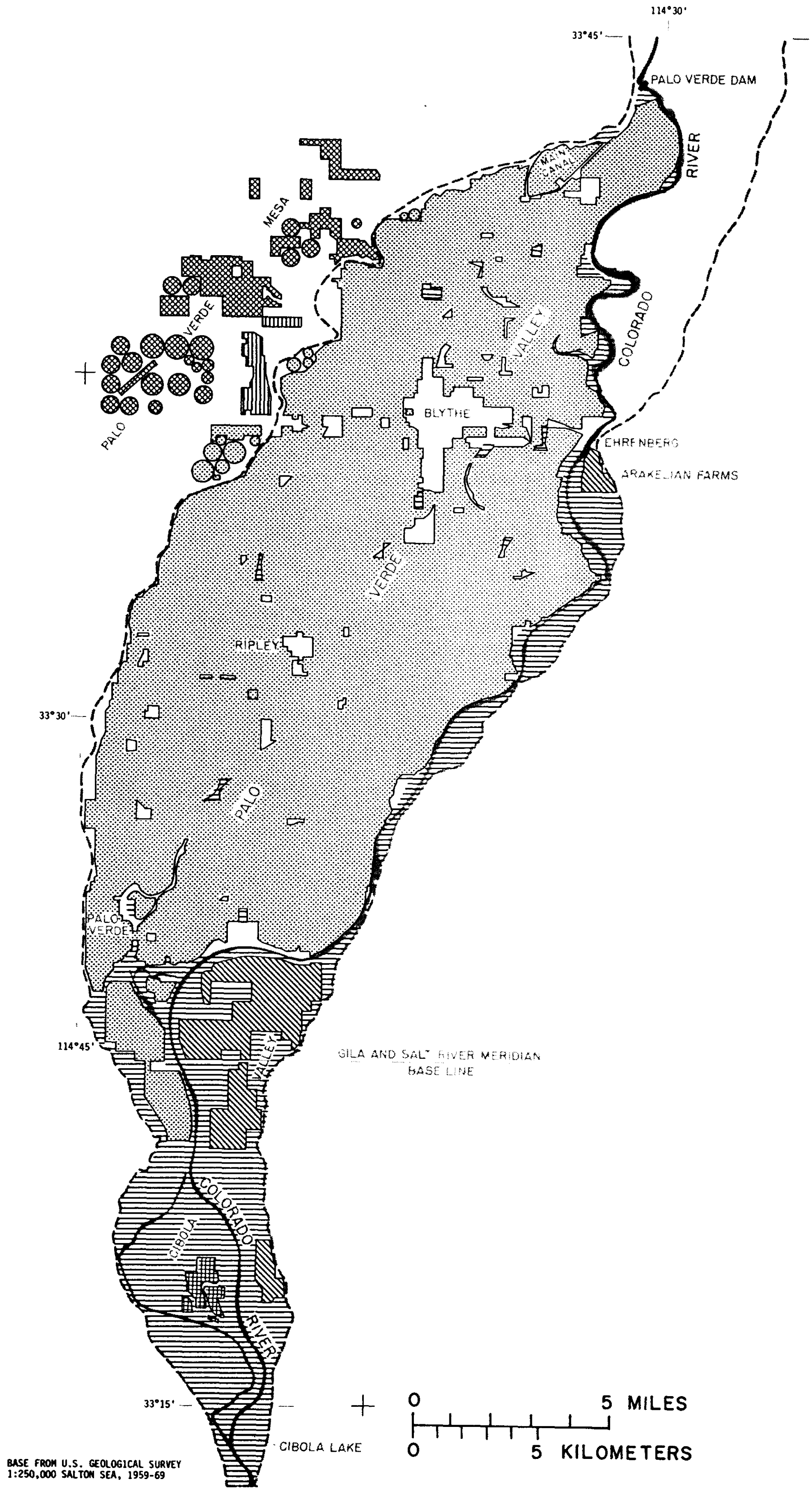

Figure 3.--Irrigated land and phreatophytes in Palo Verde Valley, California.

EXPLANATION

LAND IRRIGATED WITH WATER DIVERTED FROM THE COLORADO RIVER AT PALO VERDE DAM

LAND ON PALO VERDE MESA PARTIALLY IRRIGATED WITH WATER DIVERTED FROM THE COLORADO RIVER AT PALO VERDE DAM

LAND ON PALO VERDE MESA IRRIGATED WITH GROUND-WATER PUMPAGE

LAND IRRIGATED WITH WATER PUMPED FROM THE COLORADO RIVER AT VARIOUS SITES

LAND NOT IRRIGATED FROM 1981 TO 1984

AREA OF PHREATOPHYTES

COLORADO RIVER FLOOD-PLAIN BOUNDARY

Figure 3

Table 1.--Areas of vegetation in Palo Verde Valley, California, 1981-84, in acres

	1981	1982	1983	1984
Area drained by drainage ditches:				
Area of crops	103,100	100,833	91,950	105,925
Area of phreatophytes	4,239	4,285	6,202	5,679
Total vegetated area	107,339	105,118	98,152	111,604
Area drained by the river:				
Area of crops	9,670	9,995	3,542	5,276
Area of phreatophytes	2,697	2,651	734	1,257
Total vegetated area	12,367	12,646	4,276	6,533
Total for Palo Verde Valley:				
Area of crops[1]	112,770	110,828	95,492	111,201
Area of phreatophytes	6,936	16,936	6,936	6,936
Total vegetated area	119,706	117,764	102,428	118,137

[1] Palo Verde Irrigation District (written commun., 1984). Crop acreages include multiple-cropped fields.

During 1983, the Federal Government instituted the PIK (Payment-In-Kind) program in which cotton growers were subsidized for not planting as much as half their usual cotton acreage. The total cropped area was reduced by about 16,000 acres that year. Many of these fields were irrigated and even cultivated to preserve soil structure. Some fields grew dense covers of volunteer vegetation but records of this vegetation were not available.

HYDROLOGIC SETTING

The hydrologic system in Palo Verde Valley includes the highly regulated Colorado River and a shallow alluvial aquifer. River water is diverted for irrigation and ground water discharges to drainage ditches or to the river. Ground water occurs under water-table conditions in the alluvium. Water in the river is hydraulically connected to water in the aquifer and drainage ditches.

The flood plain of the Colorado River in Palo Verde Valley was divided into two ground-water drainage areas—one where ground water drains to drainage ditches and another where ground water drains to the river. A ground-water divide between the river and the drainage ditch nearest the river separates the two drainage areas. The location of the ground-water divide was determined from contours of annual average water-table altitudes. Consumptive use for the area drained by ditches was calculated using a water budget. Consumptive use for the area drained by the river was estimated using the consumptive use per unit area calculated for the area drained by drainage ditches (Owen-Joyce, 1984).

Agricultural development and its irrigation with Colorado River water have a significant effect on water use as well as on the amount and movement of water in Palo Verde Valley. Deep percolation of irrigation water causes a rise in the water table under the fields, which forms shallow ground-water divides between the drainage ditches. Drainage ditches are used to prevent crop damage by a too shallow water table. Most of the ground-water outflow from the aquifer discharges into the drainage ditches, which channel flow to Palo Verde Outfall drain on the west side of the valley. The Outfall drain then discharges to the Colorado River downstream from Palo Verde Valley. Ground water discharges directly to the river from a narrow strip of land adjacent to the river. During years when flood-control releases raise the river stage, some reaches of the river lose water to the aquifer and less ground water discharges directly to the river.

Flow in the Colorado River adjacent to Palo Verde Valley is controlled at Parker Dam (fig. 1). Flow in the river varies seasonally because releases from the dam are highest in summer when irrigation needs are greatest. During 1981 and 1982, flow was regulated to meet downstream water requirements. During 1983 and 1984, flow in the river exceeded downstream requirements because water was released from the reservoirs for flood control (fig. 4). In 1983, runoff that originated north of Lake Mead filled all the reservoirs from Lake Mead to the international boundary with Mexico.

Water for irrigation is diverted from the Colorado River at Palo Verde Dam into Palo Verde Canal, which distributes the water in a system of canals throughout the valley. During 1981 to 1984, 71 to 77 percent of the diverted water was applied to the fields and 59 to 72 percent of the applied water returned to the river as surface-water flow from the drainage ditches and ground-water flow from the shallow alluvial aquifer. The rest of the applied water was consumptively used through transpiration by crops and phreatophytes and evaporation from bare-soil and open-water surfaces. Phreatophytes intercept return flow from applied irrigation water. A more detailed description of the hydrologic system in Palo Verde Valley can be found in Owen-Joyce (1984).

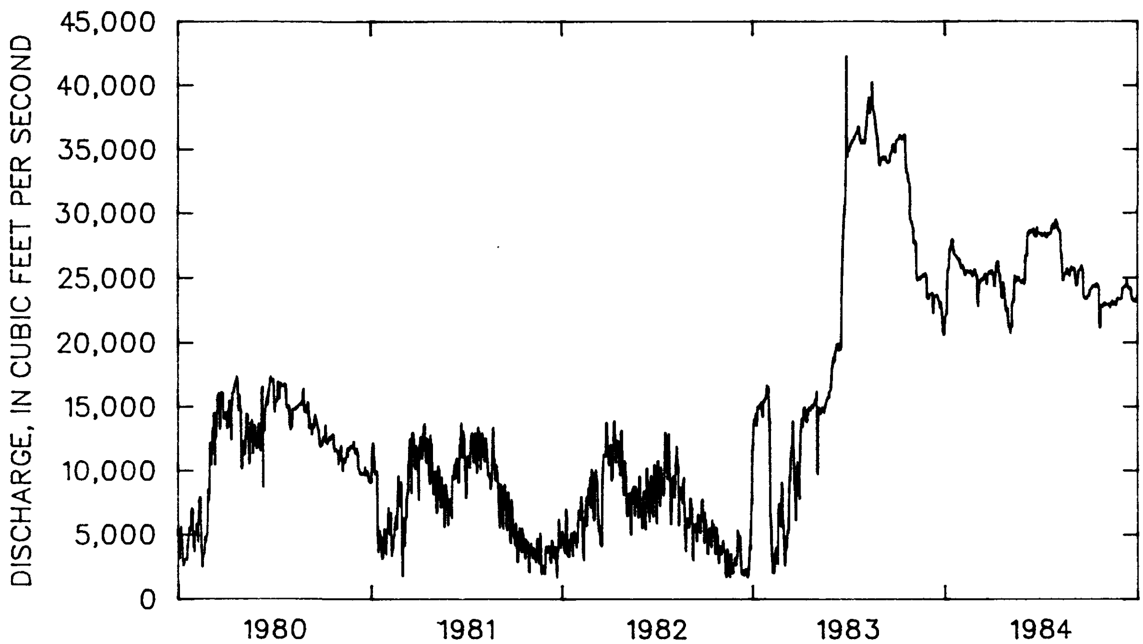

Figure 4.--Flow in the Colorado River at Palo Verde Dam, 1980-84.

EVAPOTRANSPIRATION

Evapotranspiration is the loss of water from a land area through transpiration by vegetation and evaporation from the soil surface and may be expressed as:

$$ET = \sum A \times Wu \qquad (1)$$

where

ET = estimated evapotranspiration, in acre-ft;
A = the area, in acres, of each vegetation type; and
Wu = water-use rate, in feet, for that vegetation type.

Several methods for identifying vegetation types and calculating their areas are discussed by Raymond and Rezin (1986). The method selected for Palo Verde Valley was multispectral, multitemporal classification of Landsat digital-satellite images from the MSS (multispectral scanner). Areas of vegetation types classified from image analysis were multiplied by their respective water-use rates adjusted for year-to-year climatic variations to calculate evapotranspiration.

Image Analysis

MSS images were collected by Landsats 2 and 3 for 1981, 1982, and 1983. These satellites alternately collected images once every 9 days over any given spot on the Earth. The MSS images for 1984 were collected by Landsat 5. The overpasses occurred every 16 days. Weather conditions and occasional malfunctions in the data-collection process further limit the number of satisfactory images available for an area during any particular period of time. The dates of the images selected to classify vegetation types in Palo Verde Valley for each of the 4 years were as close to each other as the foregoing limitations would permit.

Raymond and Rezin (1986) found that three image dates—late winter, late spring, and midsummer—gave the best classification of the major vegetation types in Palo Verde Valley and adjacent Parker Valley, Arizona. Of the cloud-free images available for Palo Verde Valley from 1981 to 1984, the following dates were selected to most closely correspond to maximum ground cover for the major vegetation types:

Image Dates

Year	Late winter	Late spring	Midsummer
1981	March 23	May 7	July 18
1982	February 1	April 29	June 16
1983	January 6	May 14	July 1
1984	February 26	May 25	August 24

The band-ratio technique (Taranak, 1978) was used to enhance the reflectance characteristics of the vegetated areas and minimize those of nonvegetated areas. Healthy vegetation reflects a high percentage of near-infrared radiation and absorbs a high percentage of red radiation. This characteristic reflectance response allows vegetated areas to be separated from nonvegetated areas, which tend to reflect or absorb about the same amount of radiation in both spectral bands.

The Landsat MSS records the reflectance of the ground cover in four bands of the spectrum: green, 0.4-0.5 μm (micrometers); red, 0.5-0.6 μm; and two near-infrared bands, 0.7-0.8 and 0.8-1.1 μm. The reflectance values of pixels in the 0.8-1.1-micrometer near-infrared band were divided by their corresponding values in the 0.5-0.6-micrometer red band. A linear stretch was applied to each ratio to standardize the images and to further enhance the distinction between vegetation and nonvegetation reflectance values. The band ratios were classified using the maximum likelihood classification algorithm (Graham and others, 1985). This program groups into classes those pixels that have similar reflectance characteristics on all three image dates. A vegetation map of part of Palo Verde Valley was used to identify and separate the classes. Details of the image enhancement and classification techniques used in this study are described by Raymond and Rezin (1986).

The image was georeferenced to establish the correct map coordinates for each pixel. The georeferencing program (Graham and others, 1985) uses the UTM (Universal Transverse Mercator) projection. UTM coordinates were determined for common ground-control points identified on the images and on U.S. Geological Survey 1:24,000-scale topographic maps. The georeferencing program then compared these coordinates to the location of each corresponding pixel in the image and mapped the image by generating UTM coordinates for all pixels.

The boundaries of Palo Verde Valley and the annual ground-water divides were drafted onto the maps and digitized. The boundaries were digitally registered to the georeferenced images by matching map coordinates. The number of acres of each class inside each of the digitized boundaries was calculated. The classes were then combined by vegetation type to determine the number of acres of each vegetation type in the two ground-water drainage areas.

Vegetation Classification

Different areas of the same vegetation type may have different reflectance characteristics on one or more image dates. Alfalfa is a good example. A field may be just mowed, ready to mow, or at any stage in between during the satellite's overpass. As much as one-third of all vegetation types identified in the four classifications represented alfalfa in various stages of growth on each image date. Conversely, two or more vegetation types—such as melons and tomatoes or cotton and some kinds of phreatophytes—may have similar reflectance characteristics on all three dates and may form one or more joint classes. Calibration of the classification is therefore required.

Crops were mapped by field reconnaissance in part of Palo Verde Valley from 1982 to 1984 to calibrate the vegetation classifications. Because the study began after the 1981 growing season, crop maps prepared by PVID were used to calibrate the 1981 classification. Each field on the crop maps was compared with the image classification to determine what vegetation type the class represented. Calibration of the phreatophyte areas was made using vegetation type maps published by Anderson and Ohmart (1976) and augmented by visual inspection in the field. Classes including two or more vegetation types were assigned the name of the dominant vegetation type by area where possible or by PVID records where not. A few small vegetation classes were not represented in the area mapped and were coded according to the spectral characteristics of the class they most closely resembled.

Results of the vegetation classifications are compared with PVID crop reports in figure 5. In general, vegetation types with large areas tend to be slightly overestimated because of bias during the interpretation. When most of the class in the calibration site represented a major vegetation type, the class was given that name even though a few pixels were recognized as belonging to a minor vegetation type. Also, the calibration site may not include a sample of every minor vegetation type. Classes representing these types must be identified on the basis of spectral-temporal characteristics alone. Here again, the bias was toward the major vegetation types.

Winter vegetables, particularly fall lettuce, were difficult to classify. Few cloud-free winter images were available, even for this semiarid region. In an earlier study, Raymond and Rezin (1986) showed that the addition of a late-fall image gave a poorer classification of the major crops. In this study, fall lettuce was identified as fields that had been prepared and irrigated at the time of the summer overpass, which resulted in very low band ratios in the enhanced image. When fields with these characteristics corresponded to fall lettuce in the calibration site, the class was coded as fall lettuce. Years such as 1984, in which the summer overpass occurred relatively late in the season, have the best classifications of fall lettuce; the June overpass in 1982 provided no information on this crop because cultivation had not yet begun (fig. 5).

Melons and tomatoes have approximately the same growing season and spectral characteristics at MSS resolution and generally are classified together. According to PVID records, the melon acreage generally exceeded the tomato acreage by about 5:1. For the purpose of calculating evapotranspiration, the class was identified as melons.

A direct comparison between vegetation classifications and PVID crop reports for the rest of the vegetation classes is not feasible because the classes contain a mixture of vegetation types. For the vegetation classifications, the type "other" (fig. 5) contains those classes identified principally as phreatophytes with minor amounts of volunteer vegetation, field borders, and crops. For the PVID crop reports, the type "other" includes the rest of the net cropped acreage. The PVID "other" also includes the constant 6,936 acres of phreatophytes used in the water-budget method to calculate consumptive use because PVID made no yearly estimates of phreatophyte coverage.

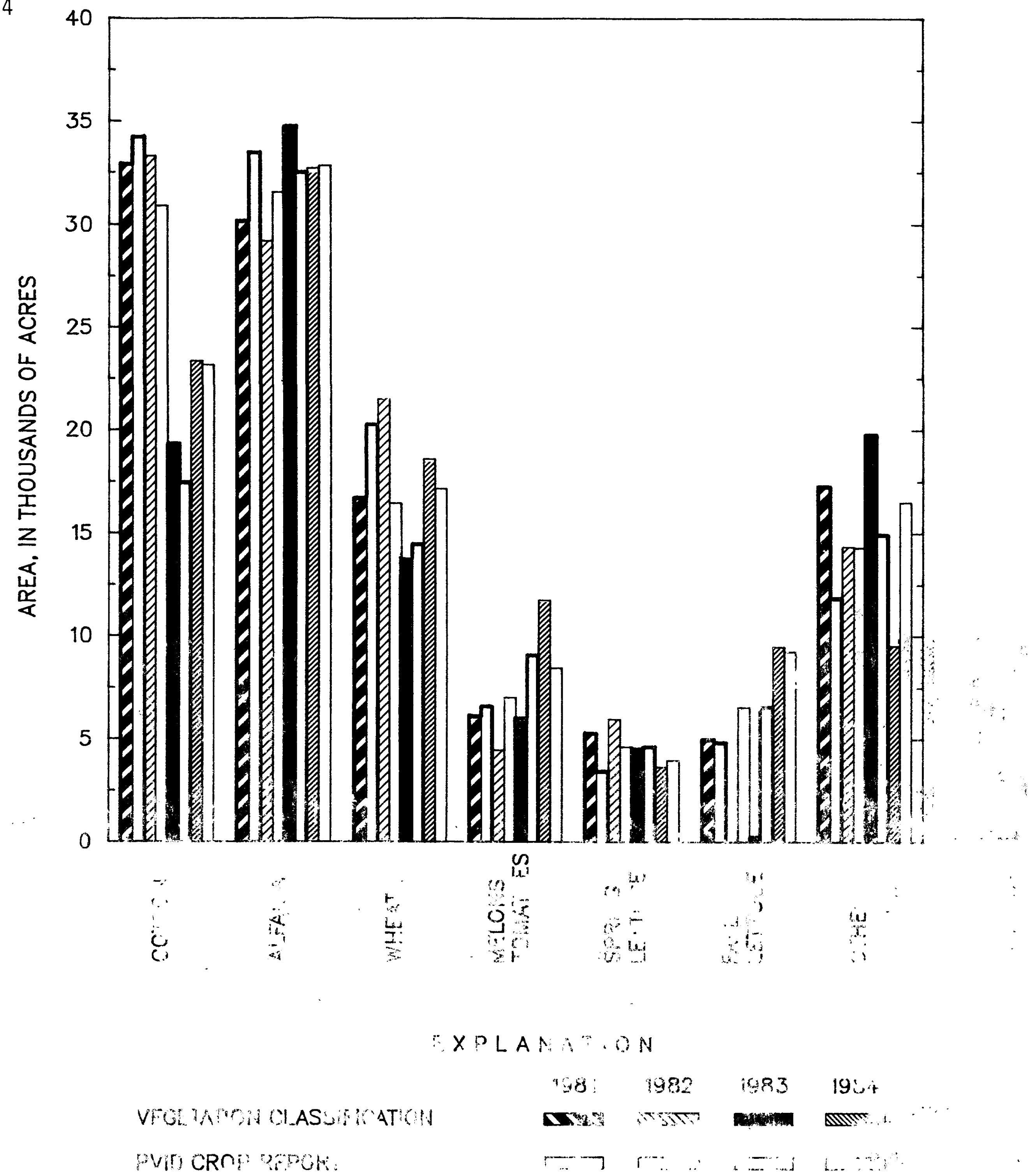

Figure 5.--Comparison of crop acreages from vegetation classifications and Palo Verde Irrigation District (PVID) crop reports in Palo Verde Valley, California.

The crop mix in Palo Verde Valley changed rather significantly in 1983 owing primarily to the PIK program (although economic and other factors also contributed) and continued to change in 1984 (fig. 5). Cotton acreage dropped sharply in 1983 and remained below average in 1984. Acreages of the minor crops, particularly melons, tomatoes, and fall lettuce, began to increase in 1983; alfalfa and wheat acreages began to increase by 1984. Several types of winter vegetables were introduced in 1984, increasing the "other" acreage as shown in figure 5. As a result, the vegetation classification tended to slightly overestimate the "other" types in 1983 and 1984 compared to 1981 and 1982 because of the calibration bias.

The PVID acreages were always slightly higher than the acreages obtained by vegetation classification because all multiple crops were included in the PVID acreages (fig. 6). The vegetation classification did not identify all multiple-cropped fields. The comparison was closest in 1983 when about 16,000 acres, which would normally have been planted with cotton, were left fallow. The volunteer vegetation in many of these fields was included in the vegetation classification but not in the crop report.

Calculation of Evapotranspiration

Average evapotranspiration by a particular vegetation type varies with local climatic conditions. Solar-radiation and wind-speed data were not available prior to 1983. The only continuous climatic data available for 1981 through 1984 were temperature and precipitation at Ehrenberg, Arizona, about 3 mi east of Palo Verde Valley (fig. 2). Therefore, only the Blaney-Criddle formula (Blaney and Criddle, 1950) could be used to adjust water-use rates for year-to-year climatic variations. The formula is expressed as:

$$U = (K \sum tp/100)/12 \qquad (2)$$

where

- U = consumptive crop water use, in feet, during growth of the crop;
- K = empirical consumptive-use coefficient that is dependent on the type and location of the crop;
- t = mean monthly temperature, in degrees Fahrenheit, and;
- p = monthly percentage of total daylight hours of the year.

Empirical coefficients for the crops were obtained from field tests conducted by the U.S. Department of Agriculture near Phoenix, Arizona (Erie and others, 1965). Mean monthly temperatures for each year were obtained from U.S. Weather

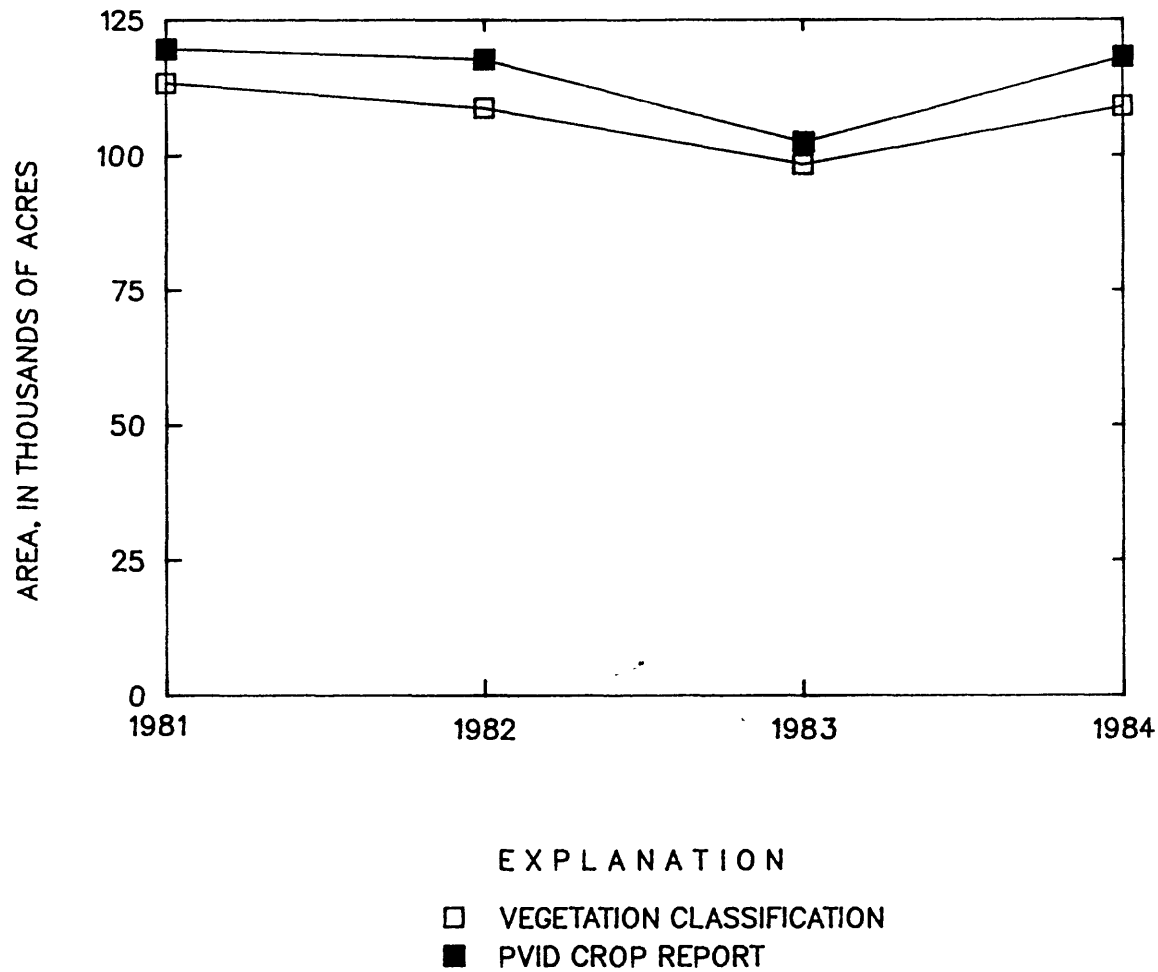

Figure 6.--Total vegetated area from vegetation classifications and Palo Verde Irrigation District (PVID) crop reports in Palo Verde Valley, California.

Bureau records for Ehrenberg. The percentage of daylight hours was interpolated from Cruff and Thompson (1967, p. M10).

Water use by phreatophytes is an important part of the total evapotranspiration and must be included in the calculations. Water-use rates have not been well established for phreatophytes growing in mixed stands of variable density. Culler and others (1982) determined water-use rates for mixed phreatophytes of various densities in south-central Arizona. The Culler rates were selected for this study because phreatophytes in the image classification could be separated by density but not by species. Other investigations by Boyle Engineering Corporation (1976), McDonald and Hughes (1968), and Rantz (1968) indicate that the Culler rates are not unrealistic for a mesquite-saltcedar-arrowweed mix that is mostly mesquite.

For each year, the number of acres classified as a particular crop or phreatophyte density class was multiplied by the respective water-use rate to determine the amount of evapotranspiration (table 2). Evapotranspiration was not adjusted for the small contribution by effective precipitation because the seasonal distribution of evapotranspiration by phreatophytes could not be determined using the Culler rates. Evapotranspiration calculated for the area drained by drainage ditches fluctuated only slightly during the 4-year period. Evapotranspiration remained about the same although the area classified as vegetated was about 10,000 acres, or 10 percent, less in 1983 than in the other years. The image classification slightly overestimated the alfalfa acreage in 1983 by including some volunteer vegetation and slightly underestimated it in the other 3 years (fig. 5). Alfalfa uses almost twice as much water as cotton and three times as much as the average amount used by the minor crops; therefore, calculated evapotranspiration is more sensitive to correct classification of alfalfa (and to a lesser extent cotton) than to that of any other crops. The proportion of alfalfa in the area drained by the river was much less in 1983 and 1984 than in the other years, so the resulting evapotranspiration varies directly with the vegetated area. Volunteer vegetation in 1983 also slightly increased the area classified as cropped fields throughout the valley.

Estimates of evapotranspiration from vegetation classifications and PVID crop reports are compared in figure 7. The estimates from vegetation classifications are lower in all years except 1983 because not all multiple cropping was identified. Evapotranspiration calculated for volunteer vegetation in 1983 accounted for part of the higher estimate that year. Differences between the estimates for all 4 years correspond most closely to differences between the areas classified as alfalfa and cotton and the areas reported for those crops (fig. 5).

CONSUMPTIVE USE

Consumptive use by vegetation for the area drained by drainage ditches was calculated for 1981, 1982, 1983, and 1984 using water budgets. Inflow occurred as (1) water diverted from the river for application to fields, (2) 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, (3) ground-water outflow to the area west of the flood plain, and (4) pumpage. Change in storage was estimated as the product of average annual changes in ground-water levels, areas of change, and specific yield. The water-budget components and estimated values are described by Owen-Joyce and Kimsey (1987).

Table 2.--Calculation of evapotranspiration using vegetation classifications in Palo Verde Valley, California, 1981-84

	1981			1982			1983			1984		
Crop	Area, in acres	Water use, in feet	ET[1], in acre-ft	Area, in acres	Water use, in feet	ET, in acre-ft	Area, in acres	Water use, in feet	ET, in acre-ft	Area, in acres	Water use, in feet	ET, in acre-ft
Area drained by drainage ditches:												
Cotton	30,646	3.77	115,535	29,888	3.65	109,091	18,681	3.69	68,933	22,348	3.67	82,017
Alfalfa	25,406	6.86	173,962	25,938	6.66	172,747	32,661	6.69	218,502	30,866	6.75	208,346
Wheat	15,302	2.45	37,490	20,001	2.40	48,002	13,453	2.36	31,749	18,037	2.42	43,650
Melons/Tomatoes	5,563	1.98	11,015	4,148	1.46	6,056	5,839	1.90	11,094	11,068	1.92	21,250
Onions[2]	724	2.09	1,513	6,919	2.05	14,184	---	---	---	---	---	---
Spring Lettuce	4,733	0.96	4,544	5,324	0.93	4,951	4,288	0.90	3,859	3,403	0.93	3,165
Fall Lettuce[3]	4,587	0.77	3,532	---	---	---	217	0.77	167	9,247	0.72	6,658
Dense mesquite/ saltcedar	4,353	3.40	14,800	3,978	3.40	13,525	7,979	3.40	27,130	2,769	3.40	9,415
Medium dense mesquite/saltcedar	995	2.80	2,790	963	2.80	2,700	3,907	2.80	10,940	2,178	2.80	6,100
Sparse mesquite/ saltcedar	5,799	1.50	8,698	5,294	1.50	7,941	6,919	1.50	10,379	3,890	1.50	5,835
Cottonwood/Willow[4]	2,879	3.50	10,076	1,303	3.50	4,560	---	---	---	---	---	---
Total	100,987		384,089	103,756		383,864	93,944		382,377	103,806		386,058
Area drained by the river:												
Cotton	2,264	3.77	8,535	3,434	3.65	12,534	674	3.69	2,487	1,001	3.67	3,674
Alfalfa	4,895	6.86	33,464	3,269	6.66	21,772	2,122	6.69	14,196	1,844	6.75	12,447
Wheat	1,357	2.45	3,325	1,542	2.40	3,701	295	2.36	295	567	2.42	1,372
Melons/Tomatoes	558	1.98	1,105	316	1.46	461	179	1.90	340	683	1.92	1,311
Onions[2]	74	2.09	155	517	2.05	1,060	---	---	---	---	---	---
Spring Lettuce	534	0.96	513	644	0.93	599	224	0.90	202	233	0.93	217
Fall Lettuce[3]	420	0.77	323	---	---	---	1	0.77	1	227	0.72	163
Dense mesquite/ saltcedar	728	3.40	2,475	722	3.40	2,455	292	3.40	993	120	3.40	408
Medium dense mesquite/saltcedar	267	2.80	748	263	2.80	736	125	2.80	350	222	2.80	622
Sparce mesquite/ saltcedar	1,631	1.50	2,446	1,455	1.50	2,182	532	1.50	798	351	1.50	526
Cottonwood/Willow[4]	634	3.50	2,219	375	3.50	1,312	---	---	---	---	---	---
Total	13,362		55,301	12,537		46,806	4,444		20,054	5,248		20,685
Total for Palo Verde Valley (rounded):												
	114,300		439,400	116,300		430,700	98,400		402,000	109,000		406,700

[1]ET, Evapotranspiration.

[2]Double-cropped lettuce and onions could be identified on the 1981 and 1982 images but not on 1983 and 1984.

[3]Fall lettuce can be identified primarily as irrigated soil in late July or August. Images were not available for these months in 1982 and the June scene used for the classification was too early to include this information.

[4]Identified as a separate class in 1981 and 1982 but not in 1983 and 1984, presumably because the spectral characteristics included open water.

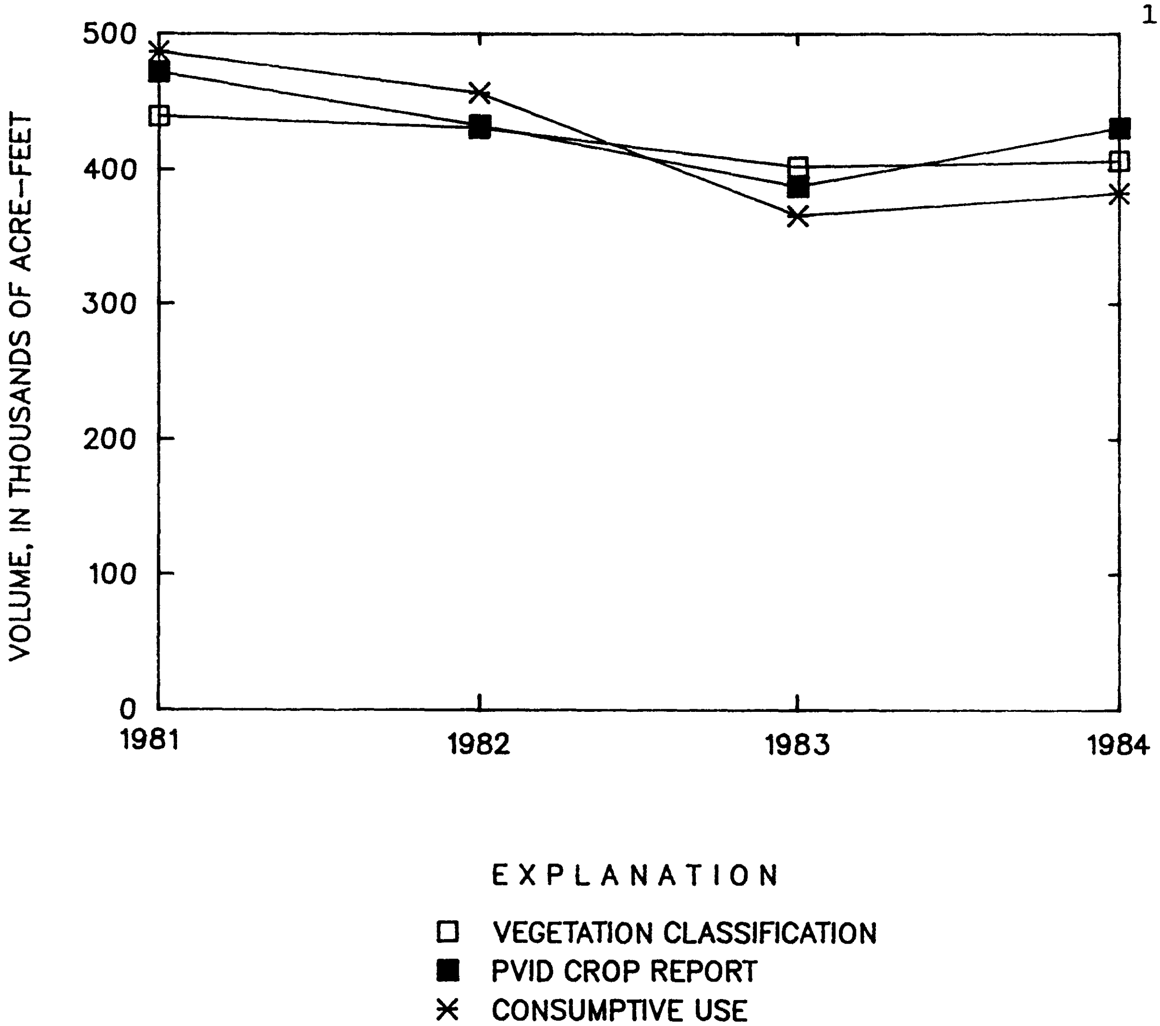

Figure 7.--Estimates of evapotranspiration from vegetation classifications and Palo Verde Irrigation District (PVID) crop reports and of consumptive use in Palo Verde Valley, California.

Owen-Joyce (1984) assumed that change in storage was negligible because flow in the river was kept at downstream requirements and water levels followed a seasonal trend. Change in storage was estimated and used in balancing the water budgets for 1981 to 1984 because flow in the river during 1983 and 1984 exceeded downstream requirements. River water flowed into the aquifer, increasing bank storage because of the high river stage. Even during years of high flow in the river, change in storage was small when compared with consumptive use. The extensive network of drainage ditches confined the major effect of changing water levels to the area between the river and the drainage ditch nearest the river. Sustained high river flows for prolonged periods increased the water in storage in the area drained by the ditches because high river stage caused backwater in the ditches (Owen-Joyce and Kimsey, 1987).

Table 3.--Estimates of consumptive use in Palo Verde Valley, California, 1981-84

	Consumptive use, in acre-feet				Consumptive use, in feet			
	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[1]	54,900	51,700	18,500	23,100	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
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[2]	54,400	50,800	18,500	22,600	4.40	4.01	4.33	3.46
Palo Verde Valley...	483,500	452,700	364,400	373,800	4.04	3.84	3.56	3.16

[1] Estimates calculated with evapotranspiration rates determined by the U.S. Soil Conservation Service on the basis of soil-moisture depletion studies in Parker Valley (H. C. Milsaps, oral commun., 1983).

[2] Estimates calculated with evapotranspiration by crop type determined using the Blaney-Criddle formula (Blaney and Criddle, 1950) for each year of study.

Consumptive use for Palo Verde Valley is the sum of consumptive use for the two ground-water drainage areas. Consumptive use for the area drained by drainage ditches was 429,100 acre-ft in 1981, 401,900 acre-ft in 1982, 345,900 acre-ft in 1983, and 351,200 acre-ft in 1984 (table 3). Consumptive use for the area drained by the river was estimated using the consumptive use per unit vegetated area determined for the area drained by drainage ditches (table 3) multiplied by the vegetated area and adjusted for the unequal distribution of vegetation types in the two drainage areas. An analysis of evapotranspiration by vegetation types using empirically determined water-use rates from Parker Valley (H. C. Millsaps, hydraulic engineer, U.S. Soil Conservation Service, oral commun., 1982) indicated that average evapotranspiration by crops and phreatophytes was about 11 percent higher in 1981, about 7 percent higher in 1982, about 23 percent higher in 1983, and about 12 percent higher in 1984 in the area drained by the river than in the area drained by drainage ditches. Consumptive use for the area drained by the river was 54,900 acre-ft in 1981, 51,700 acre-ft in 1982, 18,500 acre-ft in 1983, and 23,100 acre-ft in 1984 (Owen-Joyce and Kimsey, 1987).

Consumptive use for the area drained by the river using water-use rates derived from equation 2 was 54,400 acre-ft in 1981, 50,800 acre-ft in 1982, 18,500 acre-ft in 1983, and 22,600 acre-ft in 1984 (table 3). The annual change in consumptive use per unit vegetated area caused by using the different water-use rates is small for the area drained by the river and even less when applied to the entire valley (table 3). Annual changes in empirically determined water-use rates therefore are a minor contributing factor to the annual variations in consumptive use in addition to the factors discussed by Owen-Joyce and Kimsey (1987).

COMPARISON OF EVAPOTRANSPIRATION AND CONSUMPTIVE USE

Evapotranspiration and consumptive use were compared for 1981 to 1984. Areas of each vegetation type calculated from vegetation classifications and from PVID crop reports were multiplied by water-use rates adjusted for year-to-year climatic variations to estimate evapotranspiration. Consumptive use was calculated from water budgets. Comparisons of evapotranspiration and consumptive use were made using total values and values per unit vegetated area for Palo Verde Valley.

Estimates of evapotranspiration from vegetation classifications and of consumptive use in the area drained by drainage ditches, for which consumptive use can be calculated directly with a water budget, are shown in figure 8. A decline in consumptive use from 1982 to 1983 is apparent, whereas evapotranspiration remained fairly consistent. Possible reasons for the lack of decline in evapotranspiration from 1982 to 1983 are (1) slight overestimation of alfalfa in 1983 compared to underestimation in 1981 and 1982, (2) some fallow areas classified as vegetation because of volunteer plant growth in 1983, and (3) a smaller total area of multiple cropping in 1983.

Estimates of evapotranspiration and consumptive use differed less in the area drained by the river (fig. 9) than those in the area drained by drainage ditches. The decrease in alfalfa acreage is proportional to the decrease in total area drained by the river; the converse is true in the area drained by drainage ditches. The similarity in the estimates of evapotranspiration and consumptive use in the area drained by the river is explained by the use of crop types and acreages reported by PVID in calculating both estimates and by the much smaller percentage of area with multiple cropping than in the area drained by drainage ditches.

The combined estimates of evapotranspiration and consumptive use for all of Palo Verde Valley are compared in figure 7. The pairs of estimates for 1981, 1982, 1983, and 1984 follow the same trend from year to year, although the change is much less pronounced in the evapotranspiration estimates. The

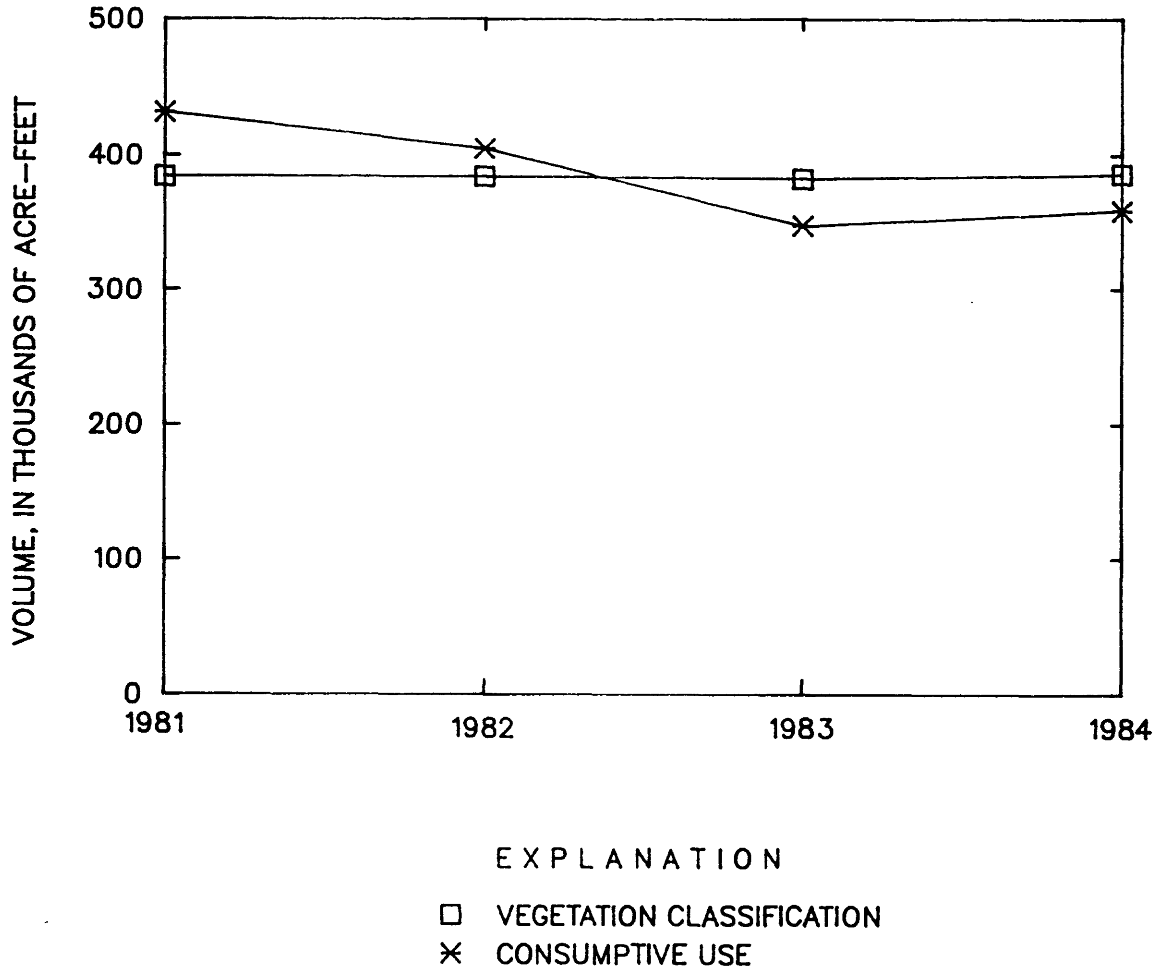

Figure 8.--Estimates of evapotranspiration from vegetation classifications and consumptive use in the area drained by drainage ditches in Palo Verde Valley, California.

differences in percentage of consumptive use are -9.1 in 1981, -4.8 in 1982, 10.3 in 1983, and 8.8 in 1984.

Estimates of evapotranspiration and consumptive use per vegetated area are compared in figure 10. Year-to-year variations in evapotranspiration per vegetated area are directly proportional to the number of acres identified as alfalfa. The effect of volunteer vegetation in 1983 is not a factor in this comparison because the higher total evapotranspiration estimate for that year is divided by the correspondingly higher area. Year-to-year variations in consumptive use per vegetated area correspond to a greater proportion of low-water-use crops in 1983 and 1984 and may be related to more conservative water-management techniques.

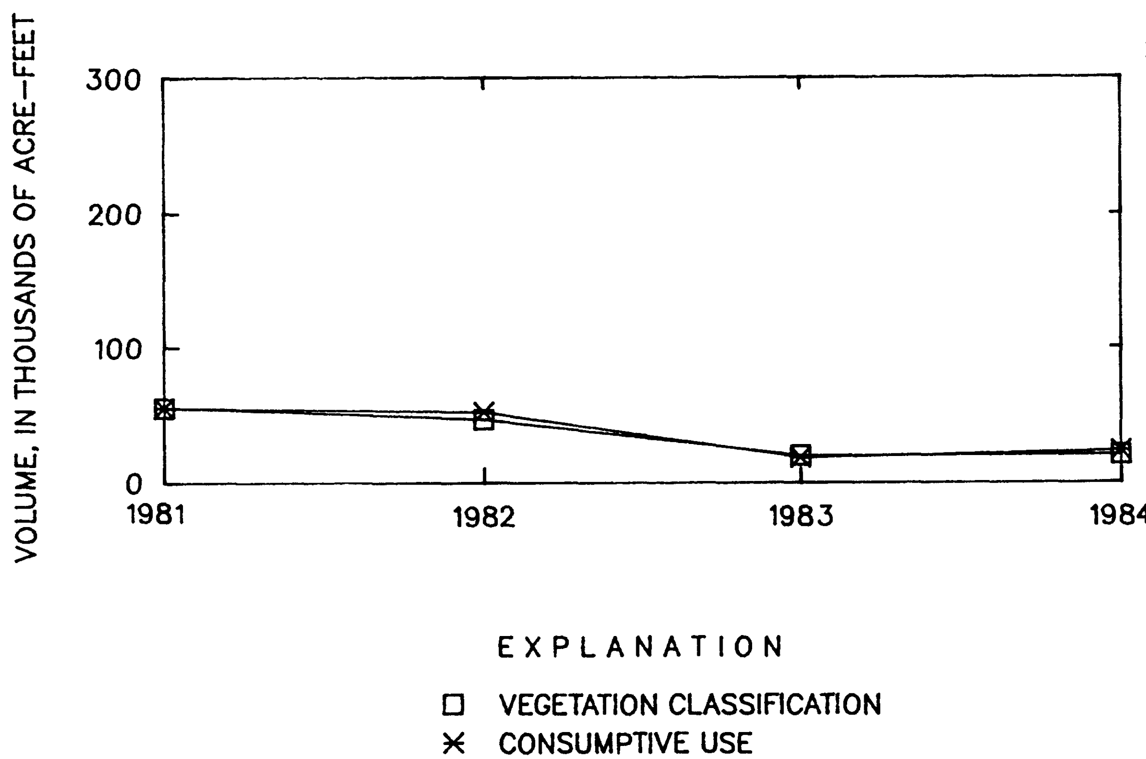

Figure 9.--Estimates of evapotranspiration from vegetation classifications and consumptive use in the area drained by the river in Palo Verde Valley, California.

The same comparisons were made for evapotranspiration calculated from PVID crop reports and consumptive use as shown in figures 7 and 10. This comparison eliminates errors caused by misclassification of the Landsat images. The estimates correspond closely for 1981 to 1983. A change in the relation between evapotranspiration and consumptive use began in 1983 and increased in 1984. Several possible reasons for the change between 1982 and 1983 have been identified:

1. Seepage from the Colorado River may have been underestimated if the value used for transmissivity was too low.

2. In areas where the water table is shallow, plants may be using water that originated as seepage from the river rather than water diverted for irrigation.

3. Backwater in the drains may have affected the amount of surface-water return flows.

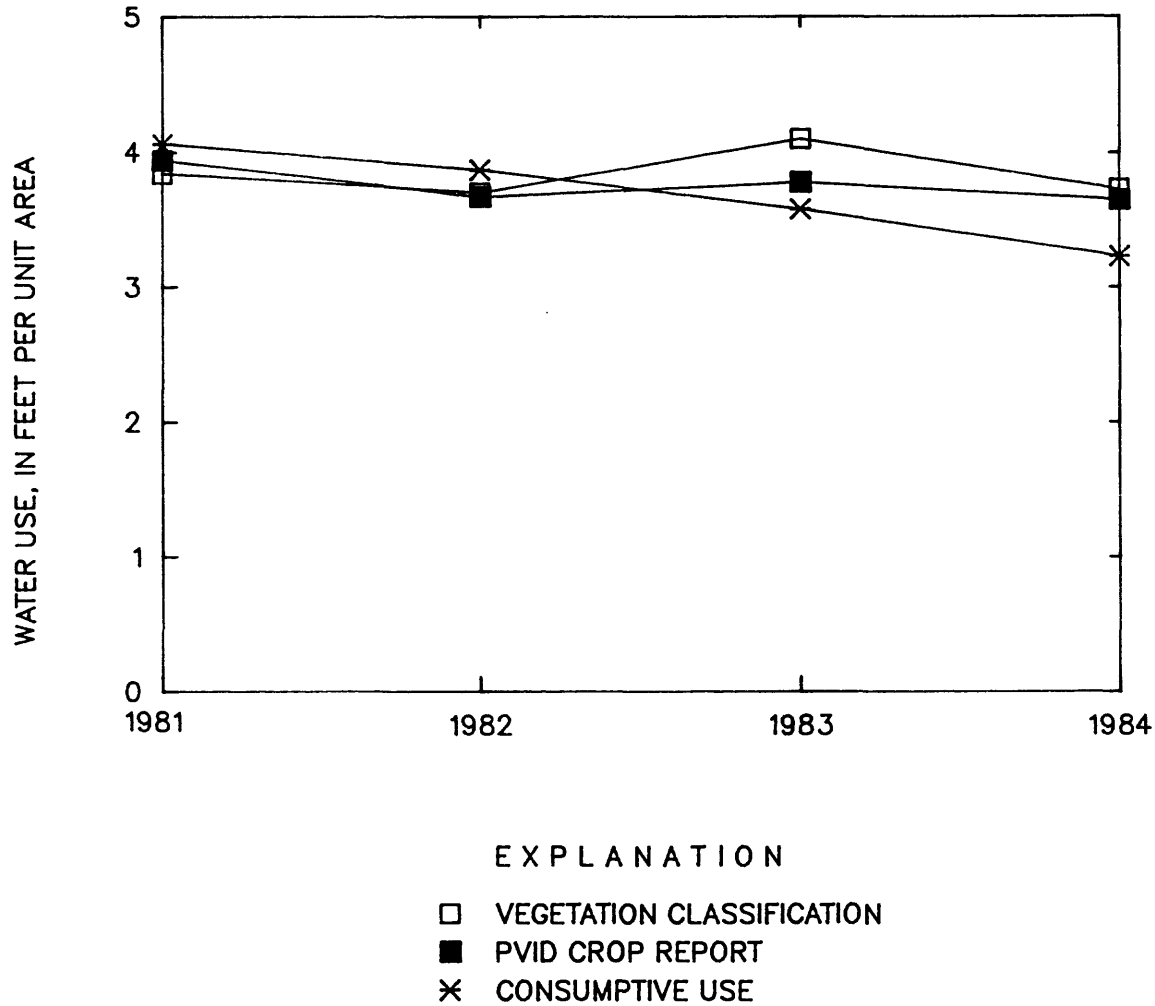

Figure 10.--Estimates of evapotranspiration from vegetation classifications and Palo Verde Irrigation District (PVID) crop reports and of consumptive use per vegetated area in Palo Verde Valley, California.

4. Normal climatic variations may play a more important role in the annual amounts of evapotranspiration than the formulas indicate. Solar-radiation and wind-speed data were not available for Palo Verde Valley prior to mid-1983. These data are necessary to compute water-use rates that truly reflect the effects of climatic variation.

5. Errors associated with the measurements and estimates for both methods may be sufficient to explain the magnitude of the differences.

SUMMARY

Estimates of evapotranspiration from vegetation classifications and consumptive use from water budgets were compared for 4 years in Palo Verde Valley. Estimates of evapotranspiration and consumptive use, respectively, were (1) 439,400 and 483,500 acre-feet in 1981, (2) 430,700 and 452,700 acre-feet in 1982, (3) 402,000 and 364,400 acre-feet in 1983, and (4) 406,700 and 373,800 acre-feet in 1984. The differences in percentage of consumptive use were -9.1 in 1981, -4.8 in 1982, 10.3 in 1983, and 8.8 in 1984. The variations were attributed principally to misidentification of some vegetation types, changes in the hydrologic system corresponding to changes in river stage, the PIK program, and errors in measurements and estimates. Accuracy of the evapotranspiration estimates depends primarily on the classification of alfalfa, and to a lesser extent, cotton, because these two crops had the largest acreages in the valley and used more water per unit area than the average of the other crops. Accuracy of the consumptive-use estimates depends primarily on the accurate measurement of diversions and surface-water return flows.

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