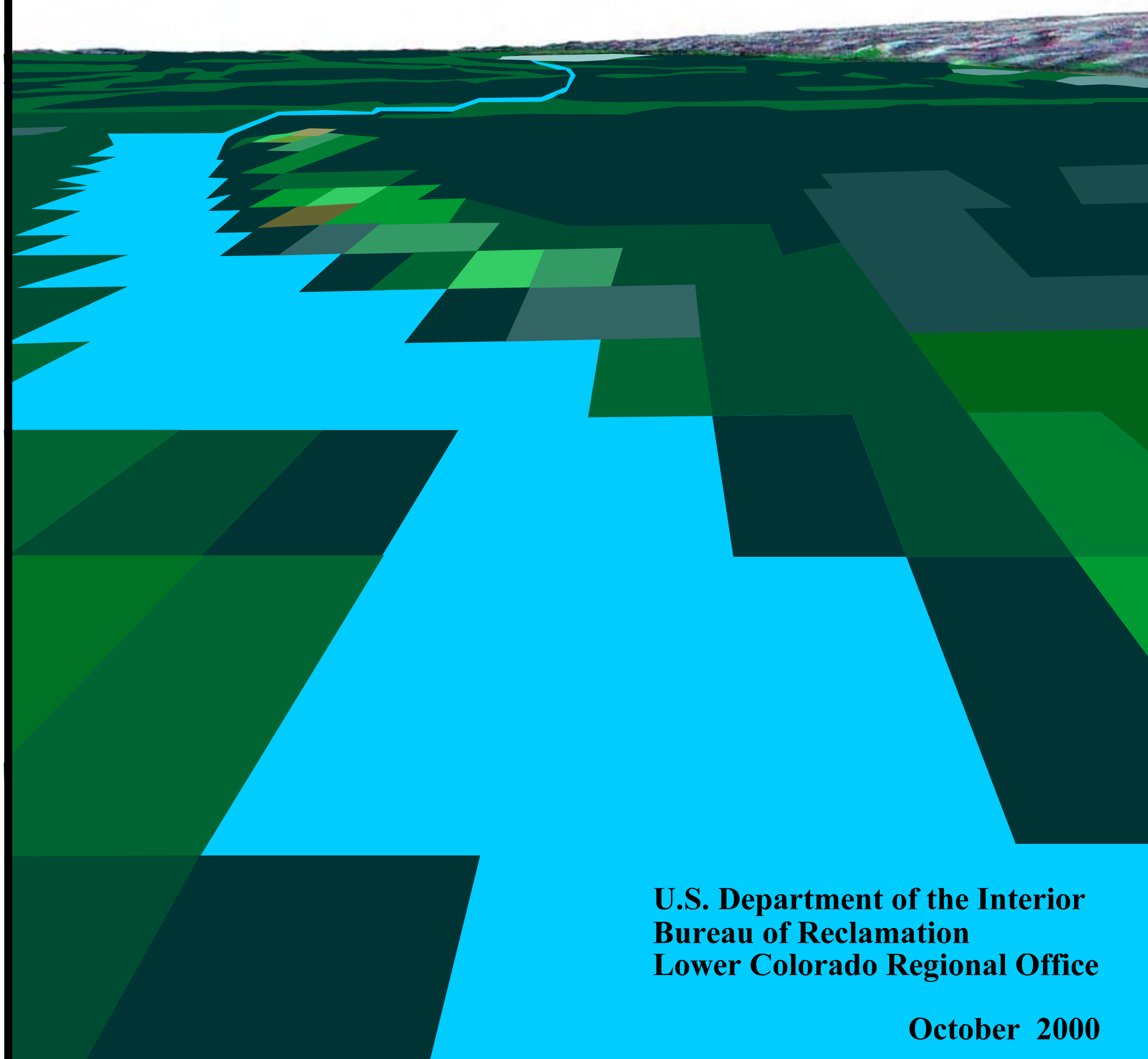
Lower Colorado River Accounting System
Demonstration of Technology

Calendar Year 1999



U.S. Department of the Interior
Bureau of Reclamation
Lower Colorado Regional Office

October 2000

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U.S. Department of the Interior
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Boulder City, Nevada

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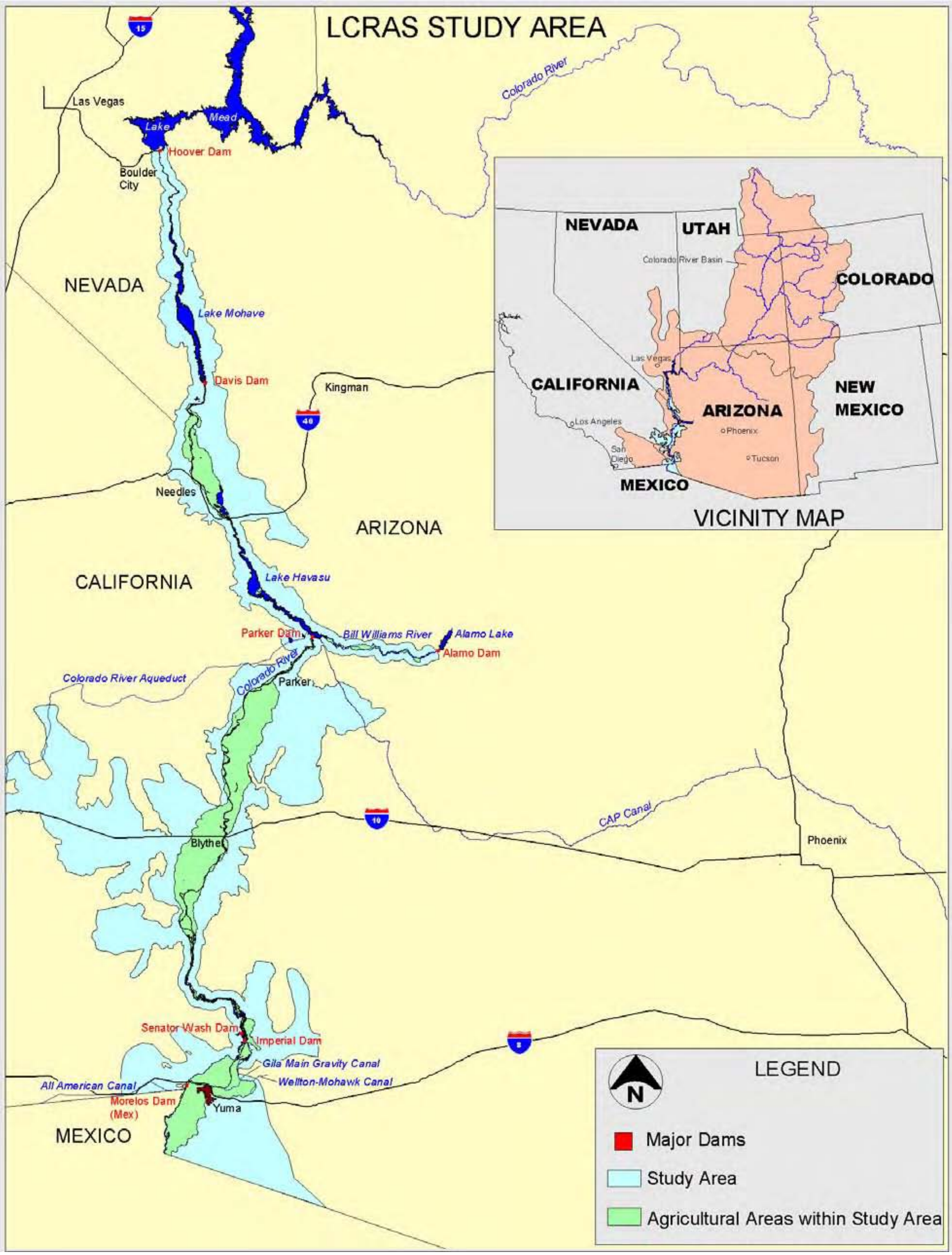
LCRAS STUDY AREA
Las Vegas
Lake Mead
Hoover Dam
Boulder City
Colorado River
NEVADA
Lake Mohave
Davis Dam
Kingman
Needles
ARIZONA
CALIFORNIA
Lake Havasu
Parker Dam
Bill Williams River
Alamo Lake
Alamo Dam
Colorado River Aqueduct
Colorado River
Parker
CAP Canal
Blythe
Phoenix
Senator Wash Dam
Imperial Dam
Gila Main Gravity Canal
Wellton-Mohawk Canal
All American Canal
Morelos Dam (Mex)
Yuma
MEXICO
NEVADA
UTAH
Colorado River Basin
COLORADO
CALIFORNIA
Las Vegas
ARIZONA
NEW MEXICO
Los Angeles
Phoenix
San Diego
Tucson
MEXICO
VICINITY MAP
LEGEND
N
Major Dams
Study Area
Agricultural Areas within Study Area

Executive Summary

The Colorado River is the principal source of water for irrigation and domestic use in Arizona, southern California, and southern Nevada. Accounting for the use and distribution of water from the Colorado River below Lee Ferry (lower Colorado River) is required by the U.S. Supreme Court Decree of 1964 (Supreme Court Decree) in *Arizona* v. *California*. In addition to its other requirements, the Supreme Court Decree dictates that the Secretary of the Interior (Secretary) provide detailed and accurate records of diversions, return flows, and consumptive use of water diverted from the mainstream "stated separately as to each diverter from the mainstream, each point of diversion, and each of the States of Arizona, California, and Nevada." These records are provided annually by the Bureau of Reclamation (Reclamation) in a report entitled "Compilation of Records in Accordance with Article V of the Decree of the Supreme Court of the United States in Arizona v. California Dated March 9, 1964" (decree accounting report). The Lower Colorado River Accounting System Demonstration of Technology reports (LCRAS reports) focus on determining values of consumptive use along the lower Colorado River from Hoover Dam to Mexico.

Reclamation manages the water resources of the lower Colorado River on behalf of the Secretary. In 1984, Reclamation joined with the U.S. Geological Survey (Geological Survey); Arizona, California, and Nevada (lower Basin States); and the Bureau of Indian Affairs to develop a method for estimating and distributing consumptive use to diverters between Hoover Dam and Mexico. This effort was in response to a request from the lower Basin States for Reclamation to account for return flows in addition to those measured as surface flows in calculations of consumptive use. These return flows in addition to those measured as surface flows were referred to as unmeasured return flows, and were not addressed in calculations of consumptive use by the water accounting method then in use.

The agencies agreed to develop the Lower Colorado River Accounting System (LCRAS), which addresses the requirements of the Secretary and responds to the lower Basin States' request to account for measured and unmeasured return flows in calculations of consumptive use. The Geological Survey completed its development of LCRAS in the late 1980s, but a final report was not published until 1996 (Owen-Joyce, Sandra J., and Raymond, Lee H., 1996). In 1990, Reclamation assumed responsibility for continuing development of LCRAS. Reclamation has modified LCRAS and issued reports which document Reclamation's previous applications of LCRAS for calendar years 1995, 1996, 1997, and 1998 (Bureau of Reclamation 1997, 1998a, 1999, and 2000).

This report documents the application of LCRAS to calendar year 1999 and the changes made to the LCRAS method since the report for calendar year 1998 was issued.

The LCRAS Method

LCRAS is an accounting method that estimates and distributes consumptive use to diverters along the lower Colorado River from Hoover Dam to Mexico. LCRAS uses a water balance in which all the inflows, outflows, and water uses are estimated. The residual of the water balance (residual), which reflects the errors of estimate of all the values used in the water balance, is distributed to all the inflows, outflows, and water uses in the water balance in proportion to the product of their magnitude and variance (the square of the standard error of estimate, see Lane, W. L., 1998).

Crop consumptive use and phreatophyte water use are initially estimated as evapotranspiration (ET). The final estimate of crop consumptive use and phreatophyte water use is made by adding a proportion of the residual to the ET. The residual can be either a positive or a negative number; therefore, the final estimates of crop consumptive use and phreatophyte water use can be slightly larger or slightly smaller than the ET.

ET is estimated using

1) reference ET values for short grass calculated from data provided by the California Irrigation Management Information System (CIMIS) and Arizona Meteorological Network (AZMET) stations sited in irrigated areas along the Colorado River from Hoover Dam to Mexico,

2) ET coefficients for each crop and phreatophyte group, and

3) the acreage of each crop and phreatophyte group along the lower Colorado River from Hoover Dam to Mexico developed from the classification of remotely sensed data (image classification).

The initial estimate of domestic consumptive use[1] is generally made by

1) subtracting a measured return flow from a measured diversion, or

2) if a measured return flow is unavailable, by applying a consumptive use factor to a measured diversion (usually 0.6), or

3) if a measured diversion and a measured return flow are unavailable, by applying a per-capita consumptive use factor to a population (0.14 acre-feet per year per capita if turf irrigation is not significant), or

4) in a few cases, domestic uses are initially estimated by a method submitted by the diverter.

The derivation of the domestic use coefficients mentioned above can be found in attachment 3 of the 1996 LCRAS Demonstration of Technology Report (Bureau of Reclamation, 1998a). The final estimate of domestic consumptive use is made by adding a proportion of the residual to the initial estimate. The residual can be either a positive or a negative number; therefore, the final estimate of domestic consumptive use can be either slightly larger or smaller than the initial estimate.

Results

LCRAS calculates crop consumptive use and phreatophyte water use for each irrigator and wildlife refuge, and domestic consumptive use for domestic diverters along the mainstream of the lower Colorado River from Hoover Dam to Mexico. The amount, if any, of the phreatophyte water use within a diverter's boundary that should be added to a diverter's total consumptive use is an open question not addressed by this report.

A description and qualitative assessment of the results for the major components of LCRAS follows.

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[1] Article I.(I) of the Decree of the Supreme Court of the United States in *Arizona* v. *California* dated March 9, 1964 defines domestic use as, "'Domestic use' shall include the use of water for household, stock, municipal, mining, milling, industrial, and other like purposes, but shall exclude the generation of electrical power." While water use on wildlife refuges is also considered a domestic use, phreatophyte water use on wildlife refuges is not included here.

Image Classification Results

The image classification results are excellent using Landsat 5 and Landsat 7 image data to discriminate crop groups. Reliable results are obtained using single-date image classification processes. Post-classification accuracy assessment shows that, overall, the crop groups can be mapped with an average accuracy of greater than 90 percent for each image classification date (four dates in calendar year 1999).

The initial phreatophyte coverage developed by Reclamation for the 1995 LCRAS report (Bureau of Reclamation, 1997) was developed in 1994. Discrimination between phreatophyte groups, while not as well defined as crop groups, was successful. Post-classification accuracy assessment of the original 1994 phreatophyte coverage showed an overall accuracy of 87 percent. Beginning in 1996 and continuing in 1999, the phreatophyte coverage has been updated using remote-sensing-based change detection methodologies. Major changes identified by the remote-sensing-based change detection methodologies, usually from fire or development, are field verified.

Image classification processes are also used to quantify open-water areas. The results for lakes Mohave and Havasu were found to be within 3 percent of the values published in elevation/capacity/area tables in 1995. This comparison is not repeated in this report.

Water Balance Results

Water balance closure is evaluated by comparing the value of the residual to the presumed measurement error of the mainstream inflow to each reach. If the value of the residual is about equal to or less than the presumed measurement error of the mainstream flow entering the reach, distributing the residual is considered optional. The residual is distributed in all reaches for 1999 to show the impact of the residual distribution on the final results. The residuals in 1999 are less than the presumed standard error of estimate in all reaches except the Hoover Dam to Davis Dam reach where the residual equals 2.0% of the flow below Hoover Dam.

The presumed standard errors of estimate for the mainstream flows entering each reach are 1.4 percent for flows below Hoover Dam, 2.2 percent for the flows below Davis and Parker Dams, and 1.5 percent for flow at Imperial Dam.

Table ES-1 presents the values used in the water balance and shows the closure of the water balance for each reach.

Table ES-1 — Water balance summary (not adjusted for residual)
(Units: annual acre-feet unless otherwise noted)

Water balance inflows, outflows, and water uses	Reach				
	Hoover Dam to Davis Dam	Davis Dam to Parker Dam	Parker Dam to Imperial Dam	Imperial Dam to Mexico	Hoover Dam to Mexico
Flow at the upstream boundary (Q_{us})	11,033,000	11,070,300	8,353,300	7,205,263	11,033,000
Flow at the downstream boundary (Q_{ds})	11,070,300	8,353,300	7,205,263	2,976,626	2,976,626
Residual (Q_{res})	-223,980	-169,837	35,137	-2,522	-361,202
Residual as a percentage of flow at the upstream boundary (Q_{us})	-2.03%	-1.53%	0.42%	-0.04%	-3.27%
Difference between flow at the upstream and downstream boundaries (Q_{dif})	-37,300	2,717,000	1,148,037	4,228,637	8,056,374
Measured Tributary inflow (Trm)	0	8,357	0	7,017	15,374
Unmeasured Tributary inflow (Trum)	6,480	36,290	33,750	3,000	79,520
Exported flow (Q_{ex})	0	2,600,232	0	3,768,997	6,369,229
Evaporation (E)	137,451	113,223	60,963	5,330	316,967
Domestic consumptive use (CU_d)	710	33,318	5,287	28,618	67,933
Crop evapotranspiration (ET_{crop})	0	75,412	734,702	371,081	1,181,195
Phreatophyte evapotranspiration (ET_{pht})	899	170,199	347,576	67,150	585,824
Change in reservoir storage (ΔS_r)	54,100	-60,900	-1,878	0	-8,678
Change in aquifer storage (ΔS_a)	0	0	0	0	0

Consumptive Use Results

Table ES-2 compares state totals of crop and domestic consumptive use, and phreatophyte water use calculated by LCRAS with consumptive use as reported in the Decree Accounting Report for calendar year 1999.

Table ES-2.— LCRAS Crop and Domestic Consumptive Use, and Phreatophyte Water Use, and Consumptive Use from Decree Accounting (Units: annual acre-feet)

LCRAS			Decree Accounting	
Diverter name	Phreatophyte water use	Crop, domestic, and export consumptive use	Consumptive use	Diverter name
Nevada				
Uses above Hoover Dam (from 1999 Decree Accounting Report)		271,615	271,615	Uses above Hoover Dam
Uses below Hoover Dam	19,819	17,070	19,521	Uses below Hoover Dam
			1,615	Unmeasured return flow credit
Nevada Total	19,819	288,685	289,521	Nevada Total
California				
			5,193,983	Sum of individual diverters
			87,203	Unmeasured return flow credit
California Total	169,011	5,098,486	5,106,780	California Total
Arizona				
Subtotal (below Hoover Dam, less Wellton-Mohawk IDD)	397,093	2,207,504	2,535,314	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (1999 Decree Accounting Report)		158	158	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (1999 Decree Accounting Report)		266,730	266,730	Wellton-Mohawk IDD
			74,223	Pumped from South Gila wells (drainage pump outlet channels [DPOCs]).
			148,258	Unmeasured return flow credit
Arizona Total	397,093	2,474,392	2,579,721	Arizona Total
Lower Basin Total				
Total Lower Basin Use	585,923	7,861,563	7,976,022	Total Lower Basin Use

Table ES-3 shows the final adjusted values of all the water balance components after the residual has been distributed and after the flows at the major dams and the flow to Mexico have been adjusted as described in Lane, W. L., 1998.

Table ES-3.— Final distributed and adjusted water balance values
(Units: annual acre-feet)

Water balance inflows, outflows, and water uses	Reach				
	Hoover Dam to Davis Dam	Davis Dam to Parker Dam	Parker Dam to Imperial Dam	Imperial Dam to Mexico	Hoover Dam to Mexico
Flow at the upstream boundary (Q_{us})	11,297,618	11,111,151	8,229,701	7,115,418	11,297,618
Flow at the downstream boundary (Q_{ds})	11,111,151	8,229,701	7,115,418	2,884,600	2,884,600
Residual (Q_{res})	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	186,467	2,881,450	1,114,283	4,230,818	8,413,018
Measured Tributary inflow (Trm)	0	8,366	0	7,017	15,383
Unmeasured Tributary inflow (Trum)	6,490	36,499	33,674	3,000	79,663
Exported flow (Q_{ex})	0	2,595,454	0	3,768,730	6,364,184
Evaporation (E)	137,324	113,166	60,970	5,330	316,790
Domestic consumptive use (CU_d)	710	33,317	5,287	28,618	67,932
Crop consumptive use (CU_{crop})	0	75,387	735,704	371,025	1,182,116
Phreatophyte water use (CU_{pht})	899	170,071	347,800	67,148	585,918
Change in reservoir storage (ΔS_r)	54,091	-60,903	-1,878	0	-8,690
Change in aquifer storage (ΔS_a)	-67	-177	74	-16	-186

Continued Development of LCRAS

Reclamation uses the best and most complete data sources and analytic techniques available to produce the results presented in this LCRAS Demonstration of Technology Report. The methods used in LCRAS are expected to continually evolve as new information and techniques become available and potential improvements are identified through reviews and experience. An outstanding question that must be resolved is the appropriate crediting of phreatophyte water use, if any, to diverter consumptive use.

Conclusions

Reclamation is directed to manage the limited resources of the lower Colorado River in a manner that is equitable and consistent for all diverters. To achieve this directive, Reclamation has taken the lead in the development of LCRAS to improve consumptive use calculations for Decree Accounting using state-of-the-art technologies.

LCRAS is a water accounting method that

1) Uses the best technology available,

2) Fulfills the Supreme Court Decree mandate to account for the consumptive use of water, and

3) Provides consistent methods of determining consumptive use for all diverters in along the lower Colorado River from Hoover Dam to Mexico.

Reclamation is currently participating in a public process to provide interested parties an opportunity to learn more about the method and provide input to improve it. Reclamation is interested in working with the State water agencies, Federal agencies, Tribes, and diverters to make the method as consistent, accurate, and understandable as possible.

The accounting of water use in accordance with Article V of the Supreme Court Decree will proceed over the next few years as follows:

1. Reclamation will use the current Decree Accounting method to develop the official Decree Accounting Report until LCRAS is implemented.

2. Reclamation will calculate consumptive use using the LCRAS method in parallel with the Decree Accounting Report for calendar years 2000 and 2001 and will continue to compare the results of the two methods.

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Chapter 1

Introduction

The Colorado River, which has its headwaters as far north as Wyoming, discharges into the Gulf of California in Mexico (frontispiece location map). The Colorado River basin includes about 246,700 square miles in the United States. The Colorado River basin is divided into the upper Colorado River basin and the lower Colorado River basin at Lee Ferry. The lower Colorado River basin includes parts of Arizona, California, Nevada, New Mexico, and Utah.

The Colorado River is the source of water for a large distribution system that provides water for irrigation and to densely populated areas in California, Arizona, and Nevada (the lower Basin States). Water is exported to parts of six counties in the coastal plain of southern California, including the cities of Los Angeles and San Diego, and to Phoenix, Arizona. However, the dominant influence on the distribution of water along the Colorado River is the diversion for irrigation.

In 1964, the U.S. Supreme Court decreed that a water use report for the lower Colorado River basin be created at least annually. Reclamation fulfills this decree through the publication of the report entitled "Compilation of Records in Accordance with Article V of the Decree of the Supreme Court of the United States in Arizona v. California Dated March 9, 1964" (decree accounting report). The most critical and controversial portion of the decree accounting report is the calculation of consumptive use. Consumptive use is defined in Article I.(A) of the Decree of the Supreme Court of the United States in *Arizona* v. *California* dated March 9, 1964 (Supreme Court decree) which states,

> "'Consumptive use' means diversions from the stream less such return flow thereto as is available for consumptive use in the United States or in satisfaction of the Mexican treaty obligation."

Since 1964 consumptive use has primarily been calculated as measured diversions from the stream less measured return flows back to the stream. In 1969, the lower Basin States asked Reclamation to develop a method that would consider all return flows, measured and unmeasured, for each diverter in a consistent and equitable manner. The initial response to this request was to establish the task force on unmeasured return flow in 1970. After extensive discussion with the lower Basin States and trials of other methods, the task force chose to develop and apply a water balance approach to the lower Colorado River in 1984. The proposal to develop and study the method was accepted by all the members of the task force, and the method was named the Lower Colorado River Accounting System (LCRAS). A more detailed history of events that led to the development of LCRAS can be found in Bureau of Reclamation, 1997.

This Lower Colorado River Accounting System Demonstration of Technology Report for calendar year 1999 documents the processes and data used to apply the LCRAS method to determine consumptive use along the lower Colorado River from Hoover Dam to Mexico for calendar year 1999.

The LCRAS Method

LCRAS is an accounting method that estimates and distributes consumptive use to diverters along the lower Colorado River from Hoover Dam to Mexico. LCRAS uses a water balance in which all the inflows, outflows, and water uses are estimated. The residual of the water balance (residual), which reflects the errors of estimate of all the values used in the water balance, is distributed to all the inflows, outflows, and water uses in the water balance in proportion to the product of their magnitude and variance (the square of the standard error of estimate, see Lane, W. L., 1998).

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ET is estimated using

1) reference ET values for short grass calculated from data provided by the California Irrigation Management Information System (CIMIS) and Arizona Meteorological Network (AZMET) stations sited in irrigated areas along the Colorado River,

2) ET coefficients for each crop and phreatophyte group, and

3) the acreage of each crop and phreatophyte group along the lower Colorado River from Hoover Dam to Mexico developed from the classification of remotely sensed data (image classification) and field surveys.

The initial estimate of domestic consumptive use is generally made by

1) subtracting a measured return flow from a measured diversion, or

2) if a measured return flow is unavailable by applying a consumptive use factor to a measured diversion (usually 0.6), or

3) if a measured diversion and a measured return flow are unavailable by applying a per-capita consumptive-use factor to a population (0.14 acre-feet per year per capita if turf irrigation is not significant), or

4) in a few cases, domestic uses are initially estimated by a method submitted by the diverter.

The derivation of the domestic use coefficients mentioned above can be found in attachment 3 of the 1996 LCRAS Demonstration of Technology Report (Bureau of Reclamation, 1998a). The final estimate of domestic consumptive use is made by adding a portion of the residual to the initial estimate. The residual can be either a positive or a negative number; therefore, the final estimate of domestic consumptive use can be either slightly larger or smaller than the initial estimate.

Comparison of LCRAS with Decree Accounting Reports

The table in attachment 3, described in chapter 2, presents a comparison between the values of consumptive use compiled for the decree accounting report and those calculated by LCRAS for all diverters. A description of the conceptual differences in the way consumptive use is compiled for the decree accounting report and calculated by LCRAS can be found in the 1995 and 1996 LCRAS Demonstration of Technology Reports (Bureau of Reclamation 1997 and Bureau of Reclamation 1998a).

Chapter 2

LCRAS in Calendar Year 1999

Reclamation's activities for the 1999 LCRAS Demonstration of Technology began with scheduled ground reference data collection to record crop groups and field conditions. Reclamation purchased satellite imagery concurrent to ground reference data collection and processed it using standard image classification methods, incorporating recent improvements to procedures developed in previous years. Reclamation also finalized the delineation of district boundaries that would be used in 1999.

Reclamation acquired standardized reference ET values calculated using the Standardized Reference Evapotranspiration Equation (standardized equation) recommended by the Task Committee on Standardization of Reference Evapotranspiration empaneled by the American Society of Civil Engineers, Evapotranspiration in Irrigation and Hydrology Committee. Reclamation then developed area-specific reference ET values for the Yuma Area, and the Palo Verde and Parker Valleys by averaging the standardized reference ET values calculated from data collected by the CIMIS and AZMET stations sited in those areas. Reclamation compiled domestic uses and changes in reservoir storage during 1999 for Lakes Mohave and Havasu, and Senator Wash Reservoir. Reclamation also compiled and analyzed the records of flow at major dams and major diversion and delivery points.

Analysis of 1999 data was performed as the data became available throughout the year. The acreage of each crop group grown, each phreatophyte group in the flood plain, and the number of acres of open water exposed to evaporation by reservoirs and in the river channel between Hoover Dam and Mexico were developed from image classification, field survey data, and GIS processes. Reclamation combined this information with the final diverter boundaries for 1999 and calculated the number of acres occupied by each crop and phreatophyte group within the boundary of each irrigator, wildlife refuge, or other reservation of land along the river.

With the information described above, Reclamation calculated the ET of each crop and phreatophyte group within the boundaries of each irrigator, wildlife refuge, or other reservation of land, and calculated the evaporation from open water required for the water balance.

Reclamation finalized the form of the water balance that would be used in 1999, then calculated and proportionally distributed the residual to each water balance inflow, outflow, and water use producing final values of crop and domestic consumptive use, final values of phreatophyte water use, and final values of water exported from the system.

The paragraphs below describe each of these activities and provide an assessment of their success and relative importance to the overall success of LCRAS for calendar year 1999.

Remote Sensing and Geographic Information Systems

Remote sensing, field survey, and GIS processes are used to identify and map crop and phreatophyte groups, and open water along the lower Colorado River from Hoover Dam to Mexico. All satellite data and GIS coverages are projected into Universal Transverse Mercator (UTM), Zone 11, North American Datum 1927.

The flood plain boundary (shown in exhibits 2 through 8) used in 1999 is the same as the flood plain boundary used in 1997. The flood plain boundary is used to identify phreatophyte areas that should be included in the image classification process. The cropped areas included in this analysis are located within the flood plain boundary along the mainstream of the lower Colorado River from Hoover Dam to Mexico and upon the Palo Verde and Yuma Mesas. These areas are used to calculate the ET for each diverter and evaporation for each reach. The domestic diverter boundaries are not part of this GIS coverage. They, and their service areas, will be incorporated in the future.

Remote sensing involves the process of using satellite imagery to identify and quantify the areas of crop, fallow, and phreatophyte groups, and open water along the lower Colorado River from Hoover Dam to Mexico. Field surveys are also used to obtain information for crop and phreatophyte cover that does not lend itself as well to being identified through the use of remote sensing. The location and acreage quantification of orchards, for example, are determined from field and airborne surveys.

GIS database management tools are used to process and store large amounts of spatial and informational data, including ground reference data and data derived from the processing of digital satellite imagery (raster data). GIS database management tools are used to calculate, summarize, and generate reports defining the area of each crop and phreatophyte group for each diverter and open water along the lower Colorado River from Hoover Dam to Mexico.

Satellite Image Processing

Remote sensing analysis is performed on multispectral image data to classify and map crop and phreatophyte groups, and open water along the mainstream of the lower Colorado River from Hoover Dam to Mexico. Crop, phreatophyte, and open-water classification processes have been developed for multispectral image data acquired by Thematic Mapper (TM) sensors mounted onboard the Landsat 5 and Landsat 7 satellites. These sensors detect and record reflected and emitted energy from the Earth's surface in seven bands within the electromagnetic spectrum. At any given instant, it focuses on only one small area of the Earth's surface, which corresponds to a single picture element or pixel. A pixel is the smallest unit composing a satellite image. The pixel size or spatial resolution of the Landsat TM data used for image analysis is resampled to 30 meters. TM image data were acquired for analysis during calendar year 1999 on the dates shown in table 1 below. Path and row designations in table 1 refer to image locations based on the World Reference System[2]

Table 1 — TM Image path-row designations and acquisition dates

Path 38, rows 36 and 37	January 26, 1999	Path 39, row 36	February 2, 1999
Path 38, rows 36 and 37	May 2, 1999	Path 39, row 36	May 25, 1999
Path 38, rows 36 and 37	July 21, 1999	Path 39, row 36	August 13, 1999
Path 38, rows 36 and 37	December 4, 1999		

Image data are selected which adequately cover the study area, are cloud-free, and which capture the variation in crop planting practices during the year.

[2] Landsat 5 and 7 images are catalogued according to their location within the World Reference System (WRS). In this system, images can be uniquely defined by specifying a path, a row, and a date. The WRS for Landsat has 233 paths corresponding to the number of orbits required to cover the earth every 16 days. The orbits of the Landsat 5 and Landsat 7 satellites are offset so any site on the Earth can be revisited every 8 days. Paths are numbered 001 to 233, east to west. The rows are numbered so that row 60 coincides with the equator on an orbit's descending node.

Ground Reference Data Collection

Correct identification and mapping of crop and phreatophyte groups using remote sensing methodologies requires a detailed understanding of the spectral characteristics and vegetation coverage of representative sites throughout the study area. TM image data contain digital values that represent a unique spectral reflectance of land-cover groups on the ground. These digital values can be analyzed to generate spectral statistics (signatures) that represent specific land cover groups on the Earth's surface. Ground reference data is required to correlate unique relationships between the spectral signatures derived from the image data and crop and phreatophyte groups on the ground.

Ground reference data are collected for approximately 1,900 of the 13,800 irrigated fields in the study area. This represents about 15 percent of the total irrigated area. From 65 to 70 percent of the ground reference data are used in image classification, and the remaining 30 to 35 percent are used to assess the accuracy of the crop and phreatophyte classifications. Selections of ground reference sites are based on the distribution of crop groups in each major irrigated area along the mainstream of the lower Colorado River from Hoover Dam to Mexico. Irrigated fields are selected randomly from a GIS database of the irrigated fields. Additional fields are added to the random sample where necessary to ensure all major crop groups are represented to provide a statistically valid data set for image classification procedures. Ground reference data are collected and satellite imagery is purchased four times a year. Ground reference data are collected at times which coincide with the acquisition of the satellite imagery. The variability in planting and harvesting times for each crop group is a critical factor in the selection of optimum image dates.

Table 2 presents the crop groups sampled. Groups such as Other Vegetables, Small Grains, and Crucifers are general group names that consist of a variety of specific crops.

Table 2 — Crop groups

Alfalfa	Cotton	Small Grain	Field Grain	Lettuce	Melons
Bermuda/Rye Grass	Citrus	Tomatoes	Sudan	Legume/Solanum Vegetables	
Crucifers	Fallow	Dates	Safflower	Deciduous Orchards	Grapes
Small Vegetables	Root Vegetables	Perennial Vegetables		Sugar Beets	

The phreatophytes are divided into the groups shown in table 3.

Table 3 — Phreatophyte groups

Group Name	Description
Marsh	40% cattail, bulrush, and phragmites
Barren	#10% vegetation
Sc_low	11-60% salt cedar and #25% arrowweed
Sc_high	61-100% salt cedar and #25% arrowweed
Sc/ms	11-60% salt cedar, 11-60% mesquite, and #25% arrowweed
Sc/aw	#75% salt cedar and $25% arrowweed
Sc/ms/aw	15-45% salt cedar, 15-45% mesquite, and 20-40% arrowweed
Ms-low	11-60% screwbean and honey mesquite, and #25% arrowweed
Ms-high	61-100% screwbean and honey mesquite, and #25% arrowweed
Ms/aw	21-60% mesquite, 31-60% arrowweed, and #20% salt cedar
Aw	51-100% arrowweed and #10% any trees
Cw	61-100% cottonwood and willow
Low veg	™10% and #30% any phreatophyte vegetation

Delineation of Crop and Phreatophyte Groups, and Open-Water Areas

A detailed description of the image processing and GIS processes used for this report can be found in attachment 4.

Delineation of Cropped Areas

A relational database (GIS coverage) has been developed that delineates the field borders in all irrigated areas along the mainstream of the lower Colorado River from Hoover Dam to Mexico. All the ground reference data collected for image classification are linked to this field-border database. These borders were originally derived from 10-meter Systemme Pour l'Observation de la Terre (SPOT) image data acquired in June and August of 1992. All field borders were digitized on screen using the SPOT data as a backdrop. Changes in field borders, noted during the acquisition of ground reference data throughout the year, have served as a data source for updates to the field-border database since 1995. This process continued in 1999. Reclamation is now using 5-meter Indian Remote Sensing satellite imagery on an annual basis to update field borders in areas where ground reference data show significant changes in field border locations. Field borders will continue to be routinely updated using these two practices.

All areas along the mainstream of the lower Colorado River from Hoover Dam to Mexico that are known by Reclamation to divert or pump water are included in this analysis and shown in exhibits 1 through 8. Exhibit 9 is an example of digitized field borders, and exhibit 10 shows an overview of the diverter boundaries.

Excellent results are obtained for crop groups listed in table 2 using a single-date image classification process several times per year. Post-classification accuracy assessment shows that, overall, the crop groups can be mapped with an average accuracy of approximately 93 percent.

Delineation of Phreatophyte Areas

Phreatophyte areas are updated by delineating areas of spectral change using image-to-image comparisons (change detection methods) of Landsat TM imagery. Areas of spectral change are field-checked to confirm that the spectral change is actually due to land-cover change. Areas of land-cover change are remapped and used to update the phreatophyte database. Image dates of May 1998 and May 1999 were used to perform the update for this report.

Delineation of Open Water

Landsat TM imagery acquired for July 21 and August 13, 1999 were overlaid with the open water classification generated for the 1998 LCRAS report to delineate areas of open water for 1999. This was done to compare and identify changes in water surface area between 1998 and 1999. The image interpretation showed no significant changes in the water surface between 1998 and 1999. Therefore, the open water acreage used in the 1998 was applied to 1999.

1998 open water area was quantified using image classification processes. A single-image classification process was performed on TM images acquired July 25, 1998 (for Hoover Dam to Davis Dam) and July 18, 1998 (for Davis Dam to Mexico) for this purpose.

The area of open water within reservoirs was quantified by image classification processes in 1995 and compared with the equivalent values published in elevation/capacity/area tables. This comparison showed the area of open water derived from classified images were within 3 percent of values published in elevation/capacity/area tables. This comparison is not repeated for this report.

Water Balance

The water balance for 1999 uses the same equation that was used for 1998 water balance. The water balance equation is shown below:

$$\mathbf{Q_{res} = Q_{dif} + T_{rm} + T_{rum} - Q_{ex} - E - CU_d - ET_{pht} - ET_{crop} - \Delta S_r - \Delta S_a}$$

Where:

Q_{res}	=	The residual
Q_{dif}	=	The difference between Q_{us} and Q_{ds} (Q_{us}-Q_{ds})
Q_{us}	=	The flow entering the reach at the upstream boundary
Q_{ds}	=	The flow exiting the reach at the downstream boundary
T_{rm}	=	Measured tributary inflow to the reach
T_{rum}	=	Unmeasured tributary inflow to the reach
Q_{ex}	=	Water exported out of the basin
E	=	Open-water evaporation
CU_d	=	Domestic, municipal, and industrial use
ET_{pht}	=	The total estimated phreatophyte ET
ET_{crop}	=	The total estimated crop ET
ΔS_r	=	The change in reservoir storage
ΔS_a	=	The change in storage in the alluvial aquifer

The water balance is applied to four reaches along the lower Colorado River— Hoover Dam to Davis Dam, Davis Dam to Parker Dam, Parker Dam to Imperial Dam, and Imperial Dam to Mexico.[3]

The data used in this report are the most accurate and complete data available when the calculations were performed. Data are gathered from Reclamation records and reports, and reports provided to Reclamation

[3] The flow at the northerly international boundary with Mexico, the southerly international land boundary near San Luis, and other flows that enter Mexico below Morelos Dam are included in this reach.

by others. The following sections of this report discuss the sources of data, calculations made with the data, and issues associated with the data.

Flow Data

Flow data include flows at upstream and downstream reach boundaries, exported water, measured tributary inflows, and changes in reservoir storage. Flow data are provided by the Geological Survey, Reclamation, the International Boundary and Water Commission (IBWC), Metropolitan Water District of Southern California (MWD), and the Central Arizona Project (CAP).

Mainstream Flow (Q_{us}, Q_{ds})

The majority of mainstream flows used by LCRAS are reported by the Geological Survey[4]. Some mainstream flows are provided by the diverter and some by the IBWC. A listing of the gages used by LCRAS and the reporting agency can be found in attachment 2.

Underflow To Mexico

The downstream flow (Q_{ds}) of the Imperial Dam to Mexico reach includes an estimate of the ground-water flow (underflow) that crosses the international boundaries defined by the Limitrophe section of the Colorado River between the northerly and southerly international boundaries with Mexico (SIB), and the southerly international boundary with Mexico. The fraction of the underflow that crosses into Mexico that results from the application of Colorado River to lands within Arizona must be added to the crop and consumptive use of the diverters who applied the water because the underflow does not return to the Colorado River and become available for other users in the United States or for satisfaction of the Mexican water treaty.

The fractions of the underflow that crosses the southerly international boundary which are added to individual diverters crop and domestic consumptive use are documented in attachment 5. The fractions of the underflow that crosses the Limitrophe section are based upon the number of acres irrigated along and

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[4] The Geological Survey provided flow information in *U.S. Supreme Court Decree Stations of the Lower Colorado River, Diversions and Return Flows Data for Calendar Year 1999.*

near the Limitrophe section. The irrigators and their estimated contributions to the underflow across the Limitrophe section can be found in the footnotes of attachment 3.

The initial estimate of underflow to Mexico is 20,000 acre-feet across the Limitrophe section and 62,443 acre-feet across SIB for a total of 82,443 acre-feet. After distribution of the residual in the Imperial Dam to Mexico reach, the final estimate of underflow to Mexico dropped to 17,400 acre-feet across the Limitrophe section and 50,900 acre-feet across SIB, for a total of 68,300 acre-feet (rounded to the nearest 100 acre-feet). Of this total, all of the 17,400 acre-feet that crosses the Limitrophe section and about 83% of the 50,900 acre-feet that crosses SIB (or about 42,200 acre-feet) is added to the crop and domestic consumptive use of irrigators in the Yuma, Arizona area who's operations contribute to the underflow to Mexico.

Export Flow (Q_{ex})

Flows into the Colorado River Aqueduct and the CAP are reported by MWD and Central Arizona Water Conservation District, respectively, from their own measurements. The initial estimate of net export by MWD is made by subtracting return flows from the two regulating reservoirs on the Colorado River Aqueduct from the diversions from Lake Havasu as reported by the Decree Accounting. The initial estimate of export by the CAP is the measured diversion from Lake Havasu.

Diversions to the Wellton-Mohawk Irrigation and Drainage District (Wellton-Mohawk) are measured in the Wellton-Mohawk Canal by Reclamation, using open-channel acoustic velocity meters (AVMs). Flows to the Imperial Irrigation District (IID) and the Coachella Valley Water District (Coachella) are measured in the All-American Canal below Pilot Knob by IID. The data measured by IID are reported by the Geological Survey. The initial estimate of export for these users is the measured values.

In 1999, 3,390 acre-feet of the water pumped by the Drainage Pump Outlet Channels (DPOC's) near Yuma, Arizona, was discharged into the Main Outlet Drain (MOD) or Main Outlet Drain Extension (MODE). This water was bypassed to the Santa Clara Slough and not returned to the Colorado River. The water balance considers the water pumped by the DPOC's and discharged to the MODE/MOD to be exported from the Colorado River system.

The initial estimates, final estimates after the distribution of the residual, and percentage change between the values for exports by MWD, CAP, Wellton-Mohawk, IID, and Coachella can be found in table 4 below. The presumed standard error of estimate for export flows is between 1 and 2 percent.

Table 4 — Changes in export values after residual distribution
(Units: annual acre-feet)

Export	Initial Estimate	Final Estimate	Change in Acre-Feet	Change in Percent
MWD	1,212,067	1,209,840	-2,227	-0.10%
CAP	1,388,165	1,385,614	-2,551	-0.18%
Wellton-Mohawk	347,407	347,382	-25	-0.01%
IID & Coachella	3,418,200	3,417,985	-215	-0.01%

The sum of the final estimates of export flows accounts for about 83 percent of the consumptive use (crop, domestic, and export) along the lower Colorado River from Hoover Dam to Mexico.

Measured Tributary Inflow Data (T_{rm})

The flows on two tributaries to the lower Colorado River below Hoover Dam are measured—the Gila River in southwestern Arizona and the Bill Williams River in west-central Arizona. Gila River flows are measured near Dome and Bill Williams River flows are measured below Alamo Dam. Both measurements are reported by the Geological Survey.

Not all of the flow measured below Alamo Dam reaches the Colorado River at Lake Havasu. There are water uses and large established stands of phreatophytes between Alamo Dam and Lake Havasu. The inflow to the Colorado River at Lake Havasu from the Bill Williams River is derived by subtracting evaporation and vegetative water uses[5] from the sum of the flow below Alamo Dam and estimates of unmeasured inflow to the Bill Williams River.

[5] Evaporation and vegetative water uses on the Bill Williams River are calculated using the same remote sensing and reference ET methods used on the Colorado River mainstream. Water uses on the Bill Williams River below Alamo Dam are not considered Colorado River water uses because no water is diverted from the Colorado River to support these uses.

The boundary of Lake Havasu is defined by the extent of the accounting surface (Wilson, Richard P. and Owen-Joyce, Sandra J., 1994) upstream from Lake Havasu into the Bill Williams River. This represents the maximum influence Lake Havasu can have on the Bill Williams River in a normal operating year based upon the areal extent of the contiguous alluvium upstream into the Bill Williams River at the normal high annual operating level of Lake Havasu. The Bill Williams River is shown on exhibit 11.

The sum of the measured tributary inflow to the lower Colorado River below Hoover Dam was 15,374 acre-feet in 1999, or about one tenth of one percent of the flow below Hoover Dam. After distribution of residual from the water balance, the final value of measured tributary inflow increased to 15,383 acre-feet, a change of less than one tenth of one percent. Measured tributary inflow values can be found in attachment 2.

Unmeasured Tributary Inflow Data (T_{rum})

Unmeasured tributary inflow values are taken directly from Owen-Joyce, Sandra J., 1987, with the exception of the unmeasured groundwater inflow from Sacramento Wash. The value for inflow from Sacramento Wash is taken from an investigation by the Arizona Department of Water Resources. The flow values presented by Owen-Joyce, Sandra J., 1987 are primarily a compilation of existing studies, based upon mean annual precipitation, available at the time of publication.

The sum of the unmeasured tributary flows used in this report is 79,520 acre-feet.

After distribution of the residual from the water balance, the final value of unmeasured tributary inflow increased to 79,713 acre-feet, a change of less than one quarter of one percent. Unmeasured tributary flow values can be found in attachment 2.

Evapotranspiration

The LCRAS method calculates ET for all crop and phreatophyte groups within the flood plain and on the Palo Verde and Yuma Mesas as an initial estimate of crop consumptive use and phreatophyte water use.

ET calculations require the following:

1) Reference ET
2) ET coefficients for each crop and phreatophyte group
3) Number of acres covered by each crop and phreatophyte group
4) Effective precipitation (used to develop crop ET only).

Reference ET

For this report, reference ET values for the three CIMIS and five AZMET automated weather station sites along the lower Colorado River from Hoover Dam to Mexico were calculated using the standardized equation derived from the ASCE Penman Monteith equation[6] (standardized equation). The standardized equation is derived by simplifying several terms within the ASCE Penman Monteith equation, and is used to calculate evapotranspiration for standardized short or tall reference crops. A more complete description of the standardized equation and the introduction of it's use in LCRAS can be found in Attachment 6.

The use of the standardized equation eliminates the portion of disparity in reference ET values reported by the CIMIS and AZMET networks which results from each network's use of slightly different equations to calculate reference ET. This improvement leaves only site conditions, equipment calibration, and micro-climatic differences between station sites as sources of site to site variations in reference ET values. A detailed account of the disparity in the reference ET values reported by the CIMIS and AZMET networks, and Reclamation's cooperative efforts with the CIMIS and AZMET networks to resolve the issue is presented in attachment 6.

For this report, Reclamation developed area-specific reference ET values for the Yuma Area, and the Parker and Palo Verde Valleys, by averaging the reference ET values calculated using the standardized equation and data collected by the CIMIS and AZMET stations sited within the areas mentioned previously.

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[6] Dr. Paul Brown of the Arizona Meteorological Network applied the standardized equation to calculated the reference ET values used in this report. Dr. Brown is a member of the Task Committee on Standardization of Reference Evapotranspiration.

The reference ET and precipitation values used to develop ET estimates for this report are shown on figure 1.

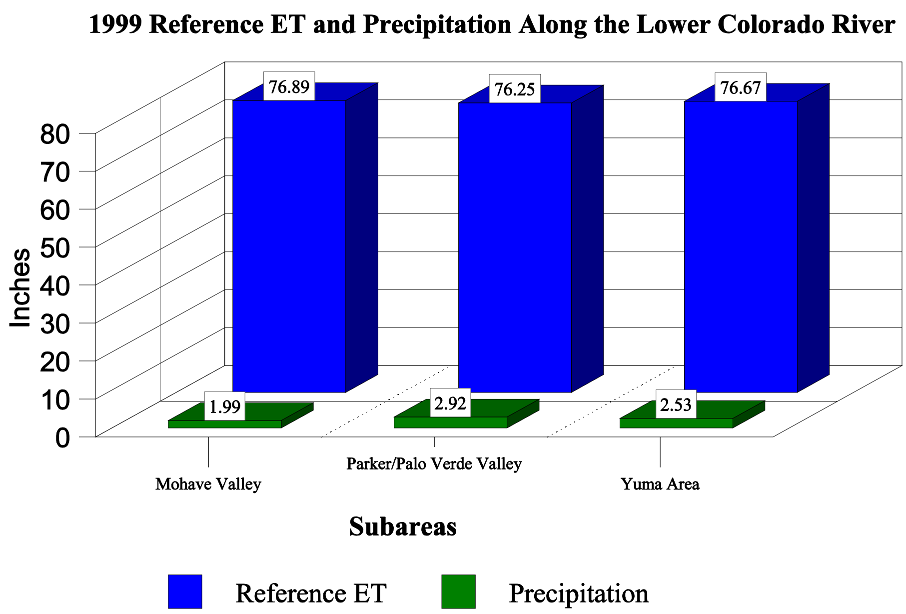


Figure 1. — Reference ET and Precipitation Values by Subarea Along the Lower Colorado River.

ET Coefficients for Crop and Phreatophyte Groups

The crop groups used in previous LCRAS Demonstration of Technology reports have been modified for use in this report to more accurately reflect the increasing variety of crops found in the Colorado River Valley, and to more accurately group crops with like growing seasons and water use. Six additional crop groups; Field Grain, Legume/Solanum Vegetables, Deciduous Orchards, Root Vegetables, Perennial Vegetables, and Sugar Beets have been added to the crop groups used in previous reports. Several crops previously grouped into the Small Vegetables group have been regrouped into the groups mentioned above.

New ET coefficients were developed for the new crop groups. The ET coefficients for the crop groups that have not changed remain the same as used in 1998[7]. A table showing the changes made to the crop groups can be found at the end of Attachment 6. The rationale used to develop crop groups for use by the LCRAS program can be found in Jensen, 1998.

Number of Acres Covered by Each Crop and Phreatophyte Group

Reclamation developed the acreage covered by each crop and phreatophyte group by applying the analysis described above in "Delineation of Crop, Phreatophyte, and Open-Water Areas."

Effective Precipitation

LCRAS calculates effective precipitation as the product of recorded precipitation and an effective precipitation coefficient. Precipitation is recorded by precipitation gauges at CIMIS and AZMET stations sited along the lower Colorado River as well as precipitation gages operated by the National Weather Service (NWS). The effective precipitation coefficients used for this report are documented in Jensen, Marvin E., 1993.

The equation used to calculate effective precipitation is:

$$\text{Effective Precipitation} = \text{Daily Precipitation} \times \text{Monthly Effective Precipitation Coefficient}$$

The depth of precipitation that fell over the lower Colorado River Valley in 1999 ranged from 1.79 inches, measured by the Bullhead City NWS station, to 3.51 inches measured by the Yuma Valley AZMET station.

[7] Daily ET coefficients were developed specifically for the LCRAS program (Jensen, Marvin E., 1998).

Crop ET (ET_{crop})

The first step in calculating the water use by crops within a diverter's boundary is to calculate an ET rate for each crop group. Average daily reference ET values (inches) are multiplied by daily ET coefficients unique to each crop group (dimensionless), to develop the daily ET rate for each crop group. The impact of rainfall on crop water use is considered by subtracting effective precipitation (inches) from the ET rate for each crop group to yield a net ET rate (inches).

In parallel with the calculations of ET rate, the number of acres covered by each crop group within the diverter boundary must be calculated. The number of acres covered by each crop group is calculated using remotely sensed data and field surveys as described above in "Delineation of Crop, Phreatophyte, and Open-Water Areas."

Monthly ET for each diverter (in acre-feet) is calculated by summing the daily net ET rate for each month (inches) and multiplying by the area (acres) covered by each crop group within each diverter boundary and dividing by 12 (inches/foot). There are 22 crop groups, some with numerous subgroups, for which this calculation is performed. These crop groups are listed in table 2 in the "Ground-Reference Data Collection" section. Monthly ET for each diverter is summed for the year to yield the annual ET for each diverter.

An example of an ET calculation using cotton is shown below:

$$ET_{cotton} = 3_n [(ET_0 \times K_{cotton}) - \text{Effective PPT}] AC_{cotton} \div 12$$

Where:

ET_{cotton}	=	The monthly or annual ET by cotton for the diverter in question (acre-feet)
3_n	=	Summation for n time (monthly or annually)
ET_0	=	Daily Reference ET (inches)
K_{cotton}	=	Daily ET coefficient specific to cotton (dimensionless)
AC_{cotton}	=	Acreage of cotton for the diverter in question (acres)
Effective PPT	=	Effective precipitation (inches)

The summation of crop ET for all diverters within a reach becomes the outflow, ET_{crop}, in the water balance.

The sum of the ET_{crop} compiled for calendar year 1999 from Hoover Dam to Mexico is 1,205,022 acre-feet. After distribution of the residual from the water balance, the final calculation of crop consumptive use increased to 1,205,363 acre-feet, a change of less than one tenth of one percent. Crop consumptive use accounts for about 15 percent of the consumptive use (crop, domestic, and export) along the lower Colorado River from Hoover Dam to Mexico.

The use of water for crops and other purposes by the Imperial Irrigation District (IID), the Coachella Valley Water District (CVWD), and the Wellton-Mohawk Irrigation and Drainage District (WMIDD) are not included here. The water diverted by IID and CVWD is considered to be exported from the system at station 1117 on the All-American Canal, and water diverted by WMIDD is considered to be exported from the system at station 791.37 on the Gila Gravity Main Canal. See the section above entitled “Export Flow (Q_{ex})” for more details.

Phreatophyte ET (ET_{pht})

Phreatophyte water use is calculated the same way as described above in the section entitled "Crop ET (ET_{crop})," except that the ET rates for phreatophytes are not corrected for effective precipitation.

Using the same process applied to crop ET, the summation of ET for all phreatophyte groups within a diverter’s boundaries yields the total phreatophyte ET for a diverter. The phreatophyte ET for all diverters within a reach is summed to give the phreatophyte outflow ET_{pht} for the water balance.

Remote sensing processes, including analysis of aerial photography, were used to develop original acreage values for each phreatophyte group used to calculate ET_{pht} in the 1995 LCRAS report. There are 14 phreatophyte groups. These groups are listed in table 3 in the section "Ground Reference Data Collection." Beginning in 1996 and continuing in 1999, phreatophyte acreage values have been updated using remote-sensing-based change detection methodologies. When major changes are identified, usually from fire or development, they are field verified.

The sum of the ET_{pht} calculated for calendar year 1999 from Hoover Dam to Mexico is 585,824 acre-feet. After distribution of the residual from the water balance, the final calculation of phreatophyte water use decreased to 585,782 acre-feet, a change of less than one tenth of one percent.

Phreatophyte water use accounts for about 7 percent of the combined use and loss from crops, domestic uses, exports, evaporation, and phreatophytes along the lower Colorado River from Hoover Dam to Mexico.

Evaporation (E)

LCRAS calculates evaporation from the open water of Lakes Mohave and Havasu, Senator Wash, and the open water of the Colorado River and adjacent backwaters (such as Topock Marsh and Mittry Lake) from Hoover Dam to Mexico. Evaporation from ponds and other open water areas within a water user boundary are identified and quantified.

LCRAS calculates a monthly open-water evaporation rate as the product of a monthly summation of average daily reference ET times a monthly evaporation coefficient. The depth of precipitation recorded at precipitation gages nearest the area of open water for each month of the year is subtracted from the monthly evaporation rate to yield a corrected monthly evaporation rate. The corrected monthly evaporation rate (converted from inches to feet) is multiplied by area of open water (acres) to yield the monthly open-water evaporation (acre-feet).

Open-water area is developed by analyzing images acquired August 13, 1999, for the Hoover Dam to Davis Dam reach and images acquired July 21, 1999, for the Davis Dam to Parker Dam, Parker Dam to Imperial Dam, and Imperial Dam to Mexico reaches. More details are available in the section on remote sensing.

The initial estimate of evaporation from Hoover Dam to Mexico for calendar year 1999 is 316,967 acre-feet. After distribution of the residual from the water balance, the final calculation of evaporation decreased to 316,785 acre-feet, a change of about 0.06 percent. Evaporation accounts for less than 4 percent of the combined water use and loss from crops, domestic uses, exports, phreatophytes, and evaporation along lower Colorado River from Hoover Dam to Mexico.

Domestic Consumptive Use (CU_d)

This section describes how domestic consumptive use along the mainstream of the lower Colorado River from Hoover Dam to Mexico, other than vegetative uses on wildlife refuges, is developed. The uses described here include municipal use, industrial use, and household use. The diversions by MWD and CAP and vegetative water use on wildlife refuges are not included here.

The CAP and MWD diversions from Lake Havasu are considered to be an export from the system. See the above heading, "Export Flow (Q_{ex})," for more details. Vegetative water use on wildlife refuges is developed in the same way as crop consumptive use and phreatophyte water use by irrigators.

Domestic consumptive use is initially estimated by

1) subtracting a measured return flow from a measured diversion, or

2) if a measured return flow is unavailable by applying a consumptive use factor to a measured diversion (usually 0.6), or

3) if a measured diversion and a measured return flow are unavailable by applying a per-capita consumptive use factor to a population (0.14 acre-feet per year per capita if turf irrigation is not significant), or

4) in a few cases, domestic uses are initially estimated by a method submitted by the diverter.

The derivation of the domestic consumptive use coefficients mentioned above can be found in attachment 3 of the 1996 LCRAS Demonstration of Technology Report (Bureau of Reclamation, 1998a).

The initial estimate of domestic consumptive use from Hoover Dam to Mexico for calendar year 1999 is 67,996 acre-feet. After distribution of the residual from the water balance, the final estimate of domestic consumptive use decreased by one acre foot to 67,995 acre-feet. Domestic consumptive use accounts for less than one percent of the consumptive use (crop, domestic, and export) along the lower Colorado River from Hoover Dam to Mexico.

Domestic uses of water diverted through the Colorado River Aqueduct, the Central Arizona Project Canal, and to the Imperial and Coachella Valleys through the All American Canal are not included here. Water diverted through the structures or to the areas mentioned above are considered to be exported from the system. See the section above entitled “Export Flow (Q_{ex})” for more details.

Change in Reservoir Storage ()S_r)

The change in reservoir storage in each reach must be considered in the water balance because an increase in reservoir storage reduces the flow at the downstream end of a reach (acts like an outflow), and a decrease in reservoir storage increases the flow at the downstream end of a reach (acts like an inflow). If there is no reservoir in a reach, the change in reservoir storage value is zero.

Reservoir storage values are reported monthly by Reclamation in Reservoir Elevations and Contents tables provided by the Lower Colorado Dams Facilities Office. The change in reservoir storage values used in this report are the difference between storage calculated on the first day of each month.

Change in Aquifer Storage ()S_a)

A initial value of zero is used for all reaches of the river for this report (as was done in previous reports). Currently, no network of wells exists that would give consistent and current water-level data throughout the study area. A non-zero value for the standard error of estimate is used for this report. The values used (5,000 acre-feet for the Hoover Dam to Davis Dam reach and 10,000 acre-feet for the remaining reaches) are derived from judgement. Incorporating values for the standard error of estimate of the change in aquifer storage provides for some of the residual from the water balance to be distributed to change in aquifer storage. The amount of the residual that is distributed to change in aquifer storage is small and can be seen on table 7.

Residual (Q_{res})

The summation of all inflows and outflows in a water balance results in a residual. If inflows to a reach exceed outflows, the residual will be positive. If outflows exceed inflows, the residual will be negative. In an ideal system, where all inflows and outflows are known and without measurement or estimation error, the residual would be zero. In the real-world of the lower Colorado River, the residual of a water balance can be expected to be small, but cannot be expected to be zero. The residual values for each reach, along with the inflows, outflows, and water uses of the water balance, are displayed in table 5.

Table 5 — Water balance summary (not adjusted for residual)
(Units: annual acre-feet)

Water balance inflows, outflows, and water uses	Reach				
	Hoover Dam to Davis Dam	Davis Dam to Parker Dam	Parker Dam to Imperial Dam	Imperial Dam to Mexico	Hoover Dam to Mexico
Flow at the upstream boundary (Q_{us})	11,033,000	11,070,300	8,353,300	7,205,263	11,033,000
Flow at the downstream boundary (Q_{ds})	11,070,300	8,353,300	7,205,263	2,976,626	2,976,626
Residual	-223,980	-169,837	35,137	-2,522	-361,202
Residual as a percentage of the flow at the upstream boundary (Q_{us})	-2.03%	-1.53%	0.42%	-0.04%	-3.27%
Difference between flow at the upstream and downstream boundaries (Q_{dif})	-37,300	2,717,000	1,148,037	4,228,637	8,056,374
Measured Tributary inflow (Trm)	0	8,357	0	7,017	15,374
Unmeasured Tributary inflow (Trum)	6,480	36,290	33,750	3,000	79,520
Exported flow (Q_{ex})	0	2,600,232	0	3,768,997	6,369,229
Evaporation (E)	137,451	113,223	60,963	5,330	316,967
Domestic consumptive use (CU_d)	710	33,318	5,287	28,618	67,933
Crop evapotranspiration (ET_{crop})	0	75,412	734,702	371,081	1,181,195
Phreatophyte evapotranspiration (ET_{pht})	899	170,199	347,576	67,150	585,824
Change in reservoir storage ()S_r)	54,100	-60,900	-1,878	0	-8,678
Change in aquifer storage ()S_a)	0	0	0	0	0

The residuals in 1999 are less than the presumed standard error of estimate in all reaches except the Hoover Dam to Davis Dam reach where the residual equals 2.0% of the flow below Hoover Dam. Reclamation considers these results to be excellent for a large river system such as the lower Colorado River. The standard error of estimate values for the upstream flows for each reach are 1.4 percent for Hoover Dam, 2.2 percent for Davis and Parker Dams, 1.5 percent for Imperial Dam, and 1.4 percent for the flow to Mexico.

The residual of the water balance is characterized as the summation of the errors of measurement and approximation associated with each inflow, outflow, and water use. The final value of crop and domestic consumptive use, phreatophyte water use, and all other values is realized when the residual is distributed to each of the water-balance terms.

Distributing the residual is considered optional if the value of the residual is smaller than the presumed standard error of estimate of the mainstream inflow. While the residual is less than the standard error of estimate of the mainstream inflow in three of the four reaches in 1999, the residual is distributed in all reaches to demonstrate the mechanics of the distribution and the distribution's impact on the results.

The residual is distributed based upon the variance (the square of the standard error of estimate) of each inflow, outflow, and water use as described in Lane, W. L., 1998. The residual is proportioned by dividing the variance of a term of the water balance by the sum of the variances for all terms of the water balance. This proportion of the residual (in acre-feet) is then subtracted from the inflows and added to the outflows and water uses that comprise the water balance. The resultant water balance produces a residual of zero.

The standard error of estimate and variance values used in this report are based upon values recommended in Lane, W. L., 1998. Minor adjustments are made to some of the recommended values based upon judgment. The standard error of estimate and variance values used for 1999 can be found on sheet A of the water-balance tables in appendix I.

Interaction between Reaches

An inconsistency in the final estimate of the flow at mainstream dams appears when the flow below the same dam is used in two different reaches. For example, the flow below Davis Dam is the outflow in the Hoover Dam to Davis Dam reach and the inflow in the Davis Dam to Parker Dam reach. When each reach is balanced independently and the residual distributed, two different adjusted values for the flow below the same dam result. For example, the distributed value of the flow below Davis Dam is different in the Hoover Dam to Davis Dam reach than it is in the Davis Dam to Parker Dam reach. When the interaction between these reaches is considered, the result is a single adjustment to the flows below the mainstream dams.

The method used to treat the interaction between reaches ensures that the average change in the flows below Hoover, Davis, and Parker Dams, at Imperial Dam, and the flow to Mexico, due to the distribution of the residual, is zero. This method can be shown to be the least squares solution (Lane W. L., 1998). This is accomplished by using a three-step process:

1. The flow below Hoover Dam is temporarily fixed at the gaged value.
2. Temporary values are calculated for the flows below Davis and Parker Dams, at Imperial Dam, and the flow to Mexico by adding to the gaged values the amount of the residual (from the water balance) apportioned to Q_{dif}[8] from the reaches above each dam and the flow to Mexico.
3. The average of the temporary changes made to the gaged flows is subtracted from the temporary flows calculated in 1 and 2 above to yield the final adjusted flow at each dam and to Mexico.

Table 6 shows the calculations and results for the adjusted values of flow below Hoover, Davis, and Parker Dams, at Imperial Dam, and the flow to Mexico.

[8] Q_{dif} is the difference between the quantity of water flowing into a reach at the upstream boundary and the quantity of water flowing out of the reach at the downstream boundary (Q_{us} - Q_{ds}).

Table 6 — Adjustments to flow below Hoover, Davis and Parker Dams,
at Imperial Dam, and the flow to Mexico
(units: annual acre-feet unless otherwise noted)

Description	Hoover Dam	Davis Dam	Parker Dam	Imperial Dam	Flow to Mexico [9]	Average
Measured flow	11,033,000	11,070,300	8,353,300	7,205,263	2,976,626	
Amount of residual apportioned to Q_{dif} of the reach below each dam from the water balance	-223,767	-164,450	33,754	-2,181	N/A	
Initial adjustment value (start with zero at most upstream dam and add cumulative to most downstream flow)	0	-223,767	-388,217	-354,463	-356,644	-264,618
Initial adjusted flow (measured flow + initial adjustment)	11,033,000	10,846,533	7,965,083	6,850,800	2,619,982	
Final adjusted flows below each dam and to Mexico (initial adjusted flow - average of initial adjustment values)	11,297,618	11,111,151	8,229,701	7,115,418	2,884,600	
Final adjustments to measured flows (final adjusted value - measured value)	264,618	40,851	-123,599	-89,845	-92,026	
Final adjustments to measured flows in percent	2.40%	0.37%	-1.48%	-1.25%	-3.09%	

By solving this boundary problem, a table of adjusted values for the whole water balance is created which yields a residual of zero for all reaches of the lower Colorado River below Hoover Dam. The final results of the water balance are shown on table 7.

[9] Includes the delivery at the southerly land boundary near San Luis, deliveries to the Limitrophe section, and underflow to Mexico.

Table 7 — Final distributed and adjusted water balance values
(Units: annual acre-feet)

Water balance inflows, outflows, and water uses	Reach				
	Hoover Dam to Davis Dam	Davis Dam to Parker Dam	Parker Dam to Imperial Dam	Imperial Dam to Mexico	Hoover Dam to Mexico
Flow at the upstream boundary (Q_{us})	11,297,618	11,111,151	8,229,701	7,115,418	11,297,618
Flow at the downstream boundary (Q_{ds})	11,111,151	8,229,701	7,115,418	2,884,600	2,884,600
Residual (Q_{res})	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	186,467	2,881,450	1,114,283	4,230,818	8,413,018
Measured tributary inflow (Trm)	0	8,366	0	7,017	15,383
Unmeasured tributary inflow (Trum)	6,490	36,499	33,674	3,000	79,663
Exported flow (Q_{ex})	0	2,595,454	0	3,768,730	6,364,184
Evaporation (E)	137,324	113,166	60,970	5,330	316,790
Domestic consumptive use (CU_d)	710	33,317	5,287	28,618	67,932
Crop consumptive use (CU_{crop})	0	75,387	735,704	371,025	1,182,116
Phreatophyte water use (CU_{pht})	899	170,071	347,800	67,148	585,918
Change in reservoir storage ()S_r)	54,091	-60,903	-1,878	0	-8,690
Change in aquifer storage ()S_a)	-67	-177	74	-16	-186

Sample Calculation

This sample calculation shows how crop consumptive use is calculated for a diverter. The Colorado River Indian Reservation in Arizona (CRIR) will serve as the sample diverter.

The calculation for crop consumptive use has four major steps.

1. Calculate the crop ET for each diverter within the reach and sum these values to calculate crop ET for the whole reach .

2. Calculate the residual for the reach by performing the water balance after calculating all inflows, outflows, and water uses within the reach.

3. Calculate crop consumptive use for the reach by distributing the residual to crop ET, and all the other inflows, outflows, and water uses within the reach, in proportion to the product of their variance and magnitude.

4. Calculate the crop consumptive use for each diverter by apportioning the crop consumptive use for the reach to each diverter in the same proportion that crop ET for each diverter is to crop ET for the reach.

Detailed explanations of each of the four steps described above, which focus on the calculation of crop consumptive use on CRIR, are presented in the following paragraphs. The tables, sheets, and values referred to in this sample calculation appear in appendix I, Part 1: Evapotranspiration Rate Calculations, and appendix I, Part 2: Water Balance and Consumptive Use Calculations. Since the tables in appendix I have identical formats, the reader can use this sample calculation as a basis for reviewing the calculations for any diverter. Readers will find that using the values listed may not yield exactly the same results as displayed on the tables because the values displayed on the tables in appendix I have been rounded.[10]

Calculate Crop ET for Each Diverters Within the Reach

Crop ET for a reach is the sum of the crop ET for all of the diverters within a reach. The crop ET of a diverter is the sum of the ET of each crop grown within the diverter's boundary. ET for a single crop is calculated as the reference ET multiplied by the ET coefficient for the crop and the number of acres of the crop grown, less the effective precipitation. The paragraphs below provide an example of crop ET calculations for a single crop (alfalfa) within a single diverter boundary (CRIR).

Crop ET calculations begin with a daily reference ET, calculated as noted in the section titled "Evapotranspiration" in Chapter 2. Daily reference ET values, ET coefficients, precipitation, effective precipitation, and resultant ET values for each crop group used in this sample calculation can be found in appendix I, Part 1, Parker/Palo Verde ET-rate Table.

[10] The crop acreage data used in this sample calculation are calculated using Reclamation's remote sensing process; they are not provided by CRIR.

This example of an ET calculation begins with the area-specific reference ET for the Parker/Palo Verde Valleys for January 25, 1999. The area-specific reference ET for the Parker/Palo Verde Valleys is used to calculate ET for CRIR. January 25th has been chosen to provide an example with a value of effective precipitation that is greater than zero to demonstrate the use of this parameter. The area-specific reference ET is the average of the ET values calculated for each of the CIMIS and AZMET station sites within the Parker and Palo Verde Valleys, shown in table 8 below.

Table 8 — Reference ET values for January 25, 1999

AZMET/CIMIS Station Name	Reference ET (Millimeters) for January 25, 1999 (Standardized Equation)
Parker AZMET station site	2.50
Palo Verde CIMIS station site	2.50
Blythe NE CIMIS station site	2.70
Ripley CIMIS station site	2.50

The area-specific reference ET calculation for January 25th is show below:

Area-Specific Reference ET =(2.50+2.50+2.70+2.50)÷4÷25.4 inches/millimeter =0.10 inches

This sample calculation proceeds using alfalfa - perennial as the sample crop group, referred to hereafter simply as alfalfa. Note the following values for January 25th:

Area-Specific reference ET	=	0.10 (listed on sheet D, inches)
ET Coefficient for alfalfa	=	0.471 (listed on page 2 of 2, sheet E, dimensionless)
Precipitation	=	0.020 (listed on sheet B, inches)

The daily ET rate for alfalfa is calculated by multiplying the area-specific daily reference ET, times the daily ET coefficient for alfalfa; then subtracting the effective precipitation (the portion of the precipitation that contributes to the ET requirement of the crop) calculated as the average of precipitation reported by stations sited within the Parker and Palo Verde Valleys. The Daily ET rate calculation for alfalfa is shown below:

The daily ET rate[11] for alfalfa on January 25th is calculated as shown below:

Daily ET $Rate_{alfalfa}$ = Reference ET (0.10 inches from sheet D) * ET coefficient for alfalfa (0.471 from sheet E, page 2 of 2), - effective precipitation (0.01 inches from sheet C) = 0.037 inches (round to 0.04 as shown on sheet E)

A daily ET rate of zero implies that the soul moisture gain from precipitation is the same as the ET requirement of the plant being grown. A daily ET rate of less than zero (a negative value) implies that the soil moisture gain from precipitation is greater than the ET requirement of the plant being grown, resulting in a net gain in soil moisture from precipitation. A daily ET rate greater than zero (a positive value) implies that the ET requirement of the plant being grown is greater than the soil moisture gain from precipitation resulting in a net loss of soil moisture. This loss of soil moisture must be met with irrigation.

The ET rate for alfalfa for the month of January is the summation of the daily ET rates for alfalfa calculated for all the days of January.

The example continues with the calculation of ET (in acre-feet) for alfalfa for the month of January. The ET for alfalfa in January is the product of the ET rate for alfalfa for the month of January (1.97 inches, from the Parker/Palo Verde ET-rate Table, sheet E, page 1 of 2) and the acreage of alfalfa on CRIR listed for January 1999 (47,626 acres, from the Parker Dam to Imperial Dam Water-Balance Table, sheet O, page 3 of 5 in appendix I, Part 2).

The calculation of ET for alfalfa for the month of January is shown below:

$ET_{alfalfa}$ for January = 1.97 (inches) * 47,626 (acres) ÷ 12 (inches/foot) = 7,819 acre-feet.

---

[11] The ET rate displayed in the tables of appendix I, Part 1, includes the effects of precipitation. These tables do not display a crop-specific ET rate without a correction for effective precipitation.

The calculation shown above results in 7,819 acre-feet while 7,822 acre-feet is shown on sheet O, page 1 of 5 in the Parker Dam to Imperial Dam Water-Balance Table. The difference is due to the rounding of the numbers presented above.

The process is repeated for each crop group. The annual crop ET for CRIR is calculated by summing the monthly ET for each crop group. The Crop ET for the reach used in the water balance is the sum of the crop ET for each crop, for each month, for each diverter.

Calculate the Residual for the Reach

The next step in the example determines the water balance between Parker and Imperial Dams which produces the water balance residual, a portion of which will be added to the crop ET calculated for CRIR to derive the crop consumptive use for CRIR. The values used are presented in the Parker Dam to Imperial Dam Water-Balance Table, sheet A.

The water balance between Parker and Imperial Dams is performed on annual values and consists of many parts. Each part used in 1999 is described in the following paragraphs.

Inflow and Outflow at the Reach Boundaries (Q_{us} & Q_{ds})

The mainstream inflow to the Parker Dam to Imperial Dam reach (Q_{us})is the flow below Parker Dam (8,353,300 acre-feet), as shown on sheet A, page 1 of 2, of the Parker Dam to Imperial Dam Water-Balance Table. The unmeasured tributary inflow between Parker and Imperial Dams (33,750 acre-feet) is shown on sheet C of the Parker Dam to Imperial Dam Water-Balance Table. The unmeasured tributary inflow value was provided by the Geological Survey (page 46 of Owen-Joyce, Sandra J., and Raymond, Lee H., 1996). Measured tributary inflow between Parker and Imperial Dams is zero (as shown on sheet C).

The flow at the downstream boundary of the Parker Dam to Imperial Dam reach is the flow at Imperial Dam (7,205,263 acre-feet, shown on sheet A), which is the sum of four flows as shown on sheet H of the Parker Dam to Imperial Dam Water-Balance Table. These flows are Station 60 on the All-American Canal (5,859,800 acre-feet), Station 30 on the Gila Gravity Main Canal (796,046 acre-feet), the inflow to Mittry Lake (11,157 acre-feet), and the Colorado River sluiceway (538,260 acre-feet).

There are no exports from the system between Parker and Imperial Dams (where exports are present they are reported on sheet D).

Evaporation

Evaporation is calculated by multiplying the area of open water by a monthly evaporation rate minus precipitation. The Parker Dam to Imperial Dam reach is divided into five subsections for evaporation calculations to account for differing water temperatures within the reach, a backwater area, and Senator Wash Reservoir. The sum of the evaporation from these subareas becomes the evaporation for the Parker Dam to Imperial Dam reach. The evaporation calculation for January for river section 1 is shown below.

> Evaporation = [[monthly sum of daily reference ET (3.23 inches) * monthly evaporation coefficient (0.52)] - precipitation (0.02 inches)] * area of open water (4,000 acres) ÷ 12 (inches/foot) = 552 acre-feet

The evaporation, reference ET, evaporation coefficient, precipitation, area of open water, and total evaporation for January (1,723 acre-feet) can be found on sheet H (pages 1 and 2) of the Parker Dam to Imperial Dam Water-Balance Table.

Domestic Consumptive Use

The initial estimate of domestic consumptive use between Parker and Imperial Dams is the sum of several users, as shown on sheet E of the Parker Dam to Imperial Dam Water-Balance Table. The methods described in the above section entitled “Domestic Use (CU_d)” are used to develop these values. For example, Poston, with a population of approximately 480 is initially estimated to use 67 acre-feet annually (480 * 0.14). Monthly values are calculated as the annual value divided by 12 unless a monthly distribution of water use is provided through diversion records or other information is available. The initial estimate of consumptive use in January for Poston is therefore 5.6 acre-feet (67 acre-feet ÷ 12).

Change in Reservoir Storage

Senator Wash is the only reservoir between Parker and Imperial Dams. Change in reservoir storage is calculated on sheet D of the Parker Dam to Imperial Dam Water-Balance Table as the difference in water held in Senator Wash between the beginning and end of each month. The January beginning-of-month storage (as measured midnight December 31, 1998) is 6,975 acre-feet and end-of-month storage (measured midnight January 31, 1999) is 8,821 acre-feet. The difference is a gain of 1,846 acre-feet. The annual change in reservoir storage is the difference between the January beginning-of-month storage and the December end-of-month storage (-1,878 acre-feet in 1999).

The Residual

The residual is calculated on sheet A, page 1 of 2, of the Parker Dam to Imperial Dam Water-Balance Table. This result for 1999 is 34,137 acre-feet, or about 0.42 percent of the flow below Parker Dam. The residual calculation is shown below (see the above section entitled “Water Balance” for definitions of terms),

$$\text{Residual } (34{,}137) = Q_{dif}\ (1{,}148{,}037) + Q_{Trum}\ (33{,}750) - S_r\ (-1{,}878) - CU_d\ (5{,}287) - ET_{crop}\ (734{,}702) - ET_{pht}\ (347{,}576) - E\ (60{,}963)$$

Calculate Crop Consumptive Use for the Reach

Crop consumptive use between Parker and Imperial Dams is the sum of Crop ET and a portion of the residual between Parker and Imperial Dams. Sheet A of the Parker Dam to Imperial Dam Water-Balance Table also shows the distribution of the residual to each inflow, outflow, and water use in proportion to the magnitude of its initial estimate times its variance (the square of the presumed standard error of estimate). The calculation of crop consumptive use between Parker and Imperial Dams is shown below:

$$\text{Crop } CU_{Reach} = \text{Crop } ET_{Reach} + [\,(VAR_{Crop\ ET} \div TVAR) \times Q_{res}\,]$$

Where:

- $\text{Crop } CU_{Reach}$ = Crop consumptive use between Parker and Imperial Dams
- $\text{Crop } ET_{Reach}$ = Crop ET between Parker and Imperial Dams
- VAR_{ETcrop} = The variance of the crop ET between Parker and Imperial Dams
- $TVAR$ = The sum of the variances for all parts of the water balance between Parker and Imperial Dams
- Q_{res} = The residual

The crop ET in the Parker Dam to Imperial Dam reach is 734,702 acre-feet, and the SEE is presumed to be 5 percent, yielding a variance of 1,349,460,225 acre-feet squared. The TVAR of the reach is 47,316,694,676 acre-feet squared, and the residual is 35,137 acre-feet. All the values in the above paragraph can be found on sheet A of the Parker Dam to Imperial Dam Water-Balance Table.

Substituting these values into the equation results in the calculation shown below:

$$\text{Crop } CU_{Reach} = 734{,}702 + [(1{,}349{,}460{,}225 \div 47{,}316{,}394{,}676) \times (35{,}137)]$$
$$\text{Crop } CU_{Reach} = 735{,}704 \text{ acre-feet}$$

Calculate the Crop Consumptive Use for Each Diverter

Crop consumptive use for each diverter is calculated by apportioning the crop consumptive use for the reach to all the diverters in the same proportion that the crop ET of each diverter is to the total crop ET for the reach. Crop consumptive use for CRIR is calculated as shown below.

$$\text{Crop } CU_{CRIR} = \text{Crop } ET_{CRIR} \div \text{Crop } ET_{Reach} * \text{Crop } CU_{Reach})$$

Where:

- $\text{Crop } CU_{CRIR}$ = Crop consumptive use for CRIR,
- $\text{Crop } ET_{CRIR}$ = Crop ET for CRIR,
- $\text{Crop } ET_{Reach}$ = Crop ET between Parker and Imperial Dams,
- $\text{Crop } CU_{Reach}$ = Crop consumptive use between Parker and Imperial Dams.

The value of Crop ET_{CRIR} can be found on sheet O, page 1 of 5 or on sheet A, page 2 of 2. Values for the other variables defined above can be found on sheet A, page 1 of 2 of the Parker Dam to Imperial Dam Water-Balance Table. Substituting values into the above equation yields the crop consumptive use for CRIR:

Crop CU_{CRIR} = 312,993 acre-feet ÷ (734,702 acre-feet * 735,704 acre-feet)
Crop CU_{CRIR} = 313,420 acre-feet [12]

Results

The results of LCRAS for Calendar Year 1999 are presented in the tables and charts found on the following pages and in attachment 3. Table 9 presents a summary of the water use values calculated using LCRAS and the consumptive use values reported in the Decree Accounting Report.

Some of the differences in reported consumptive uses between LCRAS and the Decree Accounting report shown in table 9 can be attributed to

1. diverters which are reported by LCRAS but not by decree accounting;

2. the consumptive use reported by decree accounting for each diverter does not include the unmeasured return flow from the diverter assigned to the State; and

3. consumptive use by some fields, as reported by LCRAS, is being charged to the State in which they are located and not to the adjacent irrigation district because these fields are not within the known irrigation district boundaries.

[12] Differences due to rounding can sometimes be seen between the results shown in the example and those displayed in appendix I.

Table 9 — LCRAS Crop and Domestic Consumptive Use, and Phreatophyte Water Use, and Consumptive Use from Decree Accounting (Units: annual acre-feet)

LCRAS			**Decree Accounting**	
Diverter name	Phreatophyte water use	Crop, domestic, and export consumptive use	Consumptive use	Diverter name
Nevada				
Uses above Hoover Dam (from 1999 Decree Accounting Report)		271,615	271,615	Uses above Hoover Dam
Uses below Hoover Dam	19,819	17,070	19,521	Uses below Hoover Dam
			1,615	Unmeasured return flow credit
Nevada Total	19,819	288,685	289,521	Nevada Total
California				
			5,193,983	Sum of individual diverters
			87,203	Unmeasured return flow credit
California Total	169,011	5,098,486	5,106,780	California Total
Arizona				
Subtotal (Below Hoover Dam, less Wellton-Mohawk IDD)	397,093	2,207,504	2,535,314	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (from the 1999 Decree Accounting Report)		158	158	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (from 1999 Decree Accounting Report)		266,730	266,730	Wellton-Mohawk IDD
			74,223	Pumped from South Gila wells (DPOCs): returns
			148,258	Unmeasured return flow credit
Arizona Total	397,093	2,474,392	2,579,721	Arizona Total
Lower Colorado River Basin Total				
Total Use	585,923	7,861,563	7,976,022	Total Use

Figure 2 presents results for the states of California and Arizona. Results for each diverter, as well as state and basin totals, are displayed in attachment 3.

The differences between consumptive uses reported in the Decree Accounting Report and consumptive uses and water uses calculated by LCRAS give rise to three main questions:

1. With respect to fields just outside irrigation district boundaries:

   a. Are the diverter boundaries used by LCRAS correct?

   b. Have the diverter boundaries used by LCRAS changed, or has water spreading been identified?

2. What portion, if any, of the phreatophyte water use within the boundary of a diverter should be considered part of the diverter's consumptive use?

3. What fraction of the unmeasured return flow applied to the states' apportionments in Decree Accounting Reports should be applied to the consumptive use of individual diverters?

The resolution of questions one and two, as well as other questions and concerns, are addressed in Chapter 3.

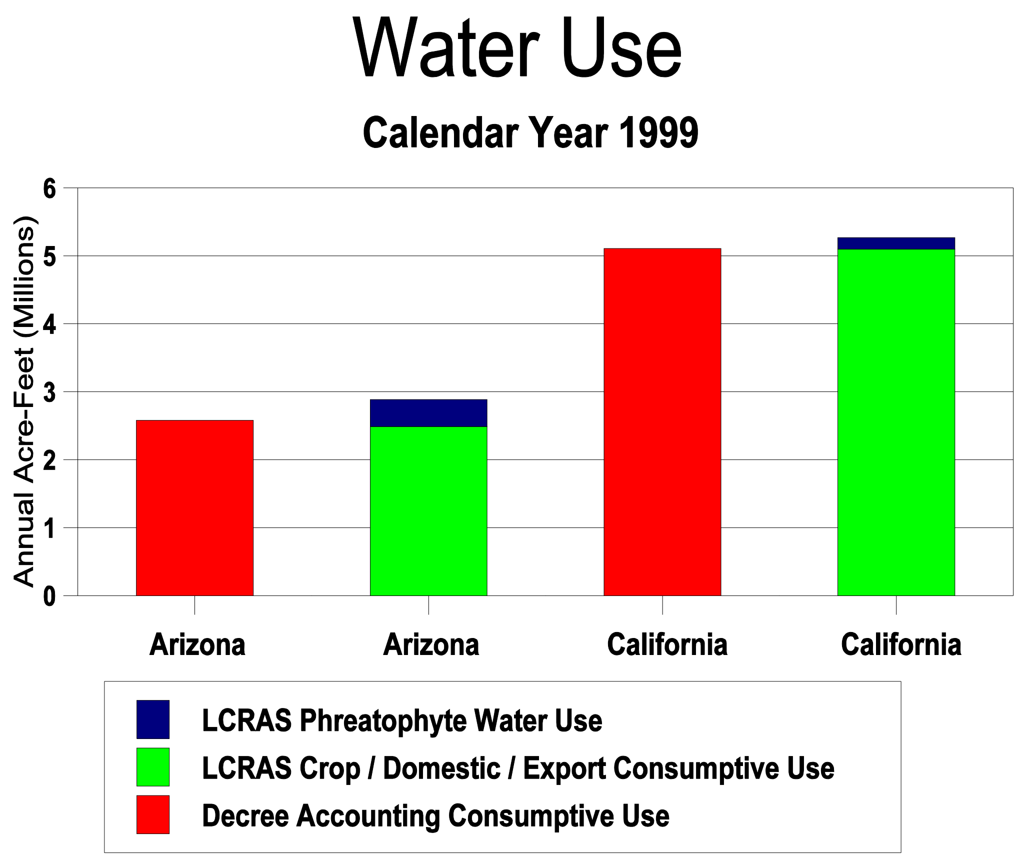
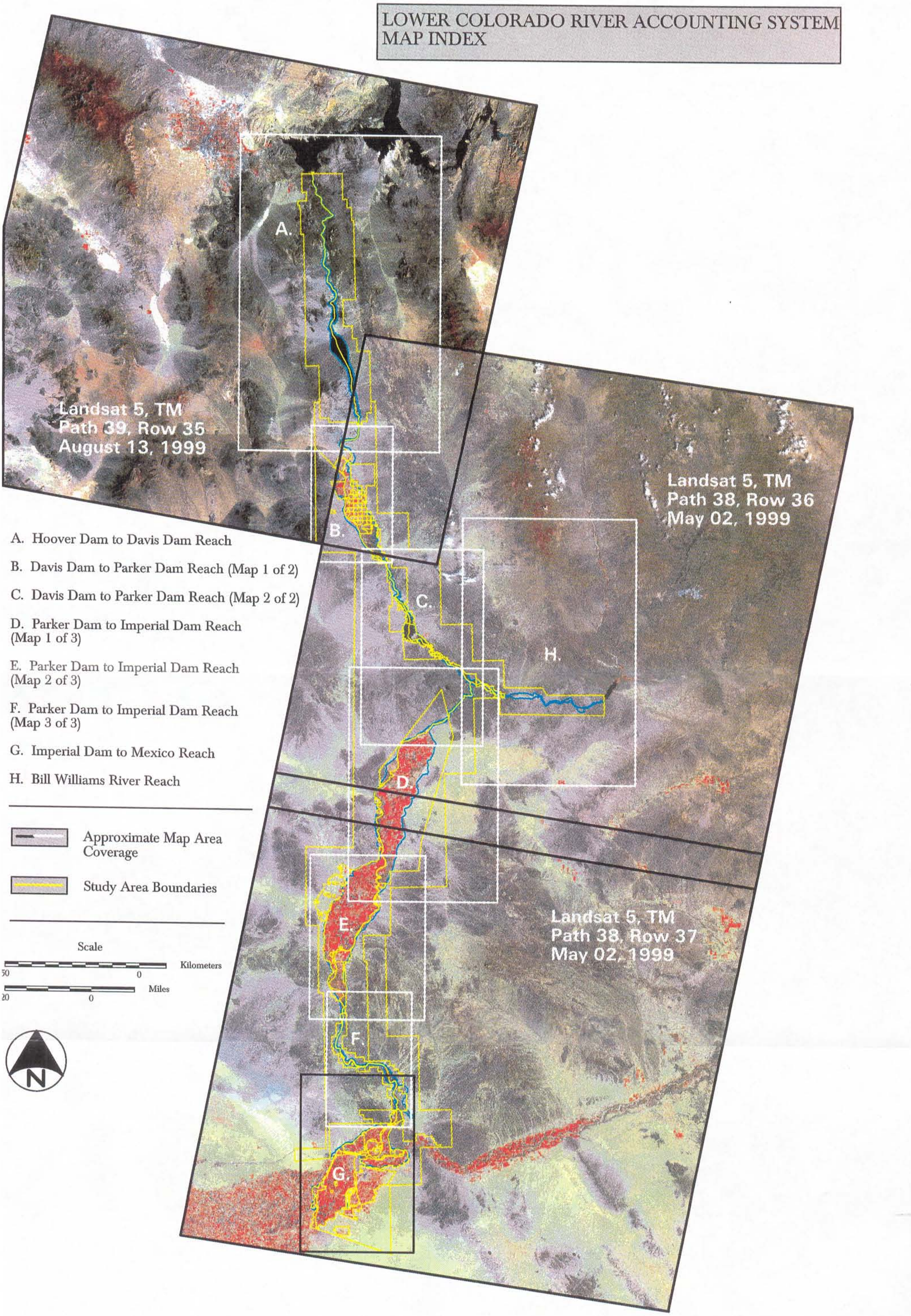
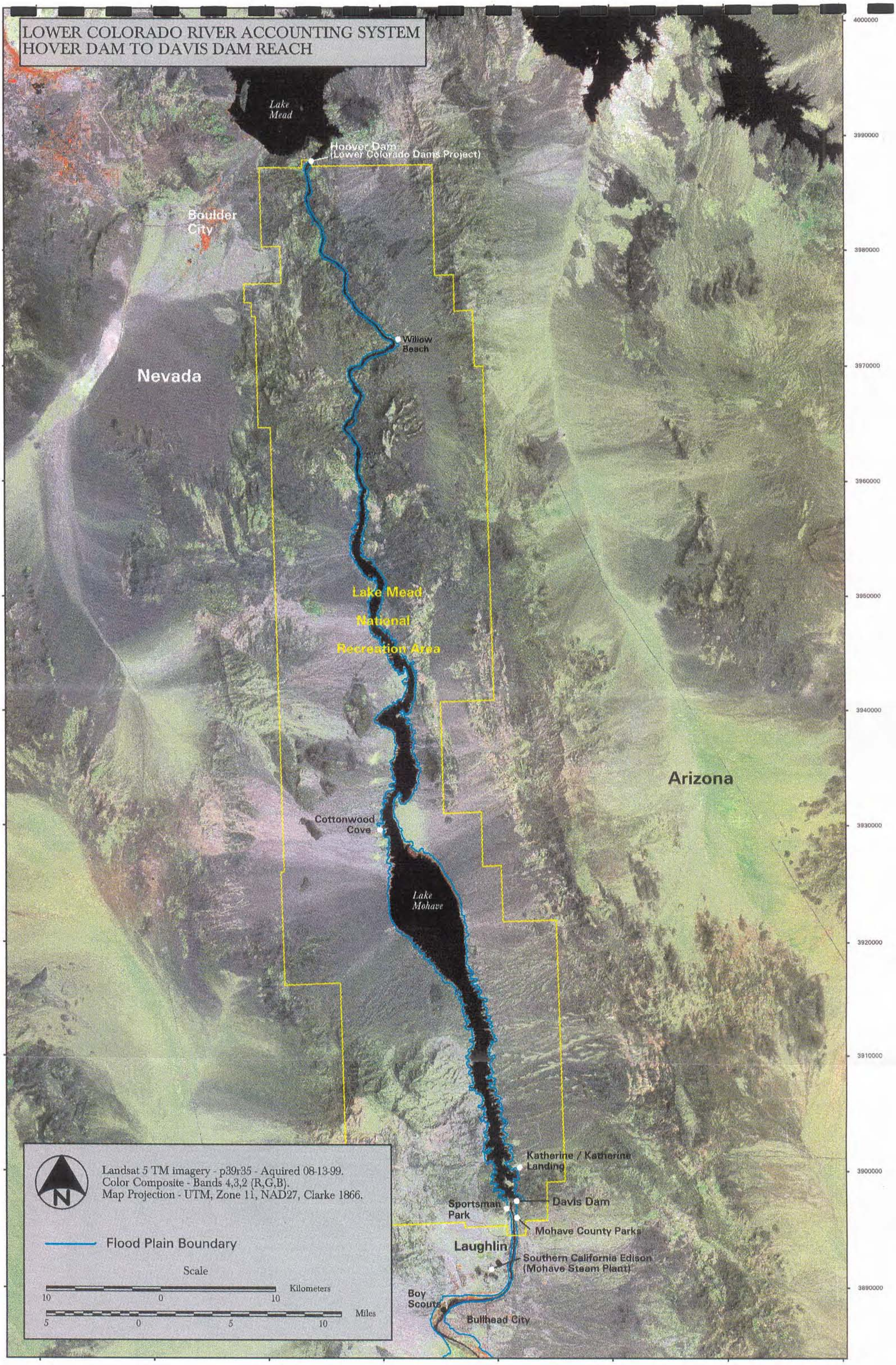


Figure 2. — State water use totals for Arizona and California (calendar year 1999).



LOWER COLORADO RIVER ACCOUNTING SYSTEM
MAP INDEX
Landsat 5, TM
Path 39, Row 35
August 13, 1999
Landsat 5, TM
Path 38, Row 36
May 02, 1999
Landsat 5, TM
Path 38, Row 37
May 02, 1999
A.
B.
C.
D.
E.
F.
G.
H.
A. Hoover Dam to Davis Dam Reach
B. Davis Dam to Parker Dam Reach (Map 1 of 2)
C. Davis Dam to Parker Dam Reach (Map 2 of 2)
D. Parker Dam to Imperial Dam Reach (Map 1 of 3)
E. Parker Dam to Imperial Dam Reach (Map 2 of 3)
F. Parker Dam to Imperial Dam Reach (Map 3 of 3)
G. Imperial Dam to Mexico Reach
H. Bill Williams River Reach
Approximate Map Area Coverage
Study Area Boundaries
Scale
Kilometers
50
0
Miles
20
0
N

Exhibit 1



LOWER COLORADO RIVER ACCOUNTING SYSTEM
HOVER DAM TO DAVIS DAM REACH
Lake Mead
Hoover Dam
(Lower Colorado Dams Project)
Boulder City
Willow Beach
Nevada
Lake Mead National Recreation Area
Arizona
Cottonwood Cove
Lake Mohave
Katherine / Katherine Landing
Sportsman Park
Davis Dam
Mohave County Parks
Laughlin
Southern California Edison (Mohave Steam Plant)
Boy Scouts
Bullhead City
Landsat 5 TM imagery - p39r35 - Aquired 08-13-99.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
N
Flood Plain Boundary
Scale
10 0 10 Kilometers
5 0 5 10 Miles

Exhibit 2

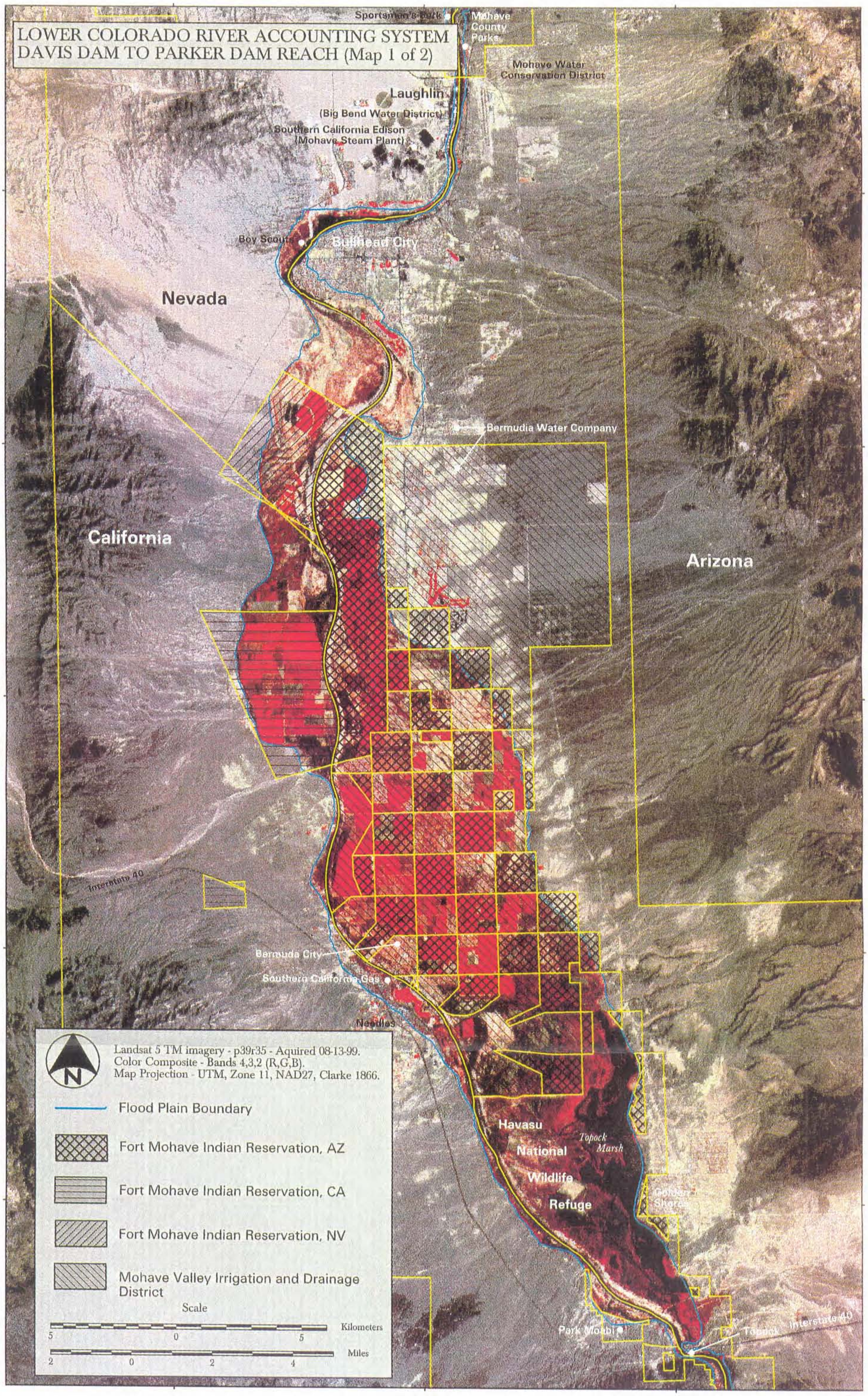

LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 1 of 2)
710000
720000
730000
3890000
3880000
3870000
3860000
3850000
Sportsman's Park
Mohave County Parks
Mohave Water Conservation District
Laughlin
(Big Bend Water District)
Southern California Edison
(Mohave Steam Plant)
Boy Scouts
Bullhead City
Nevada
Bermudia Water Company
California
Arizona
Interstate 40
Bermuda City
Southern California Gas
Needles
Havasu
National
Wildlife
Refuge
Topock Marsh
Golden Shores
Park Moabi
Topock
Interstate 40
N
Landsat 5 TM imagery - p39r35 - Aquired 08-13-99.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
Flood Plain Boundary
Fort Mohave Indian Reservation, AZ
Fort Mohave Indian Reservation, CA
Fort Mohave Indian Reservation, NV
Mohave Valley Irrigation and Drainage District
Scale
5 0 5 Kilometers
2 0 2 4 Miles

Exhibit 3

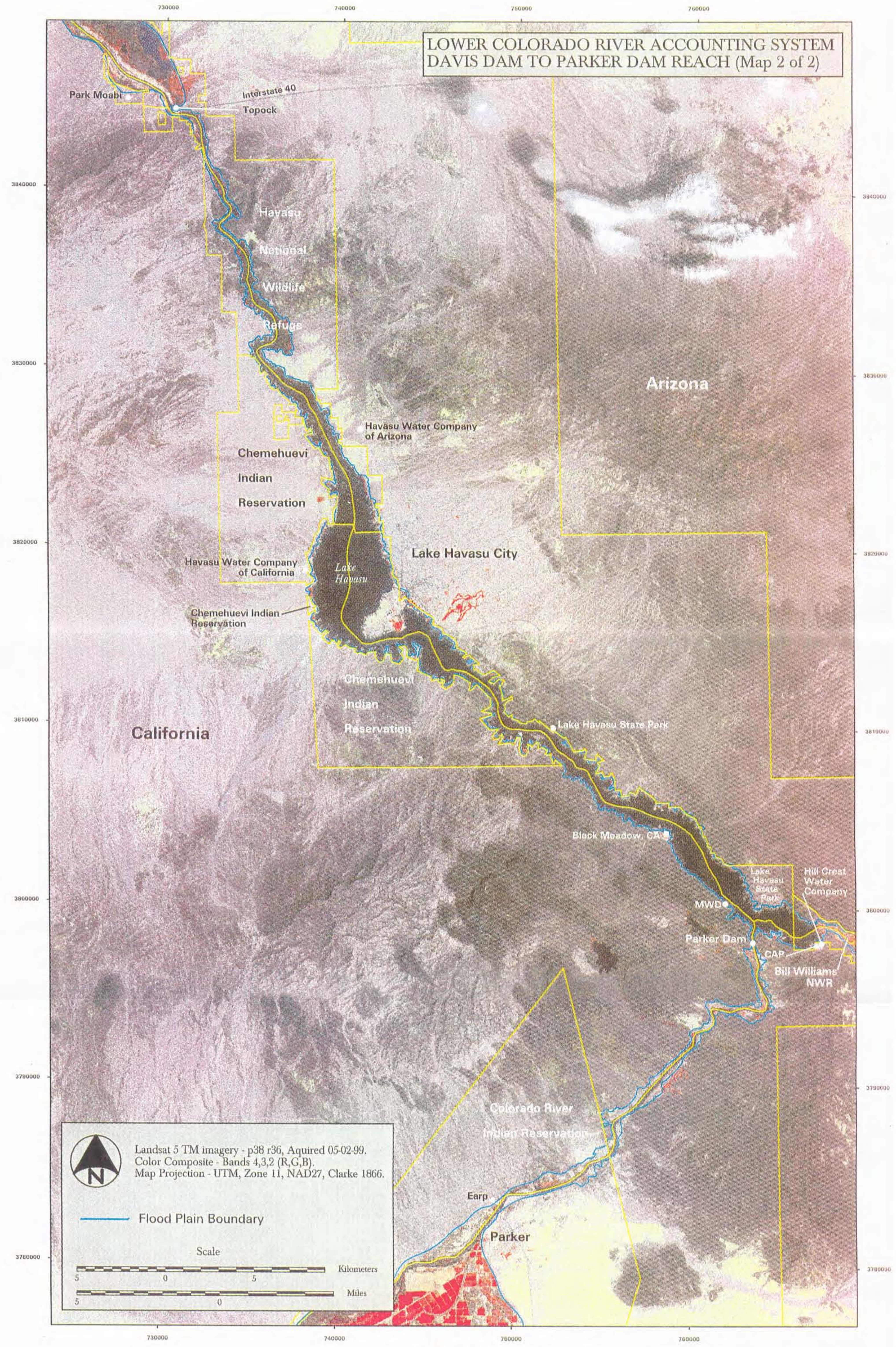

LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 2 of 2)
Park Moabi
Interstate 40
Topock
Havasu National Wildlife Refuge
Arizona
CA
Havasu Water Company of Arizona
Chemehuevi Indian Reservation
Lake Havasu City
Havasu Water Company of California
Lake Havasu
Chemehuevi Indian Reservation
Chemehuevi Indian Reservation
California
Lake Havasu State Park
Black Meadow, CA
Lake Havasu State Park
Hill Crest Water Company
MWD
Parker Dam
CAP
Bill Williams NWR
Colorado River Indian Reservation
Earp
Parker
Landsat 5 TM imagery - p38 r36, Aquired 05-02-99.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
Flood Plain Boundary
Scale
Kilometers
Miles

Exhibit 4

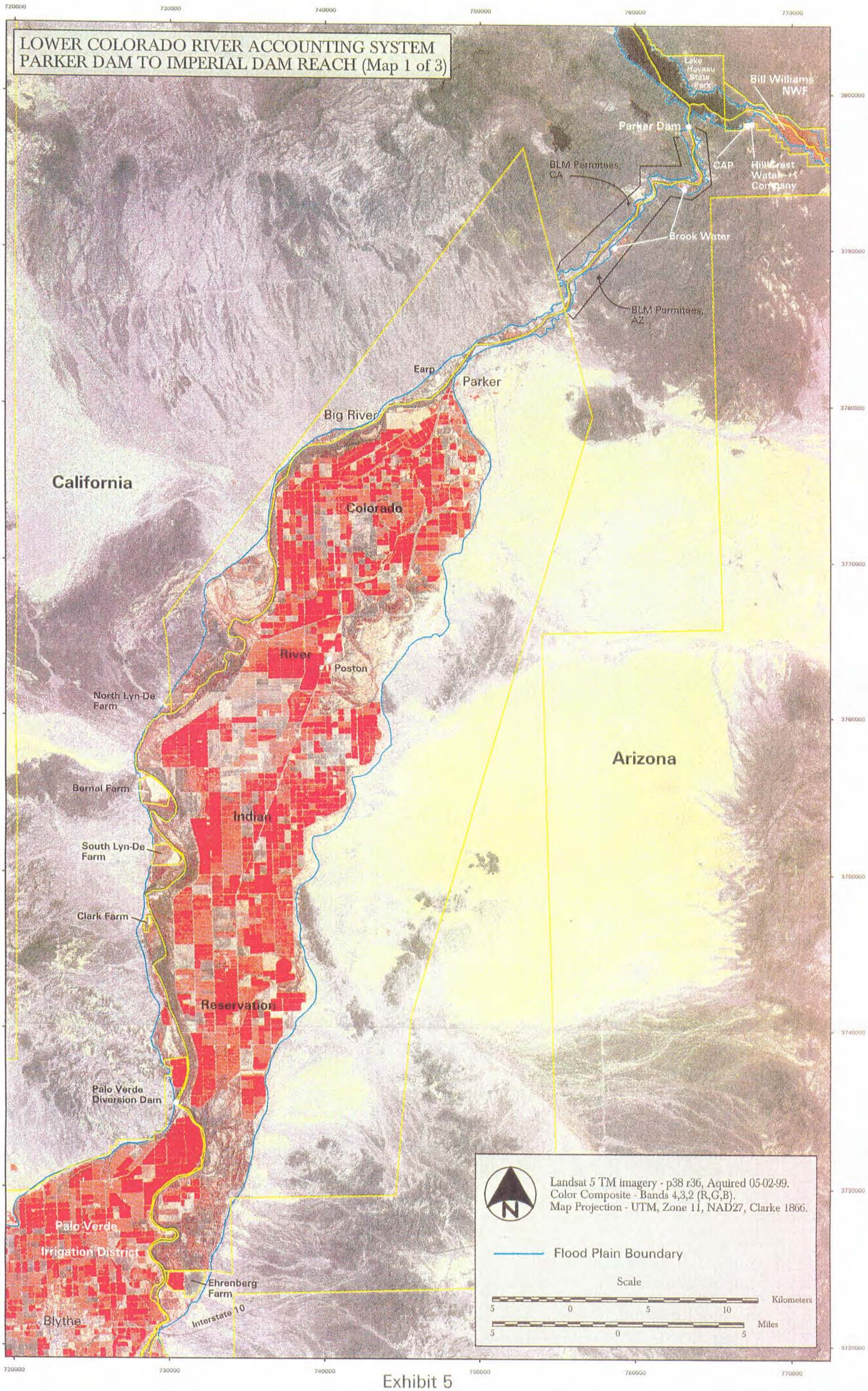

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 1 of 3)
Lake Havasu State Park
Bill Williams NWF
Parker Dam
BLM Permitees, CA
CAP
Hillcrest Water Company
Brook Water
BLM Permitees, AZ
Earp
Parker
Big River
California
Colorado
River
Poston
North Lyn-De Farm
Arizona
Bernal Farm
Indian
South Lyn-De Farm
Clark Farm
Reservation
Palo Verde Diversion Dam
Palo Verde
Irrigation District
Ehrenberg Farm
Interstate 10
Blythe
Landsat 5 TM imagery - p38 r36, Aquired 05-02-99.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
N
Flood Plain Boundary
Scale
Kilometers
5 0 5 10
Miles
5 0 5
720000
730000
740000
750000
760000
770000
3800000
3790000
3780000
3770000
3760000
3750000
3740000
3730000
3720000

Exhibit 5

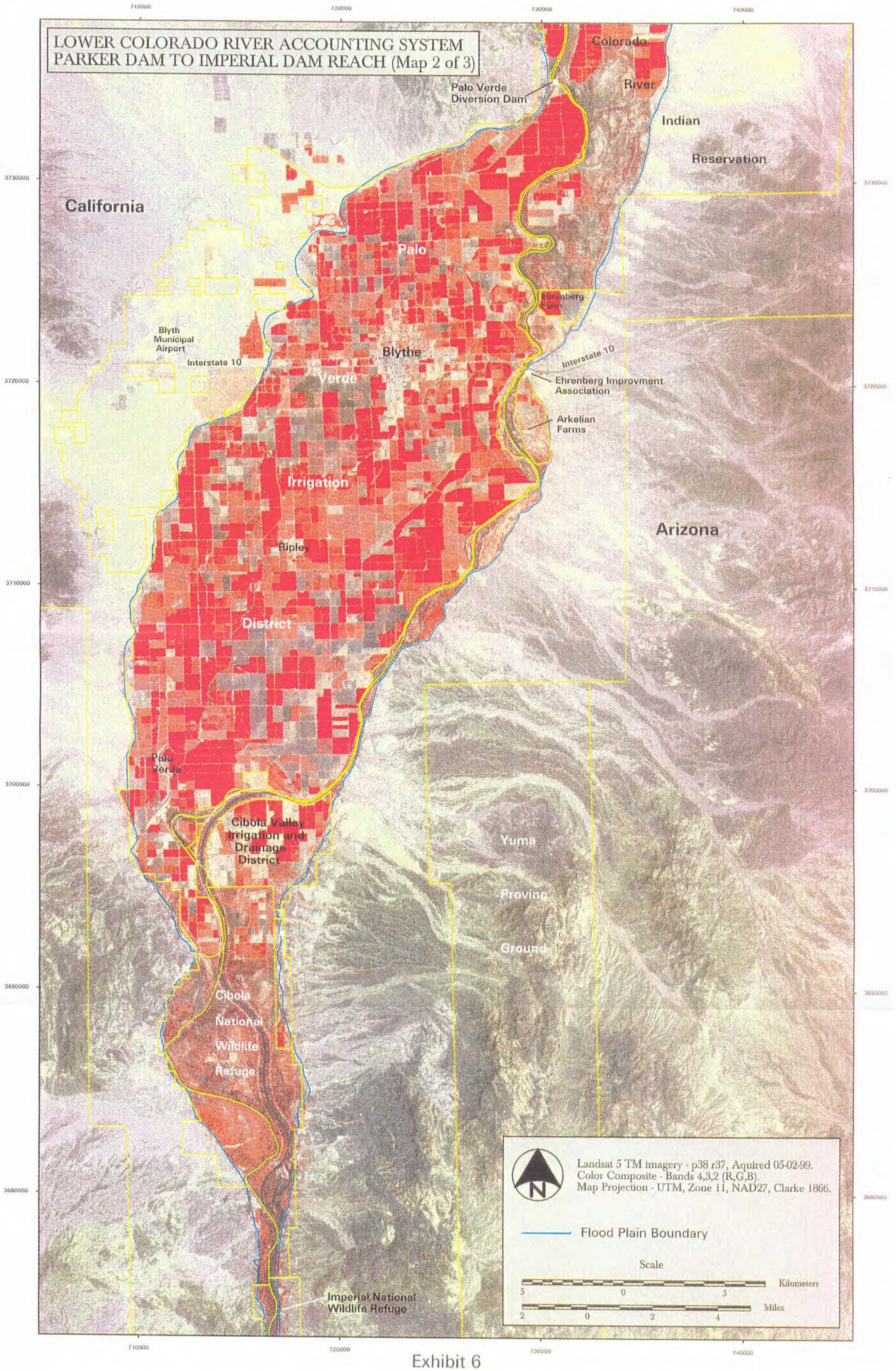

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 2 of 3)
710000
720000
730000
740000
3730000
3720000
3710000
3700000
3690000
3680000
Colorado
River
Indian
Reservation
Palo Verde
Diversion Dam
California
Palo
Blyth
Municipal
Airport
Interstate 10
Blythe
Verde
Interstate 10
Ehrenberg Improvment
Association
Arkelian
Farms
Irrigation
Arizona
Ripley
District
Palo
Verde
Cibola Valley
Irrigation and
Drainage
District
Yuma
Proving
Ground
Cibola
National
Wildlife
Refuge
Imperial National
Wildlife Refuge
Landsat 5 TM imagery - p38 r37, Aquired 05-02-99.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
N
Flood Plain Boundary
Scale
Kilometers
Miles

Exhibit 6

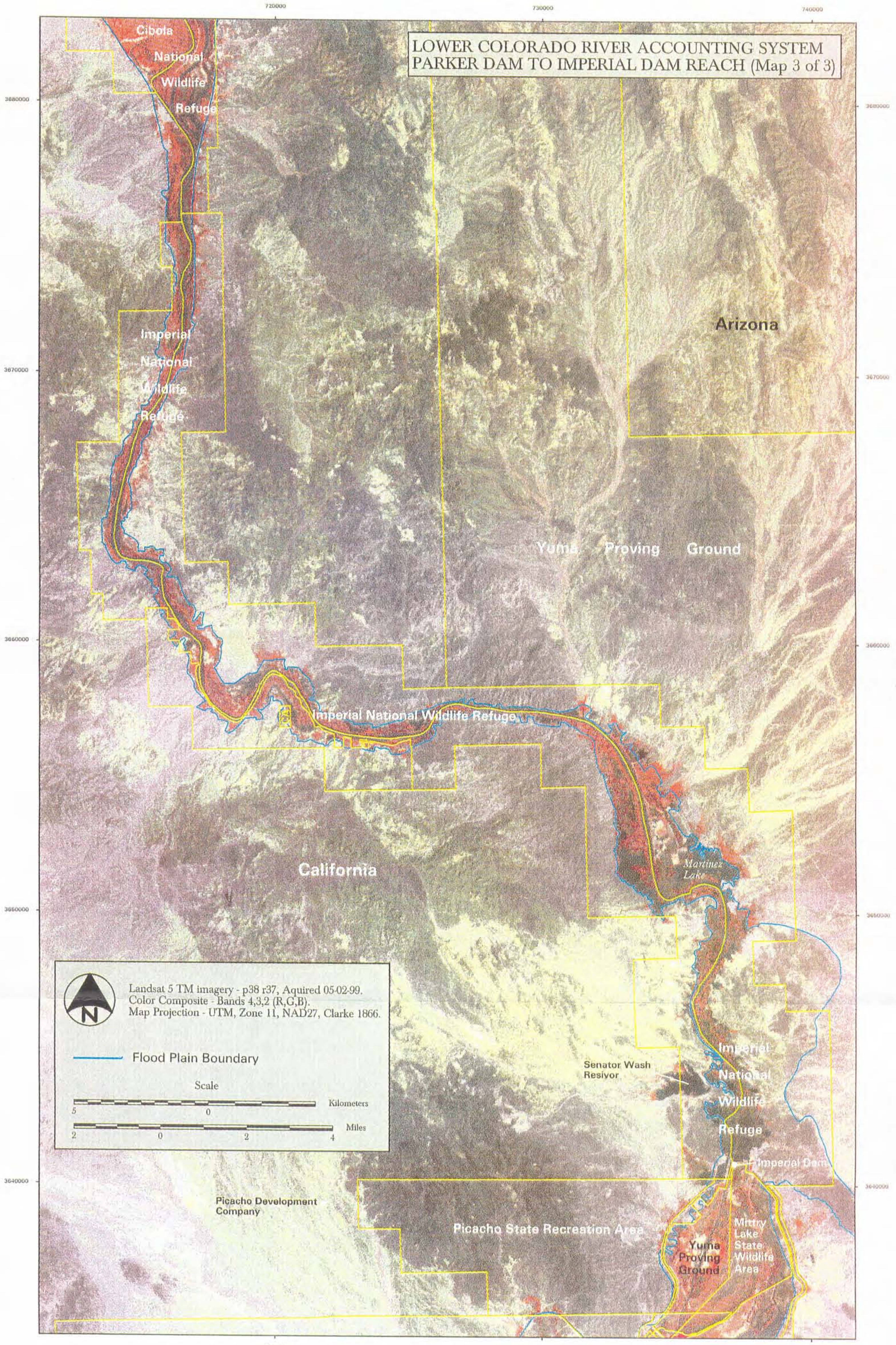
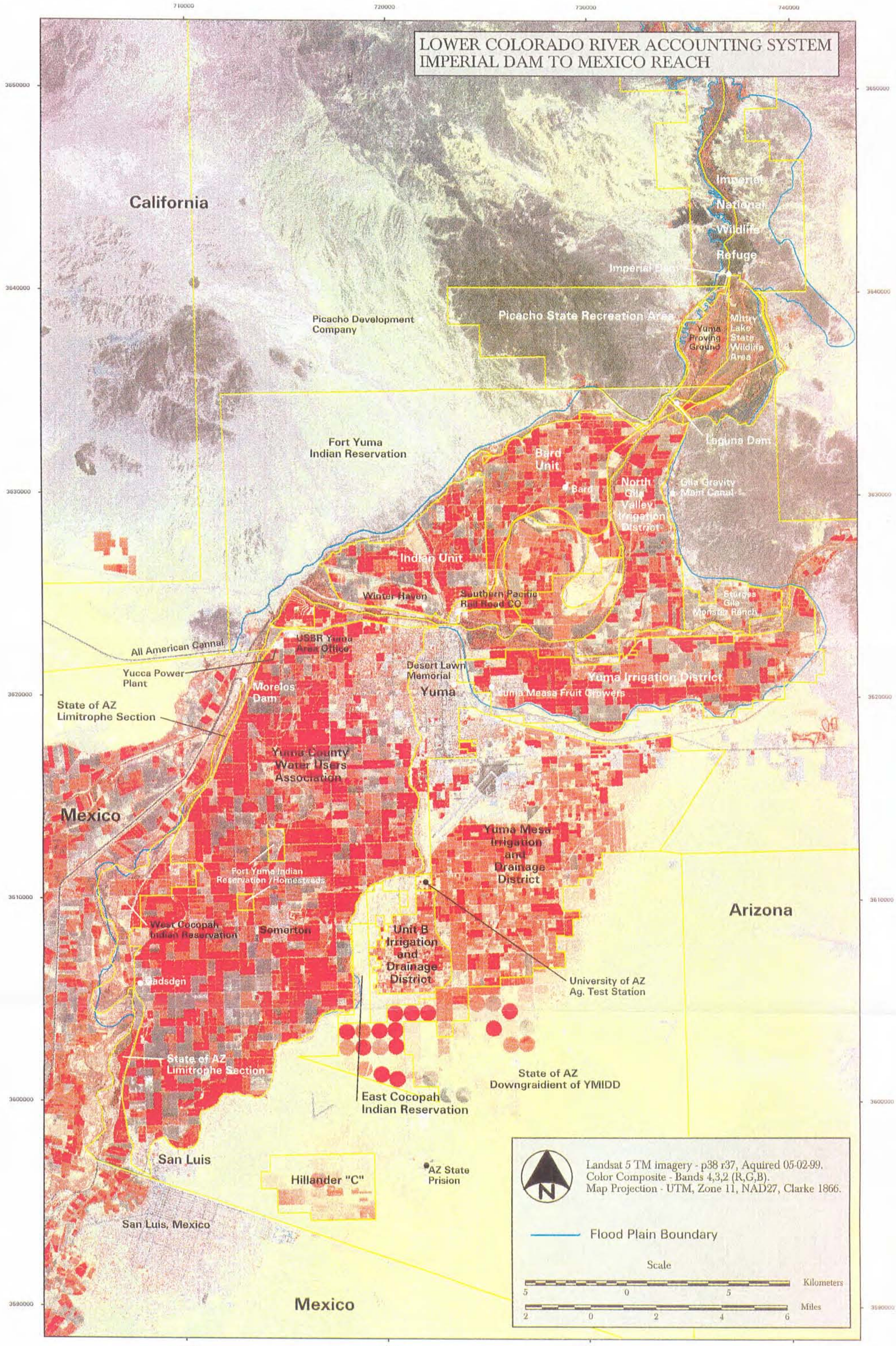

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 3 of 3)
Cibola National Wildlife Refuge
Imperial National Wildlife Refuge
Arizona
Yuma Proving Ground
Imperial National Wildlife Refuge
California
Martinez Lake
Senator Wash Resivor
Imperial National Wildlife Refuge
Imperial Dam
Picacho Development Company
Picacho State Recreation Area
Yuma Proving Ground
Mittry Lake State Wildlife Area
Landsat 5 TM imagery - p38 r37, Aquired 05-02-99.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
N
Flood Plain Boundary
Scale
Kilometers
Miles
720000
730000
740000
3680000
3670000
3660000
3650000
3640000

Exhibit 7


LOWER COLORADO RIVER ACCOUNTING SYSTEM
IMPERIAL DAM TO MEXICO REACH
California
Imperial National Wildlife Refuge
Imperial Dam
Picacho Development Company
Picacho State Recreation Area
Yuma Proving Ground
Mittry Lake State Wildlife Area
Fort Yuma Indian Reservation
Laguna Dam
Bard Unit
Bard
North Gila Valley Irrigation District
Gila Gravity Main Canal
Indian Unit
Winter Haven
Southern Pacific Rail Road CO
Sturges Gila Monster Ranch
All American Canal
USBR Yuma Area Office
Yucca Power Plant
Morelos Dam
Desert Lawn Memorial
Yuma
Yuma Irrigation District
Yuma Measa Fruit Growers
State of AZ Limitrophe Section
Yuma County Water Users Association
Mexico
Yuma Mesa Irrigation and Drainage District
Fort Yuma Indian Reservation /Homesteads
Arizona
West Cocopah Indian Reservation
Somerton
Unit B Irrigation and Drainage District
University of AZ Ag. Test Station
Gadsden
State of AZ Limitrophe Section
State of AZ Downgraidient of YMIDD
East Cocopah Indian Reservation
San Luis
Hillander "C"
AZ State Prision
San Luis, Mexico
Mexico
Landsat 5 TM imagery - p38 r37, Aquired 05-02-99.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
Flood Plain Boundary
Scale
Kilometers
5 0 5
Miles
2 0 2 4 6
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720000
730000
740000
3650000
3640000
3630000
3620000
3610000
3600000
3590000

Exhibit 8

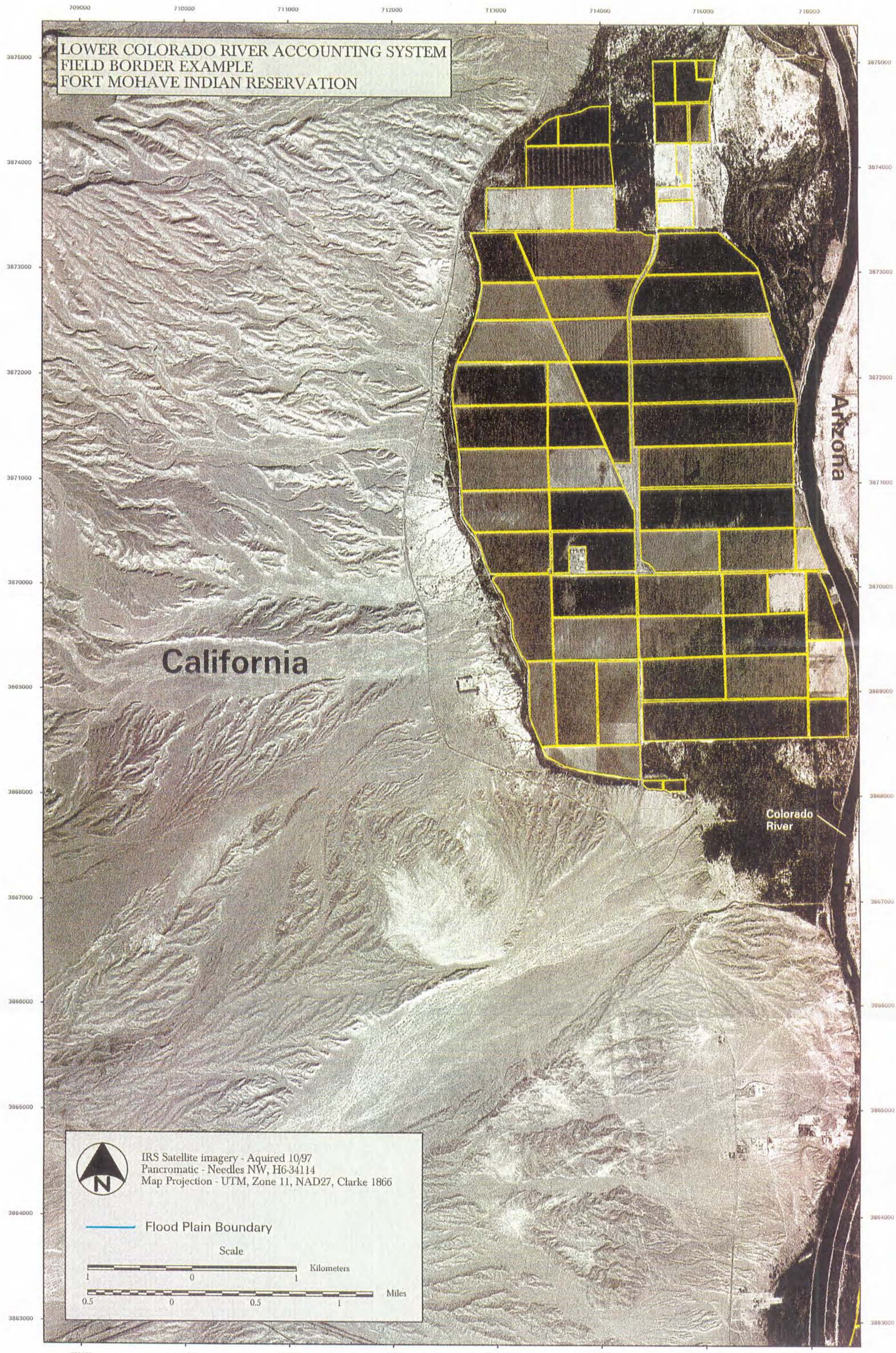
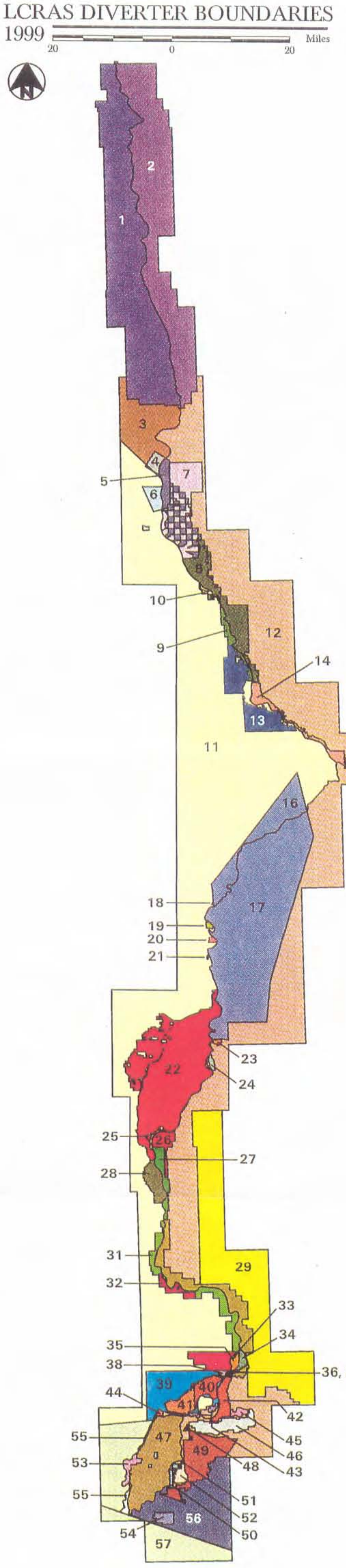

LOWER COLORADO RIVER ACCOUNTING SYSTEM
FIELD BORDER EXAMPLE
FORT MOHAVE INDIAN RESERVATION
California
Arizona
Colorado River
IRS Satellite imagery - Aquired 10/97
Pancromatic - Needles NW, H6-34114
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
Flood Plain Boundary
Scale
Kilometers
Miles

Exhibit 9



- (1) Lake Mead National Recreation Area, NV
- (2) Lake Mead National Recreation Area, AZ
- (3) State of Nevada
- (4) Fort Mohave Indian Reservation, NV
- (5) Fort Mohave Indian Reservation, AZ
- (6) Fort Mohave Indian Reservation, CA
- (7) Mohave Valley Irrigation and Drainage District, AZ
- (8) Havasu National Wildlife Refuge, AZ
- (9) Havasu National Wildlife Refuge, CA
- (10) Park Moabi, CA
- (11) State of California
- (12) State of Arizona
- (13) Chemehuevi Indian Reservation, CA
- (14) Lake Havasu State Park, AZ
- (15) Bill Williams National Wildlife Refuge, AZ
- (16) Colorado River Indian Reservation, CA
- (17) Colorado River Indian Reservation, AZ
- (18) North Lyn-De Farm, CA
- (19) Bernal Farm, CA
- (20) South Lyn-De Farm, CA
- (21) Clark Farm, CA
- (22) Palo Verde Irrigation District, CA
- (23) Ehrenberg Farm, AZ
- (24) Arkelian Farm, AZ
- (25) Palo Verde Irrigation District, AZ
- (26) Cibola Valley Irrigation and Drainage District, CA
- (27) Cibola National Willlife Refuge, AZ
- (28) Cibola National Wildlife Refuge, CA
- (29) Yuma Proving Ground, AZ
- (30) Imperial National Wildlife Refuge, AZ
- (31) Imperial National Wildlife Refuge, CA
- (32) Picacho State Recreation Area, CA
- (33) Imperial National Wildlife Refuge and Yuma Proving Ground, AZ
- (34) Mittry Lake State Wildlife Area, AZ
- (35) Yuma Proving Ground, CA
- (36) Fort Yuma Indian Reservation, Mittry Lake State Wildlife Area and Yuma Proving Ground, AZ
- (37) Fort Yuma Indian Reservation and Yuma Proving Ground, AZ
- (38) Fort Yuma Indian Reservation and Picacho State Recreation Area, CA
- (39) Fort Yuma Indian Reservation, CA
- (40) Fort Yuma Indian Reservation, Bard Unit, CA
- (41) Fort Yuma Indian Reservation, Indian Unit, CA
- (42) North Gila Valley Irrigation District, AZ
- (43) Fort Yuma Indian Reservation, AZ
- (44) North Cocopah Indian Reservation, AZ
- (45) Sturges Gila Monster Ranch, AZ
- (46) Yuma Irrigation District, AZ
- (47) Yuma County Waters Users Association, AZ
- (48) Desert Lawn Memorial
- (49) Yuma Mesa Irrigation and Drainage District, AZ
- (50) East Cocopah Indian Reservation, AZ
- (51) University of AZ-Ag Test Station, AZ
- (52) Unit B Irrigation and Drainage District
- (53) West Cocopah Indian Reservation, AZ
- (54) Hillander "C", AZ
- (55) State of Arizona - Limitrophe Section
- (56) State of Arizona - Downgradient of Yuma Mesa Irrigation and Drainage District
- (57) Mexico

Exhibit 10

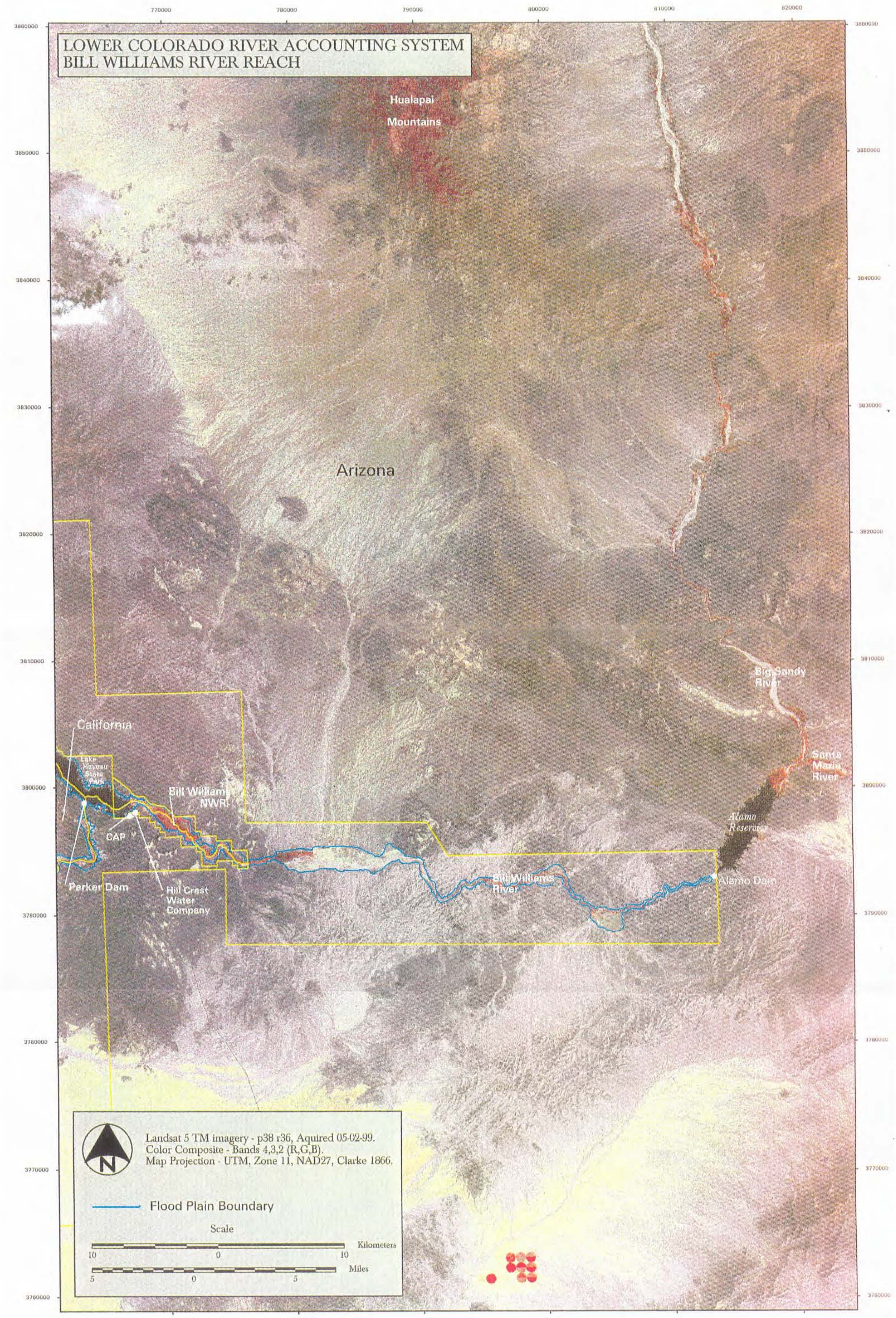

LOWER COLORADO RIVER ACCOUNTING SYSTEM
BILL WILLIAMS RIVER REACH
Hualapai
Mountains
Arizona
Big Sandy
River
Santa
Maria
River
Alamo
Reservoir
Alamo Dam
Bill Williams
River
California
Lake
Havasu
State
Park
Bill Williams
NWR
CAP
Parker Dam
Hill Crest
Water
Company
Landsat 5 TM imagery - p38 r36, Aquired 05-02-99.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
Flood Plain Boundary
Scale
Kilometers
Miles

Exhibit 11

Chapter 3

LCRAS Improvements

The LCRAS program is a program of continuous process improvement. Each application of LCRAS is reviewed, and lessons learned are incorporated in subsequent reports. Also, modifications are made to each application of LCRAS in response to long-term questions and issues as modified processes are made available. This type of continuous process improvement is expected to continue.

The following paragraphs describe potential improvements that have been identified and have been under active consideration during the past year. Below each item is a description of the changes made for this report, the change made which completed the item, the reason the item has been tabled or assigned a low priority and therefore reserved for future consideration, or the reason why the item was abandoned. Improvements or studies identified in the previous report that have been completed or assigned a low priority by the previous report are not repeated here.

Diverter Boundaries

Reclamation consulted with several irrigation districts to resolve discrepancies in diverter boundaries that exist between Reclamation's GIS coverage used for the previous report and the districts' service areas. Information gained through these meetings, and other information that has become available, has been used to update the diverter boundaries used in this report. Such information sharing and gathering will be an ongoing effort.

There were no diverter boundary changes made for 1999.

Crop Delineation and Acreage Summaries

The following improvements were incorporated for 1999:

Partial year acreage for annual crops such as alfalfa, bermuda, and orchards was calculated for improved consumptive use determination.

Crop groups were modified from those used for previous LCRAS Demonstration of Technology reports and crop subgroups (such as - young, mature, old for orchards) were developed for better consumptive use determination. See attachment 6 for a detailed discussion of this change for 1999.

Fields identified as vegetables in Spring 1999 were compared to Fall 1998 fields to avoid duplication of acreage calculations across the calendar year.

Image classification periods for the northern most processing area (see the area labeled TOP in figure Att-4.1 in attachment 4) were reduced from four to two. This decision was based on an analysis of crop planting practices in these areas which showed a much lower variation in cropping patterns than the other areas addressed by LCRAS. This reduction in image classification periods saved expenses and time in ground data collection and image processing without compromising the quality of the results.

Phreatophyte Water Use

What portion, if any, of the phreatophyte water use within the boundary of a diverter should be added to the consumptive use calculated for the diverter?

Reclamation has undertaken a series of internal meetings in an effort to develop internal consensus on the framework for a solution to this question. Reclamation will open this discussion to other Interior agencies, and then to the public after internal consensus is reached on the major issues that govern this question. This issue remains unresolved and is left open in this report.

Canal Losses

The losses from the All-American Canal, between Imperial Dam and Pilot Knob, and the Gila Gravity Main Canal are proportioned to the diverters that receive water from these canals by the current decree accounting method. These losses are not explicitly calculated in LCRAS for 1999.

The evaporation and phreatophyte water use associated with the operation of the Gila Gravity Main Canal are reported by the 1999 Decree Accounting Report as 1,397 acre-feet and 2,154 acre-feet respectively, for a total of 3,551 acre-feet. The equivalent total value for the All-American Canal was about 4,590 acre-feet in 1999. These losses are currently included in the residual of the water balance, and therefore a small portion of these losses is distributed to all users within the Imperial Dam to Mexico reach. This loss distribution is expected to be addressed as part of the LCRAS public process.

Open-Water Evaporation and Precipitation

Reclamation has introduced the use of additional precipitation information to supplement the information available from the AZMET and CIMIS stations (see the above sections describing crop ET and evaporation) with this report. The precipitation stations used to develop the effective precipitation for ET rate calculations can be found in the ET rate tables in Part I of the appendix. This item is complete and will be dropped from this section in future reports.

Reclamation is planning an evaporation study along the lower Colorado River. Plans currently include placing meteorological stations over water. Evaporation will continue to be addressed as part of the LCRAS public process.

Identifiable Patterns In Residuals

The pattern, or change, in the value of the residual for each reach of the water balance over time could assist with understanding the potential for bias in the measured flows used for Q_{us} and Q_{ds}. For example, a bias might be inferred if the residual in a reach is consistently positive or negative over time. Table 10, below, displays the water-balance residuals for the reaches used by LCRAS for 1995 through 1999.

Table 10 — Residuals By Reach And By Year
(Units: annual acre-feet)

Year	Hoover Dam to Davis Dam		Davis Dam to Parker Dam		Parker Dam to Imperial Dam		Imperial Dam to Mexico		Hoover Dam to Mexico	
	Acre-Feet	% of Q_{us}	Acre-Feet	% of Q_{us}	Acre-Feet	% of Q_{us}	Acre-Feet	% of Q_{us}	Acre-Feet	% of Q_{us}
1995	125,815	1.47%	-376,267	-4.52%	-180,481	-2.69%	106,064	1.89%	-324,869	-3.80%
1996	-62,469	-0.63%	-198,208	-2.00%	14,051	0.19%	142,625	2.34%	-104,001	-1.04%
1997	-94,144	-0.81%	-6,429	-0.06%	-43,780	-0.52%	98,706	1.34%	-45,647	-0.39%
1998	-114,548	-0.90%	-81,568	-0.63%	175,118	1.69%	31,365	0.34%	10,367	0.08%
1999	-223,980	-2.03%	-169,837	-1.53%	35,137	0.42%	-2,522	-0.04%	-361,202	-3.27%

Chapter 4

Conclusion and Future Activities

The goal of the LCRAS program is to improve consumptive use calculations for decree accounting. Reclamation has developed a consultation process to provide water users and State and Federal agencies affected by decree accounting an opportunity to gain an understanding of how LCRAS works, to examine the data and assumptions used, and to provide input to improve LCRAS and future reports. Reclamation is working with the State water agencies, Federal agencies, Tribes, and diverters to make the method as complete, consistent, and accurate as possible.

The accounting of water use in accordance with Article V of the Supreme Court Decree will proceed over the next few years as follows:

1. Reclamation plans to implement LCRAS upon the resolution of the question concerning the amount, if any, of the phreatophyte water use that should be included in the calculation of consumptive use for diverters. The resolution of this question was initially projected to be available in time to implement LCRAS for calendar year 2000. This question however, remains unresolved. Reclamation will use the current decree accounting method to develop the official Decree Accounting Report until LCRAS is implemented.
2. Reclamation will continue to calculate consumptive use using LCRAS in parallel with the current Decree Accounting Report for calendar year 2000, and future years until the question above is resolved, to compare the results of the two methods. The purpose of this exercise is to acquaint the users of the Decree Accounting Report with LCRAS.

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Attachment 1

Colorado River History and Legal Framework

The lower Colorado River (the Colorado River below Lee Ferry, also referred to as Compact Point) is a critical part of the Southwest's environmental and economic structure. The lower Colorado River and its tributaries have been extensively developed and used since the early 1900s, primarily to meet irrigation and domestic water supply needs; and since the 1930s, to generate electric power. Urban communities that receive water from the lower Colorado River include Las Vegas, Phoenix, Los Angeles, and San Diego.

Today, the waters of the lower Colorado River are needed more than ever to meet the increasing needs of agriculture, cities and suburbs, Native Americans, recreationists, and other interests in the United States and Mexico. At the same time, the United States must continue to meet existing contract obligations to power and water customers and enhance habitat needs for fish and wildlife.

The lower Colorado River is managed and operated under numerous compacts, Federal laws, court decisions and decrees, contracts, and regulatory guidelines and actions collectively known as the "Law of the River," including the five components discussed below.

Colorado River Compact

The cornerstone of the "Law of the River," the Colorado River Compact (Compact) was negotiated by the seven Colorado River Basin States and the Federal Government in 1922. It defined the relationship between the Upper Division States—where most of the river's water source originates—and the Lower Division States, where most of the water use was developing. At that time, the Upper Division States were concerned that plans for Hoover Dam and other water development projects in the Lower Basin would, under the western water law “doctrine of prior appropriation,” deprive them of their ability to use the river's flows in the future.

The States could not agree on how the waters of the Colorado River Basin should be allocated among them, so the Compact simply divided the Colorado River Basin into an Upper Basin and a Lower Basin and gave each basin the right to develop and use 7.5 million acre-feet of river water annually. The Upper and Lower Basins must share any obligation to Mexico. This approach reserved water for future Upper Basin development and allowed planning and development in the Lower Basin to proceed.

Boulder Canyon Project Act of 1928

This act accomplished the following:

- Ratified the 1922 Colorado River Compact
- Authorized the construction of Hoover Dam and related irrigation facilities in the Lower Basin
- Authorized the Lower Division States to enter into an agreement which would provide that of the 7.5 million acre-feet apportioned to the Lower Basin, 2.8 million acre-feet would be apportioned to Arizona and 0.3 million acre-feet would be apportioned to Nevada.
- Authorized and directed the Secretary of the Interior (Secretary) to function as the water contracting authority for Colorado River water use in the Lower Basin and specified that no one is entitled to use Colorado River water without a contract with the Secretary.

Mexican Water Treaty of 1944

This treaty committed 1.5 million acre-feet of the Colorado River's annual flow to Mexico, and authorized delivery of up to 1.7 million acre-feet in any year in which surplus water is available in excess of the amount necessary to supply uses in the United States and the guaranteed 1.5 million acre-feet delivery to Mexico.

Arizona v. *California* Supreme Court Decision and Decree

In 1963, the Supreme Court rendered an opinion and issued a decision that settled a 25-year-old dispute between Arizona and California regarding water supplies and what is considered Colorado River water. The opinion concluded that Congress, in passing the Boulder Canyon Project Act, created its own scheme for apportionment among Arizona, California, and Nevada of the Lower Basin’s share of mainstream Colorado River water. Further, the opinion noted that Congress gave the Secretary adequate authority to accomplish this apportionment of water by giving the Secretary the power to make contracts for the delivery of water and providing that no one could use Colorado River water without a contract with the Secretary. Moreover, the opinion confirmed that use of water from the Gila River, a Colorado River tributary, did not constitute a use of Arizona’s Colorado River apportionment.

The Supreme Court issued its decree in 1964. The Decree established decreed rights for Indian Communities, wildlife refuges, and other senior water users that either used Colorado River water prior to the effective date of the Boulder Canyon Project Act (June 25, 1929) or had a right to do so.

The decree enjoined the Secretary from delivering water outside the framework of apportionments defined by the law and mandated that consumptive use of water will be charged against the State in which it is used. The decree also requires the Secretary to develop an annual report documenting all diversion and consumptive uses of Colorado River water in all three Lower Division States.

1968 Colorado River Basin Project Act

This Act authorized construction of a number of water development projects in both the upper and lower Basins, including the Central Arizona Project. It also made the priority of the Central Arizona Project water supply subordinate to California's apportionment in times of shortage and directed the Secretary to prepare, in consultation with the Colorado River Basin States, long-range operating criteria for the Colorado River reservoir system.

Management of the lower Colorado River is unique. The Secretary serves as the lower Colorado River Water Master. In the Lower Division, the Secretary performs a role similar to that of a State engineer in allocating, contracting, and administering water rights. Through the Bureau of Reclamation, the Secretary contracts for all water used in the Lower Division States, with the exception of certain Federal entitlements, and reports the use of water in a manner consistent with the law.

Attachment 2

Measured and Unmeasured Flows for Each Reach

Measured Flows

Reach	Description	Flow in acre-feet	Station Number
Hoover Dam to Davis Dam			
	Colorado River below Hoover Dam	11,033,000	09421500
	Change in storage, Lake Mohave [A]	54,100	09422500
Davis Dam to Parker Dam			
	Colorado River below Davis Dam	11,070,300	09423000
	Colorado River Aqueduct [B]	1,212,067	09424150
	Bill Williams River below Alamo Dam	24,240	09426000
	Central Arizona Project Canal [B]	1,388,165	09426650
	Change in storage, Lake Havasu [A]	-60,900	09427500
Parker Dam to Imperial Dam			
	Colorado River below Parker Dam	8,353,300	09427520
	Change in storage, Senator Wash [A]	-1,878	
	Colorado River at Imperial Dam	7,205,263	09429490
Imperial Dam to Mexico			
	Diversion to Mittry Lake	11,157	09522400
	All-American Canal	5,859,800	09523000
	All-American Canal below Pilot Knob	3,418,200	09527500
	Gila Gravity Main Canal [C]	796,046	09522500
	Wellton-Mohawk Canal [C]	347,407	09522700
	Colorado River below Imperial Dam	538,260	09429500
	Gila River near Dome	7,017	09520500
	Colorado River at NIB [D]	2,759,700	09522000
	Eleven Mile wasteway [D]	4,777	09525000
	Cooper wasteway [D]	1,003	09531850
	Twenty-one Mile wasteway [D]	1,782	09533000
	Main drain + 242 wells [D]	112,320	09534000
	West Main Canal wasteway [D]	8,145	09534300
	East Main Canal wasteway [D]	6,456	09534500

A. Geological Survey - December 1998 minus December 1999.
B. Provided by the user and published by the Geological Survey.
C. Bureau of Reclamation open-channel acoustic velocity meter data.
D. Provided by International Boundary and Water Commission on a monthly basis.

Unmeasured Tributary Inflow Estimates

Reach	Description		Flow in acre-feet
Hoover Dam to Davis Dam			
	Springs		3,080
	Unmeasured runoff		2,100
	Groundwater discharge		200
	Eldorado Valley		1,100
Davis Dam to Parker Dam			
	Unmeasured Runoff		
		Davis Dam to Topock	12,000
		Topock to Parker Dam	15,000
		Whipple Mountains	1,150
	Unmeasured Runoff From Tributary Streams		
		Piute Wash	1,000
		Sacramento Wash	2,500
		Bill Williams River subarea[E]	4,000
	Groundwater discharge		
		Davis Dam to Topock	0
		Topock to Parker Dam	880
		Piute Valley	2,300
		Sacramento Valley	1,200
		Chemehuevi Valley	260
		Bill Williams River subarea[E]	4,000
Parker Dam to Imperial Dam			
	Unmeasured Runoff		
		Whipple Mountains	1,150
		Big Marie-Riverside Mountains	2,300
		Palo Verde-Mule Mountains	1,200
		Dome Rock-Trigo-Chocolate Mountains	16,200
	Unmeasured Runoff in Tributary Streams		
		Vidal Wash	1,300
		Bouse Wash	4,800
		Tyson Wash	2,600
		McCoy Wash	800
		Milpitas Wash	1,200
	Groundwater Discharge		
		Bouse Wash	1,200
		Tyson Wash	350
		Vidal Wash	250
		Chuckwalla Valley	400

E. Not included in unmeasured inflows to the Lower Colorado River below Hoover Dam. These flows are used in the Bill Williams reach to estimate inflow to Lake Havasu from the Bill Williams River.

Reach	Description		Flow in acre-feet
Imperial Dam to Mexico			
	Groundwater Discharge		
		Gila River	1,000
		Unmeasured runoff, Yuma area	2,000
Total Unmeasured Inflow to the lower Colorado River, Hoover Dam to Mexico			79,520

Attachment 3

Results in Tabular Form

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Nevada				
Lake Mead National Recreation Area, NV.	302	0	308	Lake Mead National Recreation Area, diversion from Lake Mohave (Cottonwood). Reported as a diversion.
Cottonwood Cove (domestic consumptive use).	0	184		
Southern California Edison (domestic consumptive use).	0	12,084	12,148	Southern Nevada Water Authority (Southern California Edison), pumped from Sec 24 T32S R66E. Diversion = consumptive use.
Big Bend Water District (domestic consumptive use).	0	2,161	2,162	Big Bend Water District Diversion Sec 12 T32S R66E. Reported as a consumptive use.
Sportsman's Park.	0	1	2	Sportsman's Park. Value in 1999 decree accounting report is in error, correction will be noted in the 2000 report.
Boy Scouts (domestic consumptive use).	0	4	7	Boy Scouts of America. Reported as a diversion.
Fort Mojave Indian Reservation, NV.	8,116	1,766	4,894	Fort Mohave Indian Reservation (Avi), 2 wells, sections 27 & 5. Reported as a diversion.
Fort Mojave Indian Reservation, NV (Avi) (domestic consumptive use).	0	870		
State of Nevada[F].	11,401	0		Not reported.
Subtotal: Uses below Hoover Dam.	19,819	17,070	19,521	Subtotal: Uses below Hoover Dam.
Uses above Hoover Dam [G].		271,615	271,615	Uses above Hoover Dam.
			1,615	Unmeasured return flow credit to Nevada.
Nevada Total.	19,819	288,685	289,521	Nevada Total.

[F] Includes all crop and domestic consumptive use, and phreatophyte water use not identified with a known diverter.

[G] From 1999 Decree Accounting.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
California				
Fort Mojave Indian Reservation, CA.	4,525	14,871	21,109	Fort Mohave Indian Reservation, pumped from river and wells. Reported as a diversion.
Needles (domestic consumptive use).		1,209	1,209	City of Needles, 4 wells NW SW Sec 29 T9N R23E SBM. Reported as a consumptive use.
Havasu Water Company.		40	68	Havasu Water Company. 1 well, T5N/R25E Sec31. Value in 1999 decree accounting report is in error, correction will be noted in the 2000 report.
Colorado River Aqueduct (export).		1,209,840	1,212,067	Metropolitan Water District, diversion from Lake Havasu. Reported as a consumptive use.
Parker Dam/Gov't. Camp (domestic consumptive use).	0	81	134	Parker Dam and Government Camp, diversion at Parker Dam. Reported as a consumptive use.
Total Colorado River Indian Reservation, CA[H].	36,267	2,769	5,788	Colorado River Indian Reservation, pumped from 11 pumps and wells, 4 pumps Big River. Reported as a diversion[I].
Colorado River Indian Reservation, CA.	34,951	0		
North Lyn-De Farm, CA[J].	2	758		
South Lyn-De Farm, CA.	2	1,447		
Bernal Farm, CA.	1,176	0		
Clark Farm, CA.	136	564		

[H] Some uncertainty exists concerning the southerly Colorado River Indian Reservation boundary in CA.

[I] Includes North Lyn-De Farm, CA; South Lyn-De Farm, CA; Bernal Farm, CA; and Clark Farm, CA. Some well locations near or in CRIR are questionable.

[J] A portion of North Lyn-De farm is not within Colorado River Indian Reservation boundary.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Total Chemehuevi Indian Reservation, CA.	49	128	265		Chemehuevi Indian Reservation, pumped from river and wells (Reported as a diversion).
Chemehuevi Indian Reservation, CA.	49	128			
Chemehuevi Indian Reservation, CA. (domestic use not reported in 1999).	0	0			
Park Moabi, CA.	262	0			Not Reported.
Havasu National Wildlife Refuge, CA.	5,773	0			Not reported.
BLM-Black Meadow (Domestic Consumptive Use)	0	106			Included in BLM Permittees (LHFO & YFO) below.
BLM Permittees, CA.	0	203	515		BLM Permittees (LHFO & YFO).
Total Palo Verde Irrigation District, CA.	8,799	395,954	468,888		Palo Verde Irrigation District, diversion from Palo Verde Dam. Reported as a consumptive use.
Palo Verde Irrigation District, CA.	8,247	392,231			
Palo Verde Irrigation District, AZ.	552	719			
Blythe (city, domestic consumptive use).	0	2,905			
Ripley (domestic consumptive use).	0	53			
Palo Verde (domestic consumptive use).	0	46			
Cibola National Wildlife Refuge, CA.	18,153	0			Not reported.
Imperial National Wildlife Refuge, CA.	19,184	0			Not reported.
Winterhaven (domestic consumptive use).	0	74	124	124	City of Winterhaven, 1 well, SE NE NE Sec 27 T16S R22E SBM.
					Town of Winterhaven, 1 well, 6S-22E 27DAA (Not Reported).
					Reported as diversions.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use	Diverter name	
LCRAS			**Decree Accounting**		
Fort Yuma Indian Reservation and Picacho State Recreation Area, CA.	5	0		Not reported.	
Picacho State Recreation Area, CA.	4,528	0		Not reported.	
Picacho Development Corp., CA (domestic consumptive use).	0	43	72	Picacho Development Corp. Reported as a diversion.	
All-American Canal below Pilot Knob[K].	0	3,417,958	3,422,790	3,088,980	Imperial Irrigation District, diversion at Imperial Dam.
				333,810	Coachella Valley Water District, diversion at Imperial Dam.
				Reported as consumptive uses.	
Earp (domestic consumptive use).	0	133		Not reported.	
Vidal (domestic consumptive use).	0	5		Not reported.	
Big River (domestic consumptive use).	0	99		Not reported.	
Southern California Gas (domestic consumptive use).	0	51	86	Southern California Gas. Reported as a diversion.	
Pacific Gas & Electric	0	6	9	Pacific Gas & Electric	
Imperial National Wildlife Refuge and Yuma Proving Ground, CA.	48	0		Not reported.	
Yuma Proving Ground, CA.	8,182	20		Not reported.	
Fort Yuma Indian Reservation and Yuma Proving Ground, CA .	825	0		Not reported.	

[K] Final estimate of export at gauge number 09527500.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use			Diverter name
LCRAS			**Decree Accounting**			
Total Fort Yuma Indian Reservation, CA.	14,243	44,999	46,226		31,182	Yuma Projects, Reservation Division Indian Unit, diversion at Imperial Dam (consumptive use).
Fort Yuma Indian Reservation, Indian Unit, CA.	508	16,057			48,620	Yuma Projects, Reservation Division Bard Unit, diversion at Imperial Dam (consumptive use).
Fort Yuma Indian Reservation, Bard Unit, CA.	807	25,026			37,383	Returns from Yuma Project, Reservation Division returns.
Bard (domestic consumptive use).	0	214		42,419		Sum Yuma Projects, Reservation Division (consumptive use).
Fort Yuma Indian Reservation, CA.	12,928	3,702		367		Valdez, Mike, Sec 35 T15S R23E DDC.
				34		Living Earth Farm, Sec 02 T16S R23E BBC.
				1,126		MivCo Packing, (C-16S-23E) 9CCA.
				0		Valdez, Mike, Sec 22 T16S R23E BDD.
				2,040		Power, Pete, Sec 14 T16S R23E CCB.
				240		Unknown, I.D., 1 well, 16S-22E 29 DAD.
				Wells are reported as diversions.		

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
State Of California[L].	48,168	9,897	14,633	246	Ida Cal, 11N/22W -31BAB.
				866	Ida Cal, 11N/21E -36ADD.
				443	Ida Cal, 11N/21E -36CDA.
				The above Ida Cal wells irrigate lands north of Fort Mohave Irrigation District in CA.	
				138	Lye, C.L., 1S/24E -16Gb.
				600	Harp, P. (R. Harp), (C-8-23) 13AAD.
				3,396	Horizon Farms, (C-8-22) 6CDA.
				225	Horizon Farms, (C-10-22) 7ABD.
				861	Horizon Farms, (C-8-22) 7BAB.
				225	Horizon Farms, (C-10-22) 6DCB.
				225	Horizon Farms, (C-8-22) 6BBD.
				0	Horizon Farms, (C-8-22) 6BCD.
				225	Horizon Farms, (C-10-22) 6CBB.
				846	Horizon Farms, (C-8-23) 1DCC.
				176	Horizon Farms, (C-8-23) 12CDB.
				773	Horizon Farms, (C-8-22) 6CBA.
				115	Living Earth Farm, (C-8-23) 2ADC.
					Ed Weavers Farms, (C-8-22) 6BCD (Not Reported).
				161	Horizon Farms, (C-8-22) 1BBA.

[L] Crop consumptive uses and phreatophyte water uses not within known diverter boundaries.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
				776	Ed Weavers Farms, (C-8-23) 1BAD.
				1,130	Horizon Farms (C-8-23) 12AAC
				0	Valdez, Mike, Sec T16S R23E SEC 30 ACC.
				0	Valdez, Mike, Sec T16S R23E SEC 30 ADD.
				117	Power, O.L., (C-8-23) 11 DCA.
				180	Harp, Robert, (C-8-23) 12 DAC.
				2,097	Dees, Alex, (C-8-23) 1 DAC.
				41	Wilson Farms, (C-8-23) 12 BBA.
				762	Land, K. H., (C-8-23) 2 DDA.
					Wells below have not been located, but are presumed to be within the State of CA polygons.
				5	Wetmore, Kenneth C.
				1	Williams, Jerry.
				3	Lindeman, William H. and Hazel D., Carney, Jerome D., and Phillips, Dorothy L. (3 wells).
			87,203		Unmeasured return flow credit to California.
California Total.	169,011	5,098,486	5,106,780		California Total.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Arizona					
Total Lake Mead National Recreation Area, AZ.	1,072	526	878		Lake Mead National Recreation Area, AZ, Diversions from Lake Mohave, (Katherine, Willow Beach). Reported as a diversion.
Lake Mead National Recreation Area, AZ (Hoover Dam to Davis Dam).	700	0			
Lake Mead National Recreation Area, AZ (Davis Dam to Parker Dam).	372	0			
Katherine Landing and Willow Beach (domestic consumptive use).	0	526			
Lower Colorado Region Dams Project (domestic consumptive use).	0	1	1		Lower Colorado Region Dams Project (Davis Dam), Diversion at Davis Dam. Reported as a consumptive use.
Bullhead City (domestic consumptive use).	0	4,690	7,690		Bullhead City, Pumped from wells. Reported as a diversion.
Mohave County Parks (domestic consumptive use).	0	77	128		Diversion at Davis Dam, Mohave Co. Parks. Reported as a diversion.
Arizona State Parks (Windsor Beach)	0	10	16		Arizona State Parks (Windsor Beach). Value in 1999 decree accounting report is in error, correction will be noted in the 2000 report.
Total Mohave Valley Irrigation and Drainage District	32,612	23,746	34,981		Total Mohave Valley Irrigation and Drainage District.
MVIDD (domestic consumptive use)[M].	0	2,687		34,981	Mohave Valley Irrigation and Drainage District, Pumped from wells. Reported as a diversion.
Mohave Valley Irrigation and Drainage District, AZ (includes no domestic use).	32,612	21,059			Domestic use. Reported as a diversion.

[M] Includes Bermuda City and other small domestic consumptive uses.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Fort Mojave Indian Reservation, AZ.	32,278	36,577	80,252	Fort Mohave Indian Reservation, 14 pumps and wells in flood plain. Reported as diversions.
Golden Shores (domestic consumptive use).	0	302	503	Golden Shores Water Conservation District, pumped from wells. Reported as a diversion.
Topock (domestic consumptive use).	0	126		Not reported.
Crystal Beach Water Conservation District	0	54	90	Crystal Beach Water Conservation District Reported as a diversion
Havasu Water Company, AZ (domestic consumptive use).	0	284	476	Havasu Water Co. of AZ (Citizens Utilities). Reported as a diversion.
Mohave Water Conservation District (domestic consumptive use).	0	376	626	Mohave Water Conservation District; pumped from wells. Reported as a diversion.
Brook Water (domestic consumptive use).	0	244	407	Brook Water, (was Consolidated Water Utilities), pumped from river. Reported as a consumptive use.
Havasu National Wildlife Refuge, AZ[N].	47,634	0	27,848	Havasu National Wildlife Refuge, Inlet-NW NE NW Sec 33 T9N RSSW, well 8N/23E-15Aa (Topock Marsh). Reported as a consumptive use.
Lake Havasu City & MCWUA, AZ (domestic consumptive use).	0	8,017	13,361	Lake Havasu City, pumped from wells. Reported as diversions.
Bill Williams National Wildlife Refuge (Lake Havasu).	994	0		Not reported.
Central Arizona Project Canal (export).	0	1,385,614	1,388,165	Central Arizona Project; pumped from Lake Havasu. Reported as a diversion.
Town of Parker (domestic consumptive use).	0	633	930	Town of Parker; pumped from river, 1 well-NW NW NW Sec 7 T9N R19W G&SRM. Reported as a consumptive use.

[N] Topock Marsh evaporation is estimated to be about 12,000 acre-feet. This evaporation is not assigned to any diverter for this report.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Lake Havasu State Park, AZ[O].	3,543	0			Not reported.
Poston (domestic consumptive use).	0	67			Not reported.
Colorado River Indian Reservation, AZ.	133,921	313,420	343,165		Colorado River Indian Reservation; diversion at Headgate Rock Dam, 1 pump from river (B-04-22) 14BBD & Town of Parker. Reported as a consumptive use.
Ehrenburg Improvement Association (domestic consumptive use).	0	260	434		Ehrenburg Improvement Association, 1 pump SW Sec 3 T3N R22W G&SRM. Reported as a diversion.
Cibola (domestic consumptive use).	0	26			Not reported.
Ehrenberg Farm, AZ.	1	2,989	4,679	4,352	Jack Rayner (B-04-22) 34 DCC (CDD).
				327	Jack Rayner (B-04-22)34 DCC (DCD).
					Reported as diversions.
Arkelian Farms, AZ.	2,202	1,567	2,208	0	George Arkelian (B-03-22)16 DBD (DAD).
				2,208	George Arkelian (B-03-22)16 DBD (DAD).
					Reported as diversions.

[O] May have missed a golf course.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Total Bureau of Land Management permittees (domestic consumptive use).	0	548	954		Bureau of Land Management permittees (LHFO & YFO). Reported as a diversion.
Bureau of Land Management permittees (Davis Dam to Parker Dam).	0	73			
Bureau of Land Management permittees (Parker Dam to Imperial Dam).	0	475			
Hillcrest Water Company (domestic consumptive use).	0	12	0		Hillcrest Water Co. Reported as a diversion.
Total Yuma Proving Ground.	362	484	806		Yuma Proving Ground, diversion at Imperial Dam, wells X,Y,M. Reported as a consumptive use.
Yuma Proving Ground.	362	0			
Yuma Proving Ground (domestic consumptive use).	0	484			
Fort Yuma Indian Reservation, Mittry Lake State Wildlife Area and Yuma Proving Ground, AZ.	837	0			Not reported.
Fort Yuma Indian Reservation and Homesteads, AZ.	3,830	1,397	5,608	1,659	Dulin, A (C-8-22) 9 CCC.
				278	Dulin, A (C-8-22) 7 DAC.
				0	Glen Curtis Cit (C-8-22) 18 CBD.
				600	Glen Curtis Cit (C-8-22) 18 DDD.
				2,111	Glen Curtis Cit, (C-8-22) 7 CCD.
				960	Yowelman, R., Sec 17 T08S/ R22W CBC.
				Reported as diversions.	
Martinez Lake (domestic consumptive use).	0	1			Not reported.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Cibola Valley Irrigation and Drainage District, AZ.[P]	6,153	15,098	26,920		Cibola Valley Irrigation District, 5 pumps Sections 20, 21, and 26T1N R23W. Reported as a diversion.
Cibola National Wildlife Refuge, AZ.	45,413	6,109	8,641	8,161	Cibola National Wildlife Refuge, 5 pumps, Section 2 and 31 T1S R23W. Reported as a diversion.
				480	Cibola Sportsman Sec. 31, T1S, R23W, CCB
Imperial National Wildlife Refuge, AZ.	31,873	231	8,000		Imperial National Wildlife Refuge, 2 wells, Sec 13 T5S R22W G&SRM. Reported as a diversion.
Mittry Lake State Wildlife Area, AZ.	9,867	188	360		Pumper L. Pratt Sec 14 T7S R22W ABC.
Sturges Gila Monster Ranch, AZ.	48	6,083	14,628		Sturges, diversions at Imperial Dam (Warren Act). Reported as a consumptive use.
City of Yuma (domestic consumptive use).	0	17,663	17,669		City of Yuma, diversion at Imperial Dam (All-American Canal), diversion at Imperial Dam (Gila). Reported as a consumptive use.
Marine Corps Air Station [Q] (domestic consumptive use).	0	1,022	1,703		Marine Corps Air Station (Yuma), diversion at Imperial Dam. Reported as a diversion.
Southern Pacific Company (domestic consumptive use).	0	29	48		Southern Pacific Company, diversion at Imperial Dam. Reported as a diversion.
Yuma Mesa Fruit Growers (domestic consumptive use).	0	7	12		Yuma Mesa Fruit Growers Association, diversion at Imperial Dam. Reported as a diversion.

[P] Part is on the California side of the river.

[Q] Located within Yuma Mesa Irrigation and Drainage District, AZ boundary.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
University of Arizona.	0	265	1,090		University of Arizona, diversion at Imperial Dam (Warren Act). Reported as a diversion.
University of Arizona crop CU & Phreatophyte water use.	0	265			
Underflow to Mexico from the application of water by the U. of A.[R]	0	0			
Yuma Union High School (domestic consumptive use).	0	115	191		Yuma Union High School, diversion at Imperial Dam. Reported as a diversion.
Desert Lawn Memorial.	0	395	394		Desert Lawn Memorial, diversion at Imperial Dam. Reported as a diversion.
North Gila Valley Irrigation District, AZ.	821	18,063	18,567		North Gila Valley Irrigation District, diversion at Imperial Dam. Reported as a consumptive use.
Yuma Irrigation District, AZ.	303	32,111	50,823	50,590	Yuma Irrigation District, diversion at Imperial Dam and pumped from private wells. Reported as a consumptive use.
				198	Cameron Bros Sec 24 T08S R22W CCB.
				0	Cameron Bros Sec 24 T08S R22W CAD.
				35	Judd T. Ott Sec 30 T08S R22W BAB.
				Individual wells are reported as diversions.	

[R] The portion of the underflow to Mexico across the Southerly International Boundary is presumed to result from the application of water within the service areas of the University of Arizona. The amount of the underflow to Mexico across SIB contributed by the University of Arizona is presumed to be negligible and is considered to be zero in this report. See Attachment 5 for a detailed explanation.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Total	0	114,558	179,690	Yuma Mesa Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use[S].
Yuma Mesa Irrigation and Drainage District, AZ.	0	71,252		
Underflow to Mexico[T].		23,900		
Consumptive use by down gradient users[U].	0	13,462		
Hillander "C" Irrigation District, AZ .	0	5,932		
The Prison (domestic consumptive use).	0	12		

[S] Includes underflow to Mexico across the Southerly International Boundary, the use by crops and domestic users down gradient of the district between the southern boundary of the district and Mexico, and the Hillander "C" Irrigation and Drainage District.

[T] The underflow to Mexico across the Southerly International Boundary presumed to result from the application of water within Yuma Mesa I&DD's service area (about 47% of 50,900, or 23,900, acre-feet, rounded to nearest 100 acre-feet after the distribution of the residual in the Imperial Dam to Mexico reach).

[U] The water use on land in Arizona down gradient of the Yuma Mesa Irrigation and Drainage District. Water applied in this area does not return to the Colorado River above the Northerly International Boundary with Mexico.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use	Diverter name	
LCRAS			**Decree Accounting**		
Total Yuma County Water Users Association, AZ.	4,124	180,984	243,496	237,587	Yuma County Water Users Association, diversion at Imperial Dam and pumped from wells[V].
Yuma County Water Users Association, AZ.	18	142,804		300	Burrell, Sec 33 T08S R24W BAB.
Underflow to Mexico[W].		33,800		19	Farmland Management Sec 19 T09S R24W BAD.
State of Arizona - Limitrophe Section.	4,106	2,136		60	Farmland Management, Sec19 T09S/ R24W BDD.
City of Somerton (domestic use).	0	720		35	Farmland Management, Sec19 T09S/ R24W BDA
City of Gadsden (domestic use).	0	24		978	Waymon Farms, Sec 36 T09S/R24W AAA.
City of San Luis (domestic use).	0	1,500		1,128	Waymon Farms Sec 31 T09S R24W BBB.
				1,026	J.W. Cumings, (C-10-25) 1BBA.
				State of Arizona Limitrophe Section:	
				318	J.W. Cumings (C-10-25), 14ADB.
				480	C & J Cummings, (C-10-25) 26BAB.
				480	J. Barkley, (C-10-25) 25CBA.
				718	Brown, Rodger S., (C-11-25) 2BBA.
				367	Earl Huges, (C-11-25) 3DAC.

[V] Includes the water use by the cities of Somerton, Gadsden, and San Luis; use by lands between the district boundaries and the Limitrophe boundary with Mexico; and underflow that crossed the Limitrophe section and the southerly international boundary (SIB) into Mexico. Individual wells reported as diversions.

[W] The underflow to Mexico across the Limitrophe section and SIB presumed to result from the application of water within Yuma County Water Users Association's service area (about 98 percent of 17,400, or 17,000, acre-feet) plus (about 33% of 50,900, or 16,800, acre-feet) as documented in attachment 5.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Total Unit B Irrigation and Drainage District, AZ.	0	9,621	22,414	22,414	Unit "B" Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use[X].
Unit B Irrigation and Drainage District, AZ.	0	8,121		0	Camille, Alec, Jr., diversion at Imperial Dam (Warren Act). Reported as a diversion. (Located with Unit B's diverter boundary)
Underflow to Mexico[Y].		1,500			
Total West Cocopah Indian Reservation, AZ.	5,916	5,987	14,085	11,505	Cocopah Indian Reservation, diversion at Imperial Dam. Pumped from wells, Pumped from wells, West Cocopah. Reported as a consumptive use[Z].
West Cocopah Indian Reservation, AZ.	5,916	5,587		630	W. Brand, D. Donnely (C-9-25) 35 ABA.
Underflow to Mexico[AA].		400		1,950	P. Sibley, (C-10-25) 2CDA.
				Wells reported as diversions.	
Yuma Area Office, Bureau of Reclamation (Domestic consumptive use).	0	968	968	Yuma Area Office, USBR diversion from Well No.8. Reported as a consumptive use.	

[X] Includes a portion of the underflow to Mexico across the Southerly International Boundary.

[Y] The underflow to Mexico across the Southerly International Boundary presumed to result from the application of water within Unit B I&DD's service area (about 3 percent of 50,900, or about 1,500 acre-feet, rounded to the nearest 100 acre-feet).

[Z] Diversions are from the Gila Gravity Main Canal, 9 wells reported by the Geological Survey in sections 25, 26, and 36, and wells reported by Yuma Area Office, Bureau of Reclamation (locations unknown).

[AA] The portion of the underflow to Mexico across the Limitrophe Section that is presumed to be from the application of water on the West Cocopah Indian Reservation. Estimated to be about 2 percent of the total underflow (17, 400 acre-feet, or about 400 acre-feet, rounded to the nearest 100 acre-feet). Basis: The acres irrigated by the West Cocopah Indian Reservation are about 2 percent of the combined acres irrigated by the West Cocopah Indian Reservation and the Yuma Valley Water Users Association.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Yucca Power Plant [BB](domestic consumptive use).	0	775	775	Yucca Power Plant. Sec 36 T16S R21E CBA. Reported as a diversion.	
Total North Cocopah Indian Reservation, AZ.	710	845	1,092	752	Huerta Packing 16S/22E-30CDA.
North Cocopah Indian Reservation, AZ.	710	641		0	Huerta Packing 16S/21E-25DAA.
Cocopah Bend RV (domestic consumptive use)[CC].	0	204		340	Cocopah Bend RV. 1 well, Sec 30 T16S R22E BDB.
				Reported as diversions.	
East Cocopah Indian Reservation, AZ. (domestic consumptive use + bingo)	0	14		Not reported.	
Yuma County (domestic consumptive use).	0	4,794		Not reported.	

[BB] Reported well location plots within the North Cocopah Indian Reservation.

[CC] Located within North Cocopah Indian Reservation.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
State of Arizona[DD].	32,579	9,531	9,542	432	Hall, Ansil (Sec 36 T16S R21E BCB
				121	Amigo Farms (Sec 28 T16S R22E CDA.
				293	Curry Family LTD (Sec 29 T16S R22E DAC
				2,850	R.E. & P. Power (Sec 29 T16S R22E BCC
				668	Ogram, George, Sec 24 T08S R23W DCC
				0	Ogram, George, Sec23 T08S R23W CDA (Indeterminate location)
				458	Peach, Sec 22 T08S R23W DCC
					AZ prod, Sec 23 T08S R23W CDA (not Reported)
				537	Ott, Judd T., (C-8-22) 19CCA
				300	Glen Curtis Cit (C-8-22) 24BDD
				3,240	Glen Curtis Cit (C-8-22) 24BDD
				643	Ott, Lee & Larry (Sec. 23 T8S R23W).
				Reported as diversions.	

[DD] Includes crop and domestic consumptive uses, and phreatophyte water uses not associated with any identified diverter boundary.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS				**Decree Accounting**
Arizona Subtotal (Below Hoover Dam, less Wellton-Mohawk Irrigation and Drainage District).	397,093	2,207,504	2,535,314	Arizona Subtotal (Below Hoover Dam, less Wellton-Mohawk Irrigation and Drainage District).
			74,223	Pumped from South Gila Wells (drainage pump outlet channels): Returns.
Arizona uses above Hoover Dam[EE].		158	158	Arizona uses above Hoover Dam.
				134 Lake Mead Nat'l Recreation, AZ. Diversions from Lake Mead (Temple Bar).
				24 Marble Canyon Company.
Wellton-Mohawk Irrigation and Drainage District [EE].		266,730	266,730	Wellton-Mohawk Irrigation and Drainage District.
			148,258	Unmeasured return flow credit to Arizona.
Arizona Total.	397,093	2,474,392	2,579,721	Arizona Total.
Total Lower Basin Use.	585,923	7,861,563	7,976,022	Total Lower Basin Use[FF].

[EE] From 1999 Decree Accounting Report.

[FF] Includes some unquantified amount of phreatophyte water use.

Selected Results in Graphic Form

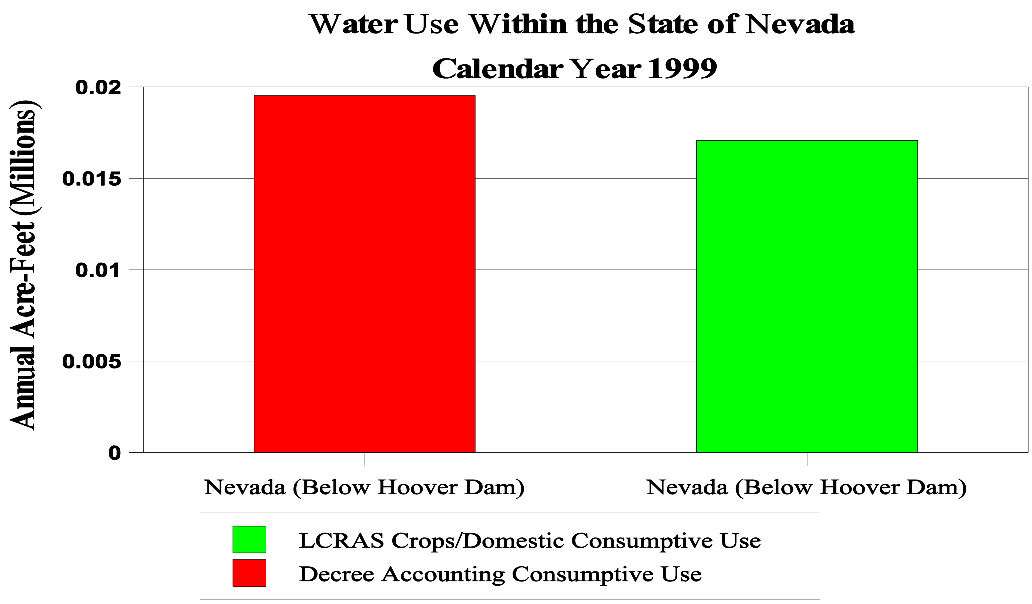
A list of the bar charts included on the following pages and a short interpretation of the information displayed upon them are presented below:

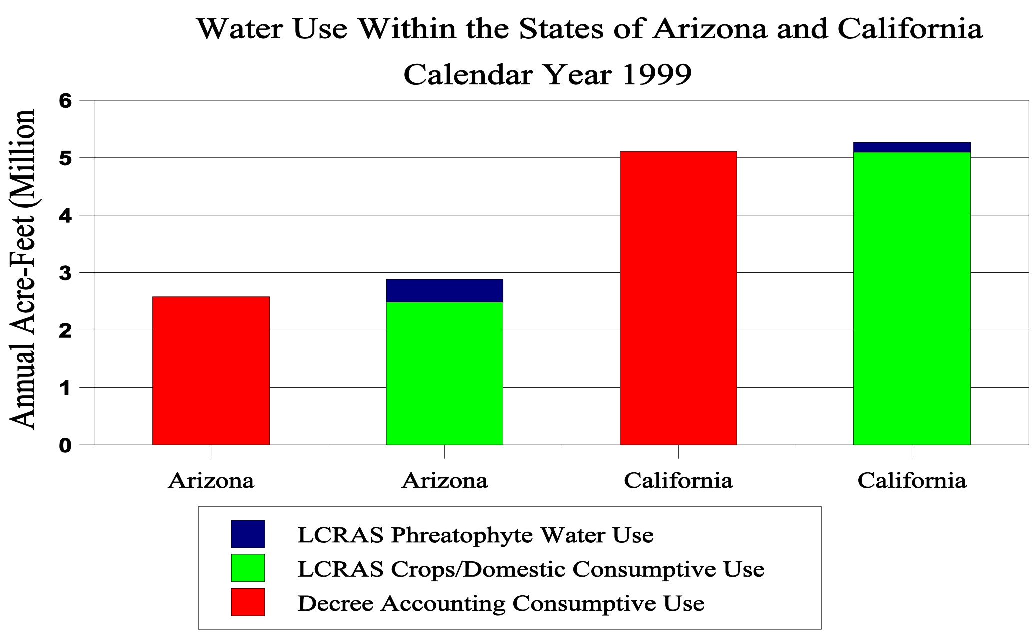
Water Use within the State of Nevada
Water Use within the States of Arizona and California
Water Use within the Palo Verde Irrigation District (CA)
Water Use within the Colorado River Indian Reservation (AZ)
Water Use within the Yuma County Water Users Association (AZ)
Water Use within the Cibola National Wildlife Refuge (AZ)
Water Use within the Cibola Valley Irrigation and Drainage District (AZ)

The following bar charts show the consumptive use reported for 1999 by Decree Accounting, and crop and domestic consumptive uses, and phreatophyte water uses produced by LCRAS for State totals and selected irrigation districts and wildlife refuges. These bar charts highlight the importance of determining the amount of phreatophyte water use, if any, that should be reported as part of a diverter's consumptive use[GG].

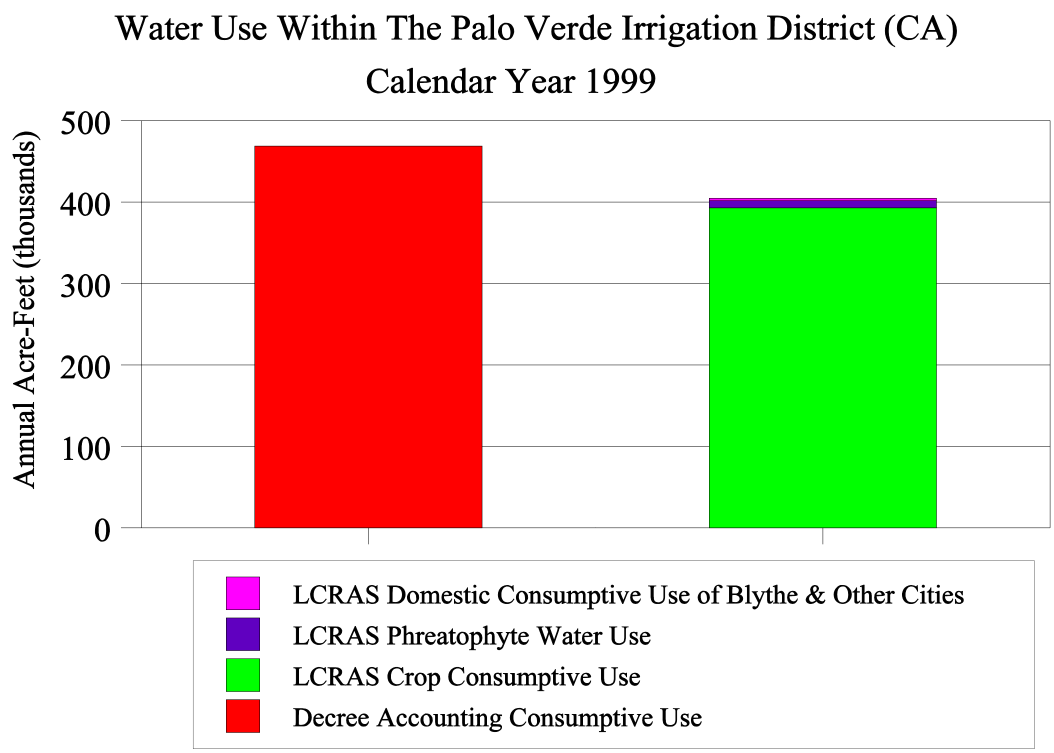
The state-total consumptive use values shown from Decree Accounting include unmeasured return flows calculated for diverters within the state, but credited to the state. The consumptive use values shown from Decree Accounting for individual diverters do not include unmeasured return flows calculated for diverters, but credited to the state.

[GG] Consumptive use reported by decree accounting does include some unquantified amount of phreatophyte water use.

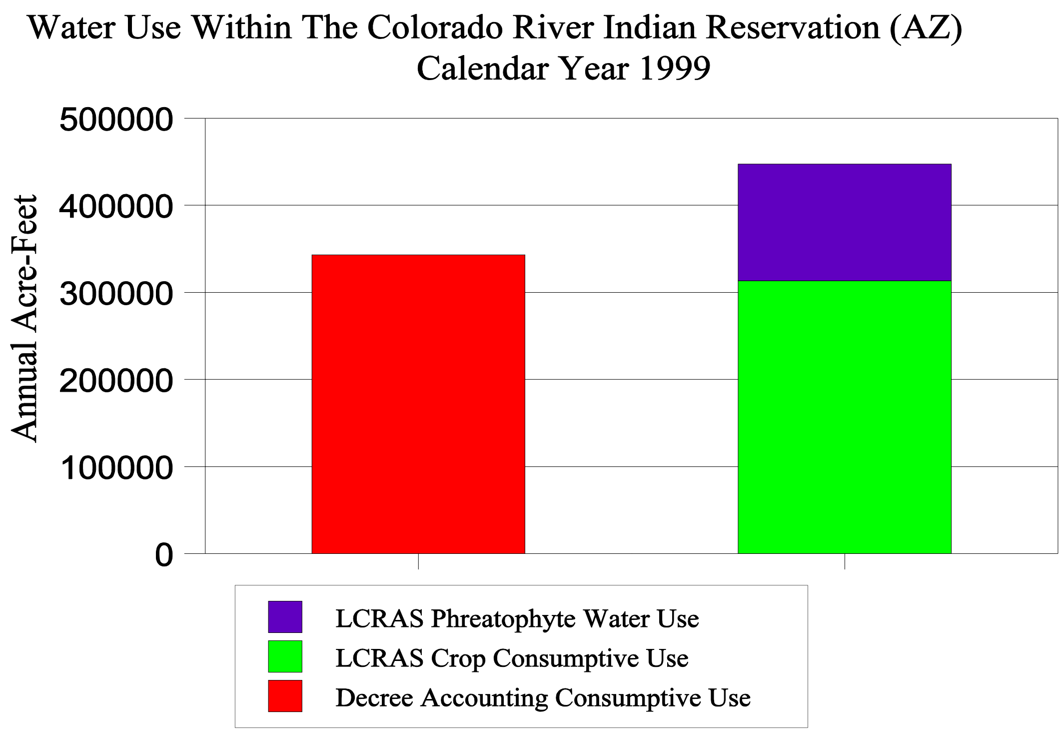




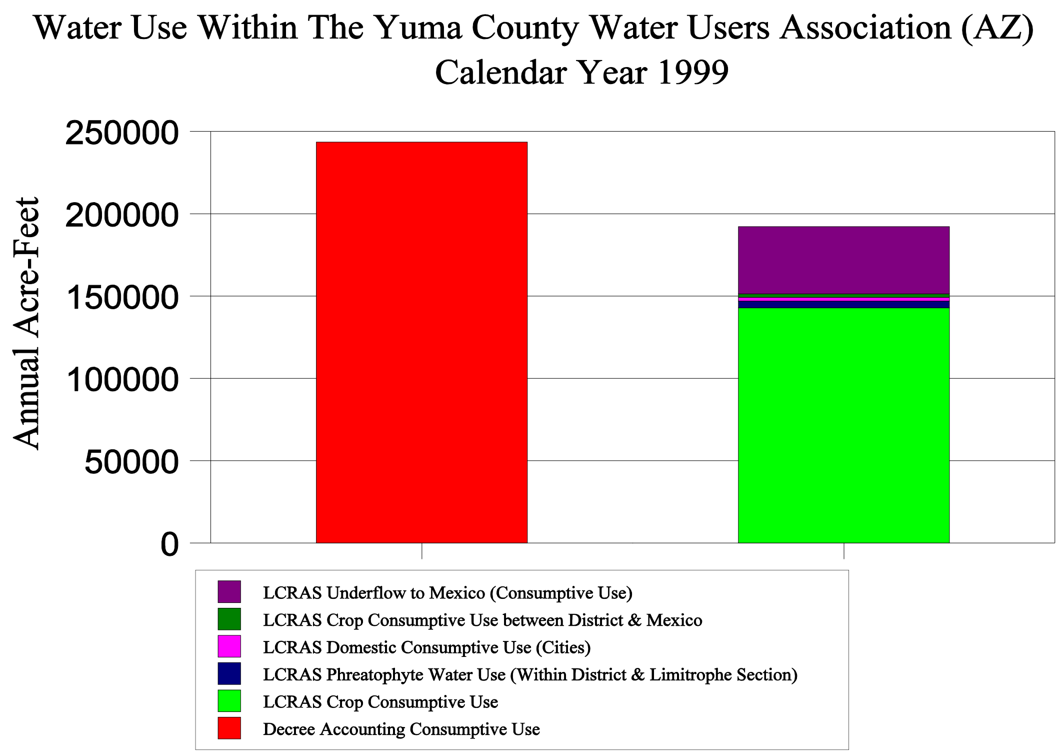
The bar chart for the State of Nevada shows the minor impact LCRAS has on consumptive use calculations in Nevada. The bar chart for the States of California and Arizona shows a good comparison between the crop consumptive uses produced by LCRAS, the consumptive uses reported by Decree Accounting (with Decree Accounting estimates of unmeasured return flows to the States included), and the minor amount of phreatophyte water use on a statewide basis.



The bar chart for the Palo Verde Irrigation District shows the sum of crop and domestic consumptive uses and phreatophyte water use compared with the consumptive use reported by Decree Accounting. The consumptive use reported for the Palo Verde Irrigation District by Decree Accounting does not include the estimate of unmeasured return flow from the Palo Verde Irrigation District that is applied to California's apportionment.

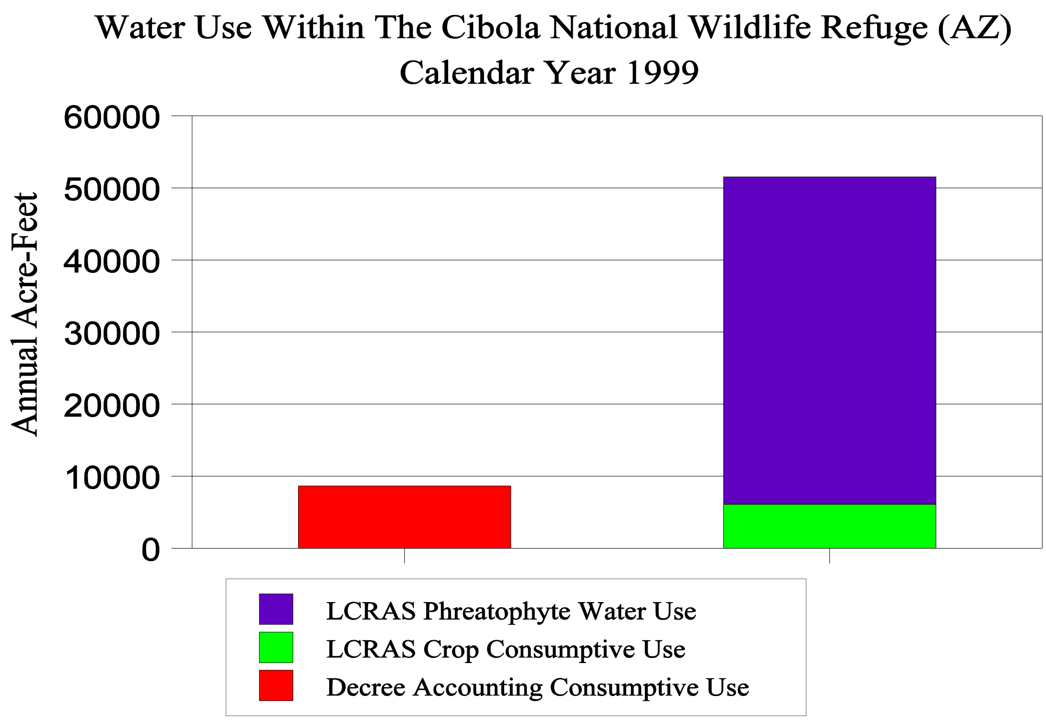


The bar chart for the Colorado River Indian Reservation (AZ) shows the crop consumptive use and phreatophytes water use, and the consumptive use reported by Decree Accounting. The consumptive use reported for the Colorado River Indian Reservation by Decree Accounting does not include the estimate of unmeasured return flow from the Colorado River Indian Reservation that is applied to Arizona's apportionment. The domestic consumptive use within CRIR is not included in the LCRAS values shown on the chart.

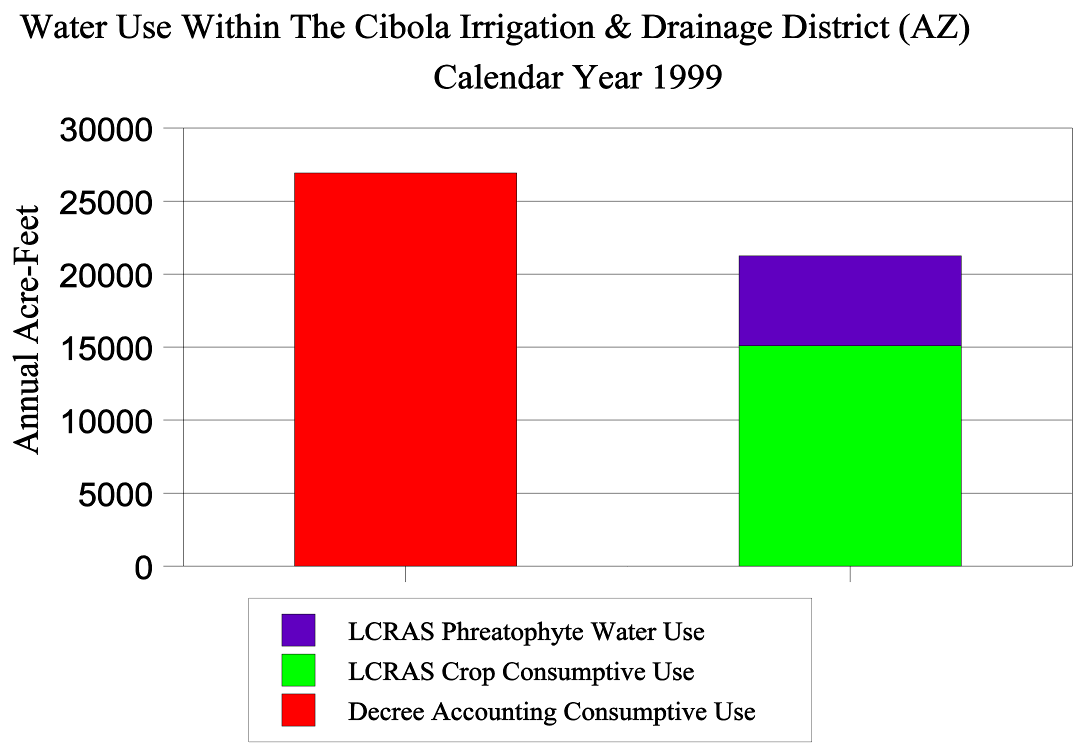


The bar chart for the Yuma County Water Users Association shows the crop and domestic consumptive uses and the phreatophyte water use within the district boundary developed by LCRAS, plus an estimate of the underflow to Mexico that results from applied but unconsumed water within the district, plus crop consumptive use and phreatophyte water use between the Mexican border and the district boundary; and the consumptive use reported by Decree Accounting. The consumptive use reported for the Yuma County Water Users Association by Decree Accounting does not include the estimate of unmeasured return flow from the Yuma County Water Users Association that is applied to Arizona's apportionment, but does include pumping by wells within the district boundaries reported in Decree Accounting as part of "Other Users Pumping from Colorado River and Wells in Flood Plain Davis Dam to International Boundary."

The underflow to Mexico, the domestic consumptive use, the crop consumptive use, and the phreatophyte water use between the district boundary and Mexico should be considered part of the Yuma County Water Users Association's consumptive use because these quantities represent diversions from the Colorado River that do not become available for satisfaction of the Mexican treaty or for consumptive use by other diverters in the United States.



The bar chart for the Cibola National Wildlife Refuge shows the crop consumptive use and phreatophyte water use produced by LCRAS and the consumptive use reported by Decree Accounting (a diversion with no return flow). The consumptive use value reported for the Cibola National Wildlife Refuge by Decree Accounting does not include the estimate of unmeasured return flow from the Cibola National Wildlife Refuge that is applied to Arizona's apportionment. This is another example of LCRAS's ability to identify and quantify phreatophyte water use, and a situation where a determination of the amount of phreatophyte water use that should be included in the consumptive use of a diverter is critical.



The bar chart for the Cibola Irrigation and Drainage District shows the crop consumptive use and phreatophyte water use produced by LCRAS and the consumptive use reported by Decree Accounting (a diversion with no return flow). The consumptive use value reported for the Cibola Irrigation and Drainage District by Decree Accounting does not include the estimate of unmeasured return flow from the Cibola Irrigation and Drainage District that is applied to Arizona's apportionment. This is another example of LCRAS's ability to identify and quantify phreatophyte water use, and a situation where a determination of the amount of phreatophyte water use that should be included in the consumptive use of a diverter is critical.

Attachment 4

Remote Sensing and GIS Procedures

Overview

Remote sensing and geographic information system (GIS) technologies are integrated to classify crops, phreatophytes, and open water within the project area, and to populate a complete digital database(s) representing the areal extent of these land cover groups. Annual acreage summaries are generated for each land-cover group by diverter boundary, river reach, and State. Accuracy assessment is performed for crop and phreatophyte groups.

Field Border Database

A relational database (GIS coverage) has been developed that delineates the field borders in all irrigated areas along the mainstream of the lower Colorado River from Hoover Dam to Mexico. All the ground reference data collected for image classification are linked to this field-border database. These field borders were originally derived from 10-meter Systemme Pour l'Observation de la Terre (SPOT) image data acquired in June and August of 1992. All field borders were digitized on screen using the SPOT data as a backdrop.

Changes in field borders, noted during the acquisition of ground reference data throughout the year, have served as a data source for updates to the field-border database since 1995. This process continued in 1999. Reclamation also uses 5-meter Indian Remote Sensing satellite imagery on an annual basis to update field borders in areas where ground reference data show significant changes in field border locations.

Refer to Table Att-4.A for metadata on this field-border database. Five field-border databases cover the project area (Figure Att-4.1). The extent of these field border databases define individual spectral processing areas for the crop classification. Each field in the database has a unique identification number (FIELD-ID) as well as various other attributes. "CROP-LABEL" contains the crop group assigned by the spectral classification process. “CROP-TYPE” is populated with the name of a specific crop if the field is a ground reference field. Other attributes such as “AVG-HT,” “GROWTH-STAGE,” etc., are populated for ground reference fields. “AA” designates if the field is a ground reference field that has been reserved for accuracy assessment.

Table Att-4.B presents a comparison of acreage calculated for fields based on the field border database captured from SPOT image data and acreage calculated using GPS control points. This comparison was made to ensure that acreage values derived from field borders captured from the SPOT satellite data fall within an acceptable degree of error when compared to GPS-generated acreage for the same fields. Total acreage for 30 fields using both methods differed by approximately 0.22 percent.

Field borders are routinely updated when changes are observed during ground reference data collection. A comprehensive field border update was completed in 1998 using Fall 1997 Indian Remote Sensing (IRS) orthorectified 5-meter panchromatic imagery. Field border updates are completed and incorporated every year based on ground reference information and new IRS imagery where needed.

Table Att-4.A — Field Border Database Items - ARC/INFO Format

COLUMN	ITEM NAME	WIDTH	OUTPUT	TYPE	N.DEC
1	AREA	8	18	F	5
9	PERIMETER	8	18	F	5
17	LOW1_0397#	4	5	B	-
21	LOW1_0397-ID	4	5	B	-
25	DATE	8	8	C	-
33	QUADNAME	13	13	C	-
46	FIELD-ID	7	7	I	-
53	CROP-LABEL	4	4	I	-
57	CROP-TYPE	8	8	N	2
65	MIN-HT	4	12	F	2
69	MAX-HT	4	12	F	2
73	AVG-HT	4	12	F	2
77	GROWTH-STAGE	2	2	I	-
79	CROP-PCT	3	3	I	-
82	OTHER-PCT	3	3	I	-
85	CONDITION	2	2	I	-
87	ROW-ORIENTATION	2	2	I	-
89	FURROW	2	2	I	-
91	BED	2	2	I	-
93	ROLL-FRAME	12	12	N	8
105	BORDER-CHANGE	4	4	N	2
109	COMMENTS	80	80	C	-
189	STUDY-AREA	2	2	I	-
191	AA	1	1	I	-
192	ACRES	12	12	N	2

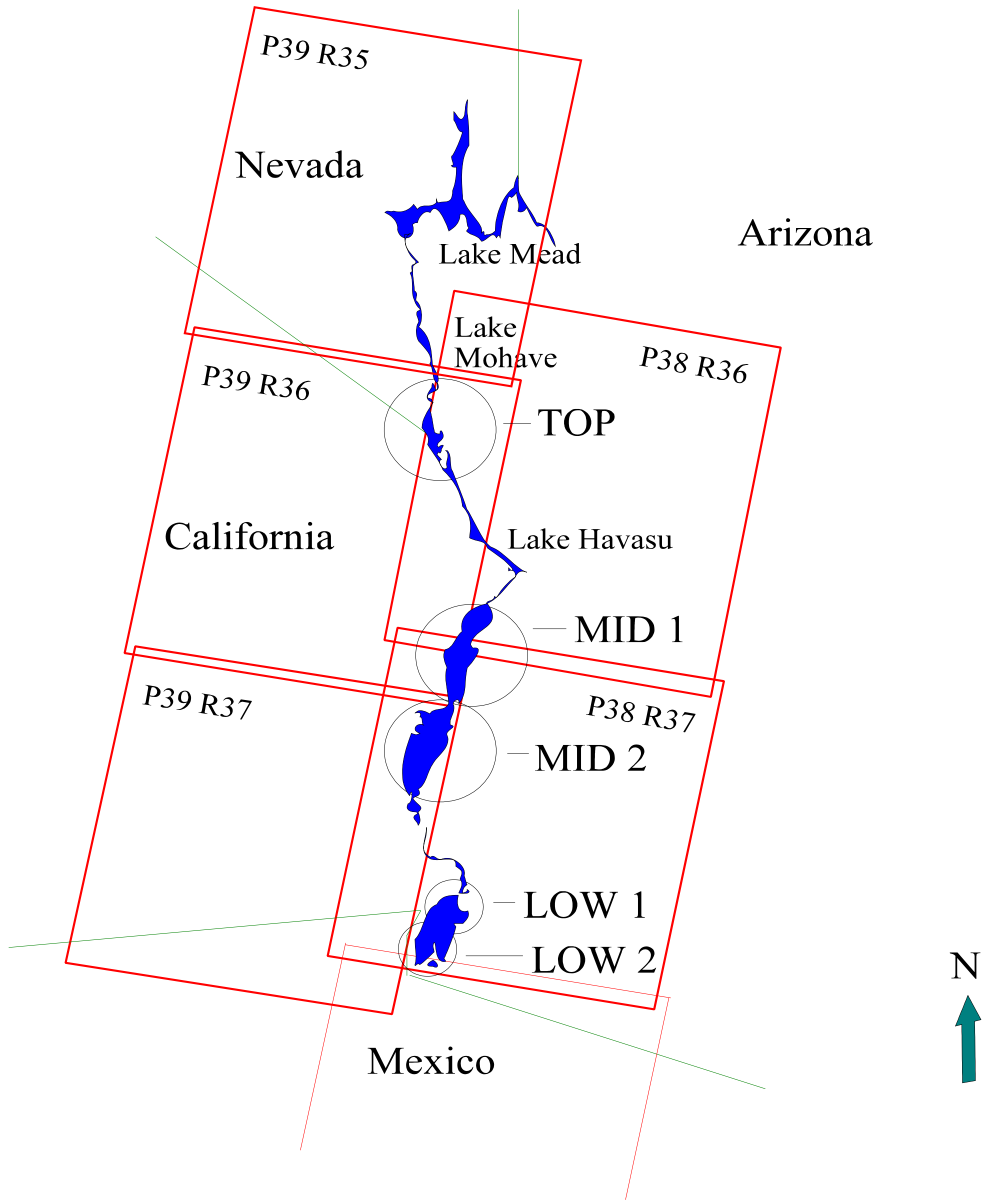


Figure Att-4.1 — Image Processing Areas and Landsat Scene Boundaries.

Table Att-4.B — Field Acreage (SPOT Image Data & GPS Control Points)

LOW2.PAT	SPOT IMAGE DATA	GPS CONTROL POINTS	DIFFERENCE	COMMENTS
FIELD-ID	ACRES	ACRES	ACRES	
10,122	34.880	32.163	2.72	1.
10,616	18.499	18.905	-0.40	
14,277	77.119	74.749	2.37	
13,321	71.949	72.367	-0.42	
13,339	19.554	17.904	1.65	
13,355	31.140	30.106	1.03	
14,289	24.138	23.866	0.27	
13,418	123.041	122.611	0.43	
13,531	76.585	76.276	0.31	
LOW1.PAT	**SPOT IMAGE DATA**	**GPS CONTROL POINTS**	**DIFFERENCE**	**COMMENTS**
FIELD-ID	ACRES	ACRES	ACRES	
8,777	18.510	22.202	-3.69	2.
9,013	37.929	41.353	-3.42	3.
9,295	4.580	4.038	0.54	
9,331	7.325	7.131	0.19	
9,399	28.000	28.526	-0.53	
9,591	8.648	8.316	0.33	

MID2.PAT	SPOT IMAGE DATA	GPS CONTROL POINTS	DIFFERENCE	COMMENTS
FIELD-ID	ACRES	ACRES	ACRES	
4,144	41.283	41.417	-0.13	
4,267	150.976	149.861	1.12	
4,314	8.073	8.074	0.00	
6,629	72.233	73.415	-1.18	
4,488	37.725	36.944	0.78	
5,010	37.2093	6.836	0.37	
5,076	70.610	71.265	-0.65	
5,082	37.272	37.583	-0.31	
5,168	38.633	36.777	1.86	
5,557	37.468	38.238	-0.77	
6,009	80.842	82.363	-1.52	
6,015	32.573	32.021	0.55	
6,042	71.596	71.975	-0.38	
MID1.PAT	**SPOT IMAGE DATA**	**GPS CONTROL POINTS**	**DIFFERENCE**	**COMMENTS**
FIELD-ID	ACRES	ACRES	ACRES	
3,406	74.832	72.686	2.15	
3,283	49.354	49.459	-0.11"	
TOTALS:	1,432.576	1,429.427	<3.15 acres>	

COMMENTS:

1. Feeder ditch between road and crops account for discrepancy.
2. Satellite acquisition problems.
3. Digitizing problems; moved nodes, but needs further editing.

Other GIS coverages used in this process include Diverter, Floodplain, and River Reach boundaries. Improvements to the Diverter coverage are ongoing based on consultation with water diverters in the project area. If needed, Reclamation will provide additional metadata on digital coverages used in this process.

Classification of Irrigated Areas

Introduction

Irrigated areas are classified four times annually. Classification dates are based on crop calendar information for the area. Orchards are not classified from spectral data, but are updated based on field verification. Landsat Thematic Mapper imagery (bands 1-5,7) is the principle source data for image classification. Note, the successful launch of Landsat 7 in 1999 now provides two satellite platforms for Thematic Mapper Imagery. Alternate sources of imagery (in the case of sensor failure or cloud cover for Landsat TM data) include Indian Remote Sensing (IRS) multi-spectral data, SPOT multi-spectral data, Space Imaging IKONOS multi-spectral data, and Japanese (JERS) LISS-III multi-spectral data. Ground reference data for training the spectral classifier are collected during a 10-day period. This period is chosen based on the Landsat satellite flyover date and crop planting practices.

Image classification processing areas are chosen as a function of the extent of irrigated areas delineated in the field border database, variability of crops, image source dates, and computer processing considerations. There are a total of five processing areas for crop classification work (Figure 6.1).

Classification methods were developed in conjunction with a private contractor, Pacific Meridian Resources. A variety of methods were tested and improved upon during the initial year of the project and Reclamation has continued to improve the process. Significant methods and improvements are discussed in this appendix.

Ground Reference Data Collection

Ground reference data are collected four times each year, coinciding with each classification time. Each data collection period takes approximately 8 days over a 10-day period using three ground reference crews. Each ground reference crew consists of a driver and coder (a person who records the data).

Ground reference collection periods are chosen to coincide as closely as possible with the Landsat satellite fly-over dates.

Data collection is designed to capture as much of the variability in crops and conditions as possible to assure that the majority of spectral variability within the satellite imagery is considered. Approximately 15 percent of the fields in the project area are sampled. Ground reference fields were originally chosen using a random number generator and reviewed to ensure an adequate geographic distribution. Although these fields are routinely visited during data collection, additional fields are often sampled to capture rare crops or other anomalous conditions important for the spectral classifier.

Each ground reference crew is provided with 7.5 minute quadrangle plots for navigation. Plots have a panchromatic IRS image backdrop, field borders with unique identifiers (id's), and annotation noting road names and other significant navigational features such as locations of canal bridges. Fields to be sampled (ground reference fields) are uniquely colored for ease of identification, and colors indicate the crop that was present during the last ground reference visit, which often helps in identifying crop residue or any significant changes in planting practices. Data are collected with laptop computers using a data collection program written for this project. Table Att-4.C lists ground-reference attributes that are collected. Table Att-4.D is a complete crop list.

The driver in a field crew notes the crop and field-id on a hard-copy form while the data coder records all attributes in digital format. Field id's and crop are quality checked between the driver and coder to avoid data entry errors. After field work is completed, digital field data are once again quality checked in the office. Once the field data have been checked, they are used to "populate" items (Arc/Info data fields) in the field border database.

Table Att-4.C — Ground Reference Attributes

Attribute	Comments
Date	MM/DD/YR
7.5' Geological Survey Quad Name	
Field-ID	Unique ID from field border database (ARC/INFO)
Crop Name	See Table Att-4.D for a crop name and group list
Average Height	Inches
Growth Stage	Emergent, pre-bloom, bloom, senescent, harvested, seeded, wind rowed, baled, defoliated
Crop Vegetative Cover	Percent crown closure
Other Vegetative Cover	Percent crown closure if other vegetation > 10% (Crop Vegetative Cover + Other Vegetative Cover = Total Vegetative Cover)
Crop / Field Condition	Good, spotty/weedy, spotty/exposed soil, diseased, stressed, weeds & soil, residue
Row (Orientation)	Row crop, uniform (leveled), pivot
Furrow moisture	Dry/Semi moist, saturated, ponding
Bed moisture	Dry/Semi moist, saturated, ponding
Signature	Yes/No - Desirable as training sample
Map Change	Yes/No - indicating field border update from field observation
Comments	Minor weeds, currently being irrigated/harvested, grazed, etc.

Spectral Classification

Figures Att-4.2, Att-4.3, and Att-4.4 are flow diagrams that summarize the crop classification procedures discussed in this section. These figures are presented at the end of this attachment.

After the field border database is populated with ground reference data, about one third of the ground reference fields are reserved as an independent accuracy assessment set. Accuracy assessment fields are chosen using a random stratified approach to ensure a statistically valid sample. The remaining ground reference fields are then used for spectral signature development.

Automated Signature Generation

Initially, a single spectral training site was created within each ground reference field (except those reserved for accuracy assessment) using the SEED function in ERDAS Imagine image processing software. SEED "grows" a training site from a starting pixel using user-defined parameters (ERDAS Imagine Field Guide, 1995). Given the large number of training sites (approximately 1,300 fields) this process is extremely time consuming and requires considerable analyst manipulation and interpretation of signature sets to achieve the desired classification accuracy.

A new process, created to automatically extract training signatures for spectral classification, utilizes spectral "region-growing" algorithms (Woodcock, et. al., 1992), ERDAS Imagine software, Arc/Info software (ESRI, 1994), and Image Processing Workbench (IPW) software (Frew, 1990). Ground reference fields are reselected from the field border database and buffered 25 meters to the inside. These fields are then used to mask a Landsat image consisting of bands 3, 4, and 5.

The resulting image of ground reference fields is then converted into IPW format and region-growing algorithms are used to partition each field into spectrally homogeneous regions. The region-growing algorithm provides for user-defined spectral and spatial thresholds similar to the SEED function in ERDAS. However, this process does not require the analyst to identify a "starting pixel" in the training field, and partitions the entire training field into regions (polygons) thereby "capturing" all of the spectral variation within that field (e.g. differences due to variation in crown closure, moisture, vegetation stress, etc.).

A number of Landsat band combinations and region-growing spectral and spatial thresholds were tested to determine the best combination for this application.

Figure Att-4.5 shows ground reference fields partitioned into spectral regions.

The spectral region coverage of ground reference fields is then converted to Arc/Info vector format. This file is used as an Area of Interest (AOI) file in ERDAS Imagine and "overlaid" with the original six-band Landsat TM image to generate spectral training site statistics for each spectral region. Ground reference data from the field border database are then related to the resulting ERDAS signature file so that crop group attributes collected in the field are included in the ERDAS signature file with each spectral training signature.

Table Att-4.D — 1999 Crop Group and Name List

Crop Group	Crop Name	Crop Group	Crop Name
Alfalfa	Alfalfa	Fallow	Idle with weeds (green)
Cotton	Cotton		Idle with weeds (senescent)
Small Grain	Oats		Bare Soil (cultivated)
	Rye		Bare Soil (not cultivated)
	Barley		Flooded Fallow
	Millet	Dates	Dates
	Wheat	Safflower	Safflower
Field Grain	Field Corn	Deciduous Orchards	Pecans
	Sorghum		Peaches
	Milo		Other
Lettuce	Head Lettuce	Small Vegetables	Carrots
	Leaf Lettuce (green)		Celantro
	Leaf Lettuce (red)		Celery
	Spinach		Garlic
	Other Lettuce		Onions (dry)
Melons	Watermelon		Onions
	Honeydew		Parsley
	Cantaloupe		Radishes
	Squash		

Crop Group	Crop Name	Crop Group	Crop Name
Bermuda/Rye Grass	Bermuda	Root Vegetables	Beets (table)
	Bermuda Over-Seeded with Rye Grass		Parsnip
Citrus	Young, 1-2 Meter		Turnip & Rutabaga
	Mature, 2 + Meter	Perennial Vegetables	Artichokes
	Declining		Asparagus
Tomatoes	Tomatoes	Sugar Beets	Sugar Beets (summer)
Sudan	Sudan		Sugar Beets (winter)
Legume/Solanum Vegetables	Beans (green)	Grapes	Grapes
	Beans (dry)	Crucifers	Broccoli
	Beans (Garbanzo)		Cauliflower
	Peas		Cabbage
	Peanuts		Bok-Choy
	Peppers		Mustard
			Kale

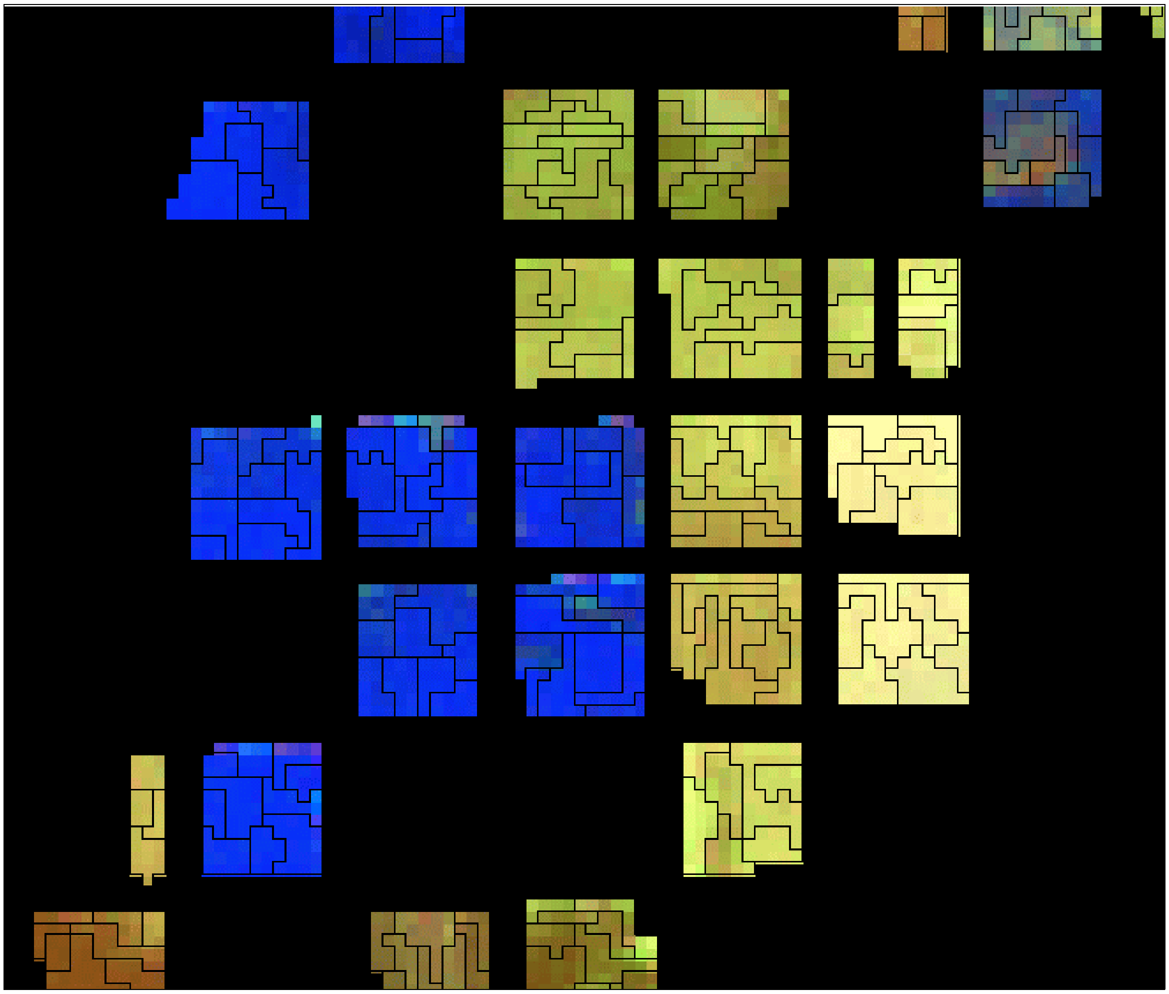


Figure Att-4.5 — Ground Reference Fields - masked and partitioned into spectral regions for signature generation. Black lines denote spectral regions plotted on Landsat bands 4, 3, 2.

This process typically produces over 4,000 signatures (more than one spectral region per ground reference field). The signature set is refined based on specific criteria. In this case, a valid signature must consist of 10 or more pixels and have a standard deviation value of less than or equal to three in all six bands. Standard deviation cutoffs were chosen based on classification results; however, this cutoff can vary dependent on spectral properties of individual crop groups. The refined signature set is also visually inspected over the imagery to check for any signatures representing anomalous field conditions that would be better left out of the spectral classifier.

Image Classification

Once the signature set is refined, a supervised maximum likelihood classification is performed in ERDAS Imagine to classify all fields. The resulting pixel classification is then "overlaid" with the field border database and each field is given a single crop group label based on the distribution of classified pixels within that field. A simple plurality rule is used (the field label is given to the group that has the most classified pixels within that field). This initial classification is evaluated by creating a frequency table that compares labels derived from ground observations to labels derived from the classifier. Only those fields that are used for spectral training sites are included in the frequency table. This table is a measure of how well the classification process classified the training fields. If the overall accuracy based on this frequency is less than 93 percent, then it is assumed that the accuracy based on the independent accuracy assessment fields will also be less than 93 percent, and an iterative classification procedure is employed to improve the classification.

Training signatures that may be responsible for causing a field to be mislabeled are identified. This is accomplished by generating a summary table of the pixel classification for mislabeled training fields. This table shows which signatures are responsible for classifying each pixel within a field. If necessary, cluster analysis is also performed to evaluate spectrally similar signatures that may represent different crop groups. Once problem signatures are identified and the signature set is refined, a second classification is performed and evaluated as before. Up to four classification iterations may be necessary to achieve an overall accuracy of 93 percent within the training fields.

Accuracy Assessment

Accuracy assessment error matrices are generated for all final crop classifications. Errors of omission and commission are reported based on crop group acreage and number of fields correct. For each classification time, about one third of the ground reference fields are reserved as an independent sample for accuracy assessment purposes. This is a random stratified sample which represents the relative proportions of crop groups being grown at each classification time, as well as the variety of conditions for each crop group. Due to crop rotation practices, some crop groups for a particular classification time are under-sampled with respect to accuracy assessment needs. However, these crop groups generally represent crops that are either grown in such a minor amount that an adequate sample is not possible or are not grown at that particular time of year. In both cases, any error associated with these crop groups typically does not represent significant acreage and therefore has a minor effect on consumptive use (of water) calculations.

Accuracy assessment matrices

Error matrices based on the number of acres correctly classified and matrices based on the number of fields correctly classified are both useful. Accuracy figures reported on an acreage basis are the most useful for relating crop classification error to consumptive-use calculations and are the only accuracy figures included in this report. Accuracy figures reported on the number of fields correct help the analyst define which crop groups are being confused in the classifier and are useful in determining ways of improving the classification process and the creation of annual crop group summaries. Therefore, displaying accuracy figures by field would add little to this report.

Tables Att-4.E, Att-4.F, Att-4.G, and Att-4.H are accuracy assessment error matrices for each classification time. These error matrices represent the established standard for reporting classification accuracies of maps produced using remotely sensed data (Campbell, 1987; Story and Congalton, 1986). In this case, columns in the matrix represent "truth" derived from ground observation (GROUND REFERENCE FIELDS) and rows represent the label given by the spectral classification process for the same reference fields (MAP LABEL). An error matrix represents the accuracies of each crop group in the map and can be interpreted with respect to both errors of exclusion (omission errors) and errors of inclusion (commission errors). An omission error occurs when an area (in this case an irrigated field) is excluded from the group to which it actually belongs (reported in the columns of the error matrix). A commission error occurs when an area is included into a group to which it does not belong (reported in the rows of the error matrix). Every error of omission from the correct group is also an error of commission to a wrong group.

These error matrices also contain additional information specific to this application. Some reported accuracy percentages are adjusted for expected spectral confusion. These adjustments are specific to confusion between any crop group and a fallow condition.

Most crops do not have a great enough crown closure to spectrally differentiate them from a fallow field when at an immature growth stage. It is important to note that after the annual crop group summary (discussed in the next section) takes into account all four classification times, error between fallow and any crop group is negligible. Further studies will present the effects of known error on water consumption calculations.

Table Att-4-E - February 1999 Accuracy Assessment Error Matrix - by Acreage

Ground Reference Fields

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Legume/ Solanum Vegetables	Crucifers	Fallow	Dates	Safflower	Deciduous Orchards	Small Vegetables	Root Vegetables	Perennial Vegetables	TOTALS	%correct	% correct with
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		(commission)	fallow correction
Alfalfa	**1**	**8240.10**		561.55		60.74							78.21	143.5				96.8			**9180.90**	89.75%	91.32%
Cotton	**2**		**0**																		**0.00**		
Small Grain	**4**	17.59		**946.26**		122.73								27.32							**1113.90**	84.95%	87.40%
Corn	**5**				**0**																**0.00**		
Lettuce	**6**	25.72		88.94		**1324.07**							229.45	71.42				37.75			**1777.35**	74.50%	78.52%
Melons	**7**						**0**														**0.00**		
Bermuda Grass	**8**							**802.28**													**802.28**	100.00%	100.00%
Citrus	**9**								**700**												**700.00**	100.00%	100.00%
Tomatoes	**10**									**0**											**0.00**		
Sudan Grass	**11**										**0**										**0.00**		
Legume/ Solanum Vegetables	**12**											**16.47**									**16.47**	100.00%	100.00%
Crucifers	**13**					75.98							**524.52**					28.46			**628.96**	83.39%	83.39%
Fallow	**14**	25.61		266.84		96.56							18.62	**6418.48**				275.98			**7102.09**	90.37%	100.00%
Dates	**15**														**126.57**						**126.57**	100.00%	100.00%
Safflower	**16**															**0**					**0.00**		
Deciduous Orchards	**17**																**28.13**				**28.13**	100.00%	100.00%
Small Vegetables	**18**			71.02									20.72					**397.52**			**489.26**	81.25%	81.25%
Root Vegetables	**19**																		**0**		**0.00**		
Perennial Vegetables	**20**																			**0**	**0.00**		
TOTALS		**8309.02**	**0.00**	**1934.61**	**0.00**	**1680.08**	**0.00**	**802.28**	**700.00**	**0.00**	**0.00**	**16.47**	**871.52**	**6660.72**	**126.57**	**0.00**	**28.13**	**836.51**	**0.00**	**0.00**	**21965.91**	Total Samples	
%correct by crop		99%		49%		79%		100%	100%			100%	60%	96%	100%		100%	48%			**19524.40**	Total Correct	
																					89%	**% correct**	
total with fallow correction		8283.41	0	1667.77	0	1583.52	0	802.28	700	0	0	16.47	852.9	7068.35	126.57	0	28.13	560.53			21689.93		
% correct with fallow correction		99%		57%		84%		100%	100%			100%	61%	100%	100%		100%	71%			**92%**	% correct with fallow correction	

Table Att-4-E - May 1999 Accuracy Assessment Error Matrix - by Acreage

		Ground Reference Fields																					
		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Legume/ Solanum Vegetables	Crucifers	Fallow	Dates	Safflower	Deciduous Orchards	Small Vegetables	Root Vegetables	Perennial Vegetables	**TOTALS**	%correct	% correct with
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		(commission)	fallow correction
Alfalfa	**1**	**8887.23**			95.6		82.5				252.93	59.3		357.15				96.8			**9831.51**	90.40%	94.03%
Cotton	**2**		**1254.93**				53.67							904.5							**2213.10**	56.70%	97.57%
Small Grain	**4**	53.28		**2159.72**								32.43		40.13							**2285.56**	94.49%	96.25%
Corn	**5**	25.47		22.71	**202.59**		71.73				51.65										**374.15**	54.15%	54.15%
Lettuce	**6**					**0**												37.75			**37.75**	0.00%	
Melons	**7**	20.39	161.29	10.64	26.23		**1027.03**				18.36			316.69							**1580.63**	64.98%	85.01%
Bermuda Grass	**8**							**739.66**													**739.66**	100.00%	100.00%
Citrus	**9**								**700**												**700.00**	100.00%	100.00%
Tomatoes	**10**									**0**											**0.00**		
Sudan Grass	**11**	103.07	12.68								**1701.15**	19.31									**1836.21**	92.64%	92.64%
Legume/ Solanum Vegetables	**12**											**106.9**									**106.90**	100.00%	100.00%
Crucifers	**13**												**0**	180.69				28.46			**209.15**	0.00%	86.39%
Fallow	**14**	16.55	**433.34**	6.05		31.81	35.59				113.82			**4659.52**				275.98			**5572.66**	83.61%	100.00%
Dates	**15**														**112.7**						**112.70**	100.00%	100.00%
Safflower	**16**															**0**					**0.00**		
Deciduous Orchards	**17**																**28.13**				**28.13**	100.00%	100.00%
Small Vegetables	**18**																	**397.52**			**397.52**	100.00%	100.00%
Root Vegetables	**19**																		**0**		**0.00**		
Perennial Vegetables	**20**																			**0**	**0.00**		
TOTALS		**9105.99**	**1862.24**	**2199.12**	**324.42**	**31.81**	**1270.52**	**739.66**	**700.00**	**0.00**	**2137.91**	**217.94**	**0.00**	**6458.68**	**112.70**	**0.00**	**28.13**	**836.51**	**0.00**	**0.00**	**26025.63**	Total Samples	
%correct by crop (ommission)		98%	67%	98%	62%	0%	81%	100%	100%		80%	49%		72%	100%		100%	48%			**21977.08**	Total Correct	
																					84%	**% correct**	
total with fallow correction		9089.44	1428.9	2193.07	324.42	0	1234.93	739.66	700	0	2024.09	217.94	0	7371.82	112.7	0	28.13	560.53			26025.63		
% correct with fallow correction		98%	88%	98%	62%	100%	83%	100%	100%		84%	49%		100%	100%		100%	71%			**88%**	% correct with fallow correction	

Table Att-4-E - July 1999 Accuracy Assessment Error Matrix - by Acreage

Ground Reference Fields

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Legume/ Solanum Vegetables	Crucifers	Fallow	Dates	Safflower	Deciduous Orchards	Small Vegetables	Root Vegetables	Perennial Vegetables	**TOTALS**	%correct	% correct with
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		(commission)	fallow correction
Alfalfa	**1**	**8092.08**	289.71								302.25			242.75							**8926.79**	90.65%	93.37%
Cotton	**2**	790.61	**3409.26**								92.96	115.11		16.77							**4424.71**	77.05%	77.43%
Small Grain	**4**			**0**																	**0.00**		
Corn	**5**	71.18	50.93		**180.84**						136.33		4.43								**443.71**	40.76%	40.76%
Lettuce	**6**					**0**															**0.00**		
Melons	**7**						**0**														**0.00**		
Bermuda Grass	**8**							**651.19**													**651.19**	100.00%	100.00%
Citrus	**9**								**700**												**700.00**	100.00%	100.00%
Tomatoes	**10**									**0**											**0.00**		
Sudan Grass	**11**	227.18	113.86		16.95		38.92				**1190.44**			126.36							**1713.71**	69.47%	76.84%
Legume/ Solanum Vegetables	**12**	34.81										**0**									**34.81**	0.00%	0.00%
Crucifers	**13**												**0**								**0.00**		
Fallow	**14**	101.66	**18.27**				86.1				231.25			**7369.87**		40.38					**7847.53**	93.91%	100.00%
Dates	**15**														**123.31**						**123.31**	100.00%	100.00%
Safflower	**16**															**108.24**					**108.24**	100.00%	100.00%
Deciduous Orchards	**17**																**24.98**				**24.98**	100.00%	100.00%
Small Vegetables	**18**																	**0**			**0.00**		
Root Vegetables	**19**																		**0**		**0.00**		
Perennial Vegetables	**20**																			**0**	**0.00**		
TOTALS		**9317.52**	**3882.03**	**0.00**	**197.79**	**0.00**	**125.02**	**651.19**	**700.00**	**0.00**	**1953.23**	**115.11**	**4.43**	**7755.75**	**123.31**	**148.62**	**24.98**	**0.00**	**0.00**	**0.00**	**24998.98**	Total Samples	
%correct by crop		87%	88%		91%		0%	100%	100%		61%	0%	0%	95%	100%	73%	100%				**21850.21**	Total Correct	
																					87%	**% correct**	
total with fallow correction		9215.86	3863.76	0	197.79	0	38.92	651.19	700	0	1721.98	115.11	4.43	8233.41	123.31	108.24	24.98				24998.98		
% correct with fallow correction		88%	88%		91%		0%	100%	100%		69%	0%	0%	100%	100%	100%	100%				**89%**	% correct with fallow correction	

Table Att-4-E - December 1999 Accuracy Assessment Error Matrix - by Acreage																							
		Ground Reference Fields																					
		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Legume/ Solanum Vegetables	Crucifers	Fallow	Dates	Safflower	Deciduous Orchards	Small Vegetables	Root Vegetables	Perennial Vegetables	**TOTALS**	%correct	% correct with
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		(commission)	fallow correction
Alfalfa	**1**	**6208.02**	111.84											45.79				92.35			**6458.00**	96.13%	96.84%
Cotton	**2**	20.14	**671.22**		38.28									78.78							**808.42**	83.03%	92.77%
Small Grain	**4**			**0**																	**0.00**		
Corn	**5**				**0**																**0.00**		
Lettuce	**6**					**1564.87**							97.86	9.18				55.77			**1727.68**	90.58%	91.11%
Melons	**7**						**0**														**0.00**		
Bermuda Grass	**8**							**700**													**700.00**	100.00%	100.00%
Citrus	**9**								**700**												**700.00**	100.00%	100.00%
Tomatoes	**10**									**0**											**0.00**		
Sudan Grass	**11**										**0**										**0.00**		
Legume/ Solanum Vegetables	**12**											**16.47**									**16.47**	100.00%	100.00%
Crucifers	**13**					143.95							**624.28**								**768.23**	81.26%	81.26%
Fallow	**14**	159.44	130.75			274.01							90.61	**6172.18**				88.46			**6915.45**	89.25%	100.00%
Dates	**15**														**123.31**						**123.31**	100.00%	100.00%
Safflower	**16**															**0**					**0.00**		
Deciduous Orchards	**17**																**30.84**				**30.84**	100.00%	100.00%
Small Vegetables	**18**	70.04																**193.54**			**263.58**	73.43%	73.43%
Root Vegetables	**19**																		**0**		**0.00**		
Perennial Vegetables	**20**																			**0**	**0.00**		
TOTALS		**6457.64**	**913.81**	**0.00**	**38.28**	**1982.83**	**0.00**	**700.00**	**700.00**	**0.00**	**0.00**	**16.47**	**812.75**	**6305.93**	**123.31**	**0.00**	**30.84**	**430.12**	**0.00**	**0.00**	**18511.98**	Total Samples	
%correct by crop		96%	73%		0%	79%		100%	100%			100%	77%	98%	100%		100%	45%			**17004.73**	Total Correct	
																					92%	**% correct**	
total with fallow correction		6298.2	783.06	0	38.28	1708.82	0	700	700	0	0	16.47	722.14	6960.74	123.31	0	30.84	341.66			18423.52		
% correct with fallow correction		99%	86%		0%	92%		100%	100%			100%	86%	100%	100%		100%	57%			**96%**	% correct with fallow correction	

Results

Accuracy assessment tables indicate that overall accuracies of over 90 percent can be achieved after accounting for expected confusion at the growth stages discussed above. Multiple classifications per year ensure that immature crops are classified correctly when they are at a mature state. It is important to note that the crop groups (at a particular classification time) that represent the majority of acreage in the study area tend to have the highest classification accuracies. Individual crops with lower classification accuracies generally do not represent a significant amount of acreage, or are statistically under sampled for that particular time because of planting practices (very little to no acreage was planted in the crop during the classification period).

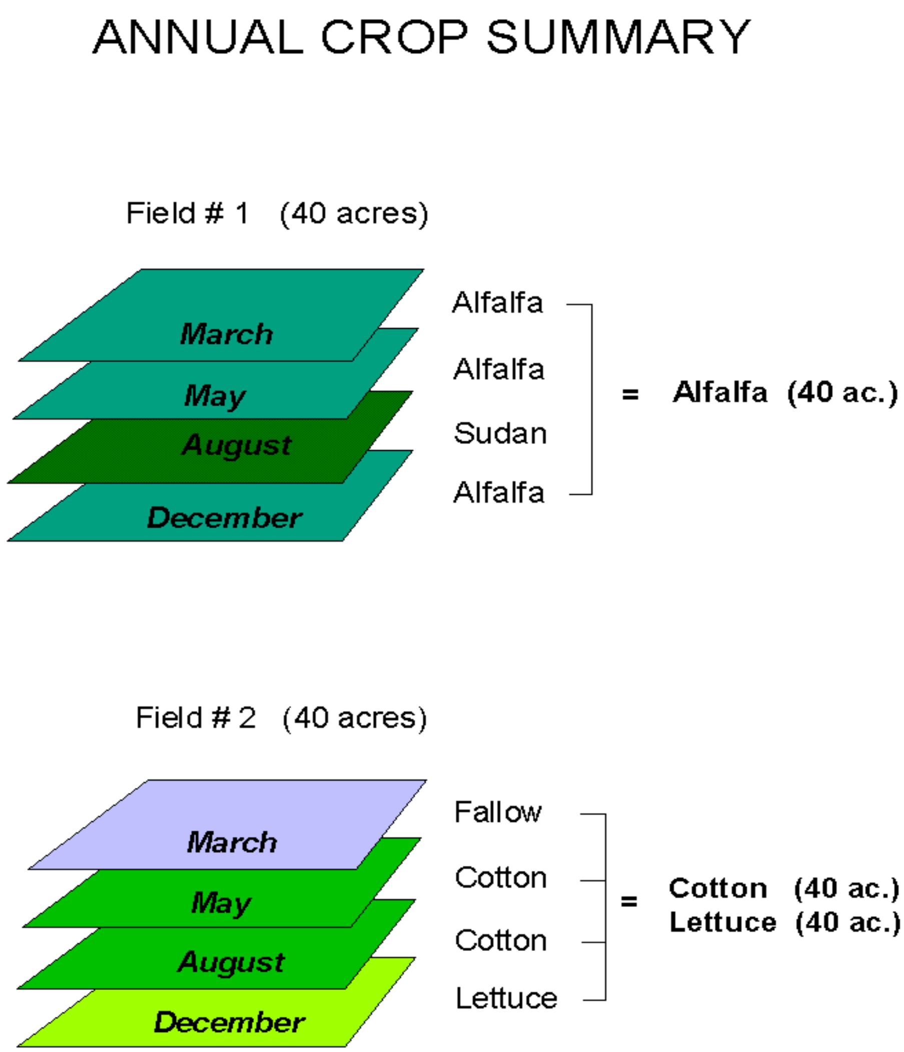
It is very important to understand the intended use of the crop classification when assessing the meaning of the classification error. The goal of LCRAS is to calculate the consumptive use of water. The meaning of the classification error must be understood in terms of the impact the classification error has on the resultant consumptive use value. Classification error that results in the misidentification of crop groups with similar water demands or which represent a very small portion of the irrigated acreage within a diverter boundary will have a negligible impact on the resultant value of consumptive use within the diverter boundary.

Annual Crop Group Summary

Annual acreage figures for each crop group are generated and summarized by diverter boundaries, river reach boundaries, and State boundaries. This summary is based on all four crop classification periods. An Arc/Info “regions” coverage is created that contains crop groups for all four times, as well as diverter boundaries, state boundaries, and river reach boundaries. The “regions” coverage retains unique field boundaries for each classification period as well as crop groups for each field at each classification time.

A computer program for crop group acreage calculations is used with the “regions” coverage database. This program contains logic that accounts for error indicated in the accuracy assessment data, ground reference data information from each classification period, and knowledge of the crop calendar. The program accounts for the majority of possible multi-temporal crop group combinations (over 800 unique combinations in the 1999 database) and assigns acreage of crop group(s) for each field. Figure Att-4.6 is a graphic example of how this program functions. In Figure Att-4.6, field #1 is assigned 40 acres of alfalfa for the year (alfalfa is generally an annual crop), yet the August classification classified the crop in field #1 as Sudan. Accuracy assessment data indicate that Alfalfa and Sudan are sometimes confused in the August classification. Because the crop in field #1 was classified as Alfalfa for all classification dates except August, the August Sudan label is assumed to be classification error. Other similar types of error between two crops can also be accounted for and corrected in the annual summary based on knowledge of the nature of the error (from the accuracy assessment matrices) and knowledge of crop planting practices. Field #2 is assigned double cropping of 40 acres of Cotton and 40 acres of Lettuce as this combination is expected from crop planting practices. Results of the annual summary program are extensively reviewed for error and edited where necessary.

Figure Att-4.6 — Annual Crop Group Summary.



Classification of Phreatophyte Areas

Introduction

Phreatophyte areas were initially classified in 1994. Landsat Thematic Mapper imagery (bands 1-5,7) was the principle source data. Available aerial photography was routinely used as an ancillary data set to help in spectral classification processes and editing. Image classification processing areas were chosen as a function of image dates and a flood plain boundary from Wilson and Owen-Joyce (1994), modified to be continuous from Hoover Dam to Mexico and to include all phreatophyte communities.

Annual phreatophyte updates are accomplished using change detection methodologies. This procedure identifies spectral difference between image dates (i.e. May 1998 and May 1999) and focuses remapping efforts in areas of spectral change.

Ground Reference Data Collection

Ground reference data are collected for training the spectral classifier similar to that done for the crop classification. Data are collected to adequately sample the variety of phreatophytes being mapped. Samples are collected throughout the project area to ensure a good geographic distribution of ground reference data. Field forms are filled out at each ground reference site and GPS units are used to locate the site. Attributes collected in the field include site #, location, GPS information, phreatophyte name, percent crown closure by phreatophyte name, moisture conditions, basic soil types, and any other pertinent information. Plots with image backdrops are provided as an aid to navigation and to help ensure that spectral variability is being captured during ground reference data collection.

Mapping phreatophytes often requires a different approach than that used for crops because image pixels often consist of a mixture of phreatophytes rather than one crop (i.e. irrigated field with one crop). Unsupervised classifications consisting of unlabeled spectral groups are often generated before field work and plots of these are also taken into the field to help in establishing correlation between particular phreatophyte groups and spectral groups. Additionally, because phreatophyte groups typically change more gradually, there is often opportunity to revisit the field as needed during the classification process. However, it is always important to collect field data during the same season in which satellite data are collected. After ground reference data are collected, a digital coverage of data collection sites is generated from the GPS data and used in the classification process.

Classification Strategies

A number of image band combinations were explored to determine the optimum combination for phreatophyte classification purposes. The following combinations were evaluated:

1. A texture band generated from band 4 added to the Landsat Thematic Mapper (TM) 6-band image.

2. A 5/4 ratio band added to the TM 6-band image.

3. Both the texture and ratio bands added to the TM 6-band image.

Each image is classified using both supervised and unsupervised algorithms. Signature files from the classifications are merged and analyzed using statistical clustering algorithms. The presence of the additional bands does not appear to improve the discrimination of phreatophyte groups when compared to the classification generated from the TM 6-band image. A May 1994 TM 6-band image was used for the initial phreatophyte classification. Further work in determining the optimum imagery may be warranted, as spectral signature files were not as refined at this point in the original process.

Spectral Classification

Image Preparation

Imagery is masked to isolate general phreatophyte areas, and NDVI images are created to separate vegetated from non-vegetated areas for classification purposes. This tends to reduce classification error in deeply shadowed areas and reduces error caused by high-variance “barren” pixels. There are a variety of valid ways to address these types of problems.

Signature Generation, Analysis, and Classification

Supervised spectral signatures are created using the GPS locations from field data and the "SEED" function in ERDAS Imagine software. Unsupervised groups (or signatures) are also generated using "ISODATA" in ERDAS Imagine. Both sets of spectral statistics are merged and then analyzed using clustering algorithms. This analysis helps identify spectral signatures that are "informationally" unique (always represent the same phreatophyte group in the landscape), signatures that are spectrally similar but represent different phreatophyte groups in the landscape (spectrally confused groups), and spectral signatures (from ISODATA) that are significantly different than all supervised signatures indicating that the analysis has not accounted for all of the spectral variability in the area of interest.

Other diagnostic tools are also used to assess the signature sets. Divergence measures (Transformed Divergence [TD] and Jeffries-Matusita [JM]) are used to assess how statistically separable two signatures are from each other and also to select the best band combinations. Contingency matrices also allow the analyst to see how well training sites are being classified by the signature set (training sites used to generate signatures should be grouped correctly unless another signature is causing confusion and misclassifying the site). Classifications and signature sets are typically refined through an iterative process that often includes the use of ancillary data such as current aerial photography. Once the "per-pixel" classification (each pixel in the imagery is given a phreatophyte label) is complete, these data are used to label spectrally derived polygons.

Polygon generation and labeling

Polygons with a minimum mapping unit of 2.5 acres are generated for the phreatophyte groups. Polygons are spectrally derived using Landsat bands 3 and 4 and a texture band generated from band 4 (Ryherd and Woodcock, 1990). Image segmentation algorithms are used to spectrally derive polygons (Woodcock and Harward, 1992). This procedure creates polygons directly from the raw image data rather than from a post-classification thematic layer. These polygon boundaries tend to better represent natural boundaries in the landscape, as they are not based on post-classification aggregation rules and do not introduce any classification error into polygon formation.

Polygons can be labeled by overlaying polygon boundaries with any corresponding digital thematic data layer. In this case, polygon boundaries are "overlaid" with the phreatophyte pixel classification, and a histogram showing the distribution of phreatophyte pixel groups within each polygon is generated. Labeling rules specific to the classification system are then applied based on the relative percentages of phreatophyte pixel groups within each polygon.

Editing

Once polygons are labeled, the polygon phreatophyte map is edited to correct as much error in the classification as possible. A certain amount of error in the classification product is always expected. This error is typically due to spectral confusion related to the effects of deep shadows and sparse phreatophyte densities, as well as unresolvable spectral confusion between some phreatophyte groups. Aerial photography is the principle ancillary data source for editing purposes.

Phreatophyte Update

Phreatophytes are updated annually using change detection methodologies. Landsat imagery is used for image-to-image comparison to identify spectral change from year to year.

Coregistration and image normalization

Images from each date are first coregistered to reduce apparent change due to misregistration between the two image dates. Images are then radiometrically calibrated in order to reduce effects caused by differences in atmospheric conditions, illumination conditions, and sensor calibration between different image dates. The technique normalizes pixel values in one image date based on a regression equation derived from sampling invariant features (i.e. barren, deep water, etc.) in both images (Schott, et. al., 1988).

Image differencing

Once the imagery is coregistered and normalized, various image subtraction tests using different band combinations are performed to determine the optimum band combinations for this application. Test results are analyzed by examining the image subtraction outputs in combination with imagery, field notes, maps, and aerial photography. An image subtraction is chosen based on these results.

The image difference layer subtraction is then categorized into five groups based on all available ancillary data. This five-group map of change focuses on changes in phreatophytes and includes

1. No Change

2. Slight Increase in Phreatophytes

3. Significant Increase in Phreatophytes

4. Slight Decrease in Phreatophytes

5. Significant Decrease in Phreatophytes

Areas of change are visited in the field to verify the change as "real" and not apparent land-cover change, as well as to indicate the general nature of the change (i.e. change due to fire, clearing, etc.).

Classification

After the final change map is verified, areas deemed as significant change with respect to the phreatophyte groups are remapped. Remapping is accomplished by using classification processes as described above for phreatophytes, or manual photo interpretation techniques. Remapped areas are then incorporated into the existing phreatophyte layer as an update.

Accuracy Assessment

Accuracy assessment work is ongoing for phreatophyte updates in conjunction with Reclamation's Resource Management Office which is also mapping phreatophyte communities. Accuracy assessment for phreatophytes will include fuzzy set logic to address complexities associated with phreatophyte groups (Gopal, et. al., 1994).

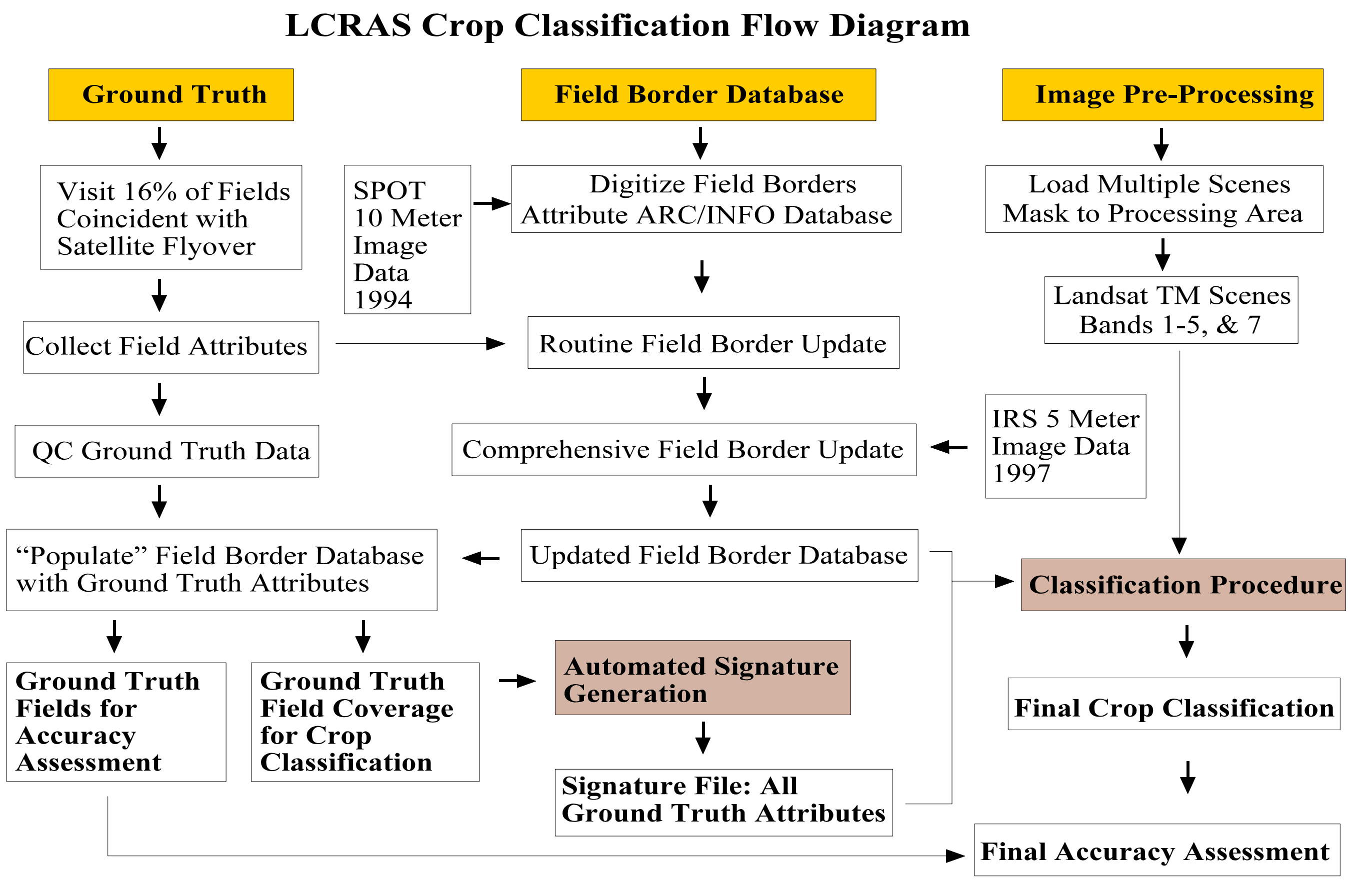


Figure Att-4.2 — LCRAS Crop Classification Flow Diagram.

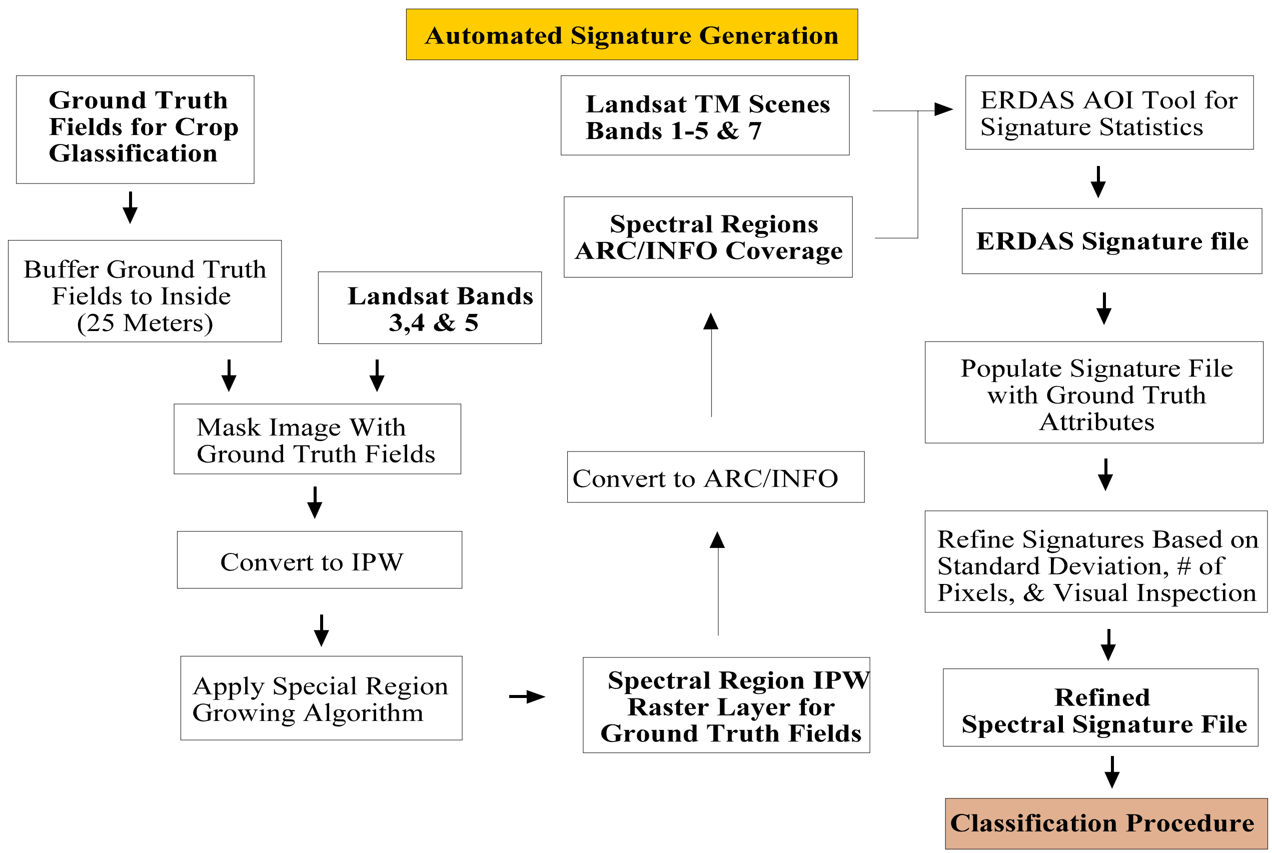


Figure Att-4.3 — Automated Signature Generation.

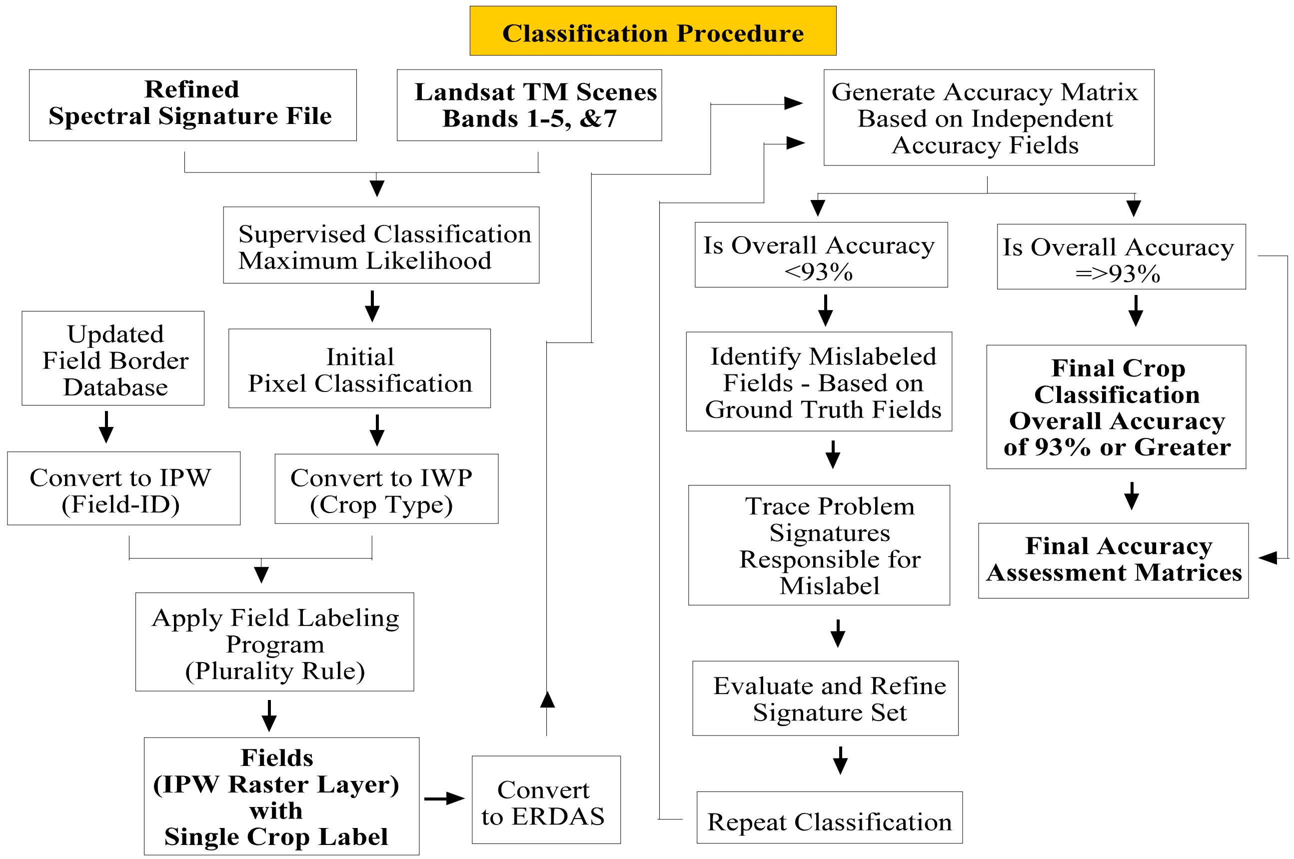


Figure Att-4.4 — Classification Procedure.

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Attachment 5

Use of a Particle Tracking Study to Estimate the Fractions of the Underflow into Mexico Across the Southerly International Boundary, that Should Be Added to District Crop and Domestic Water Use to Calculate District Consumptive Use in the Lower Colorado River Accounting System

Introduction

This attachment documents the derivation of contribution fractions of the underflow into Mexico across Southerly International Boundary (SIB), from excess irrigation by districts near Yuma, Arizona who divert and apply water from the Colorado River, based upon a particle tracking study performed by William Greer of the Yuma Area Office, Bureau of Reclamation. Mr. Greer's study is documented in a report entitled, "Determination of the Contributions of Recharge from Six Irrigated Areas near Yuma Arizona to Drainage Wells and Drains and to Underflow Across International Boundaries into Mexico Using Particle Tracking" (particle tracking study). For the purposes of this attachment, excess irrigation includes water applied in excess of the evapotranspiration requirement of the crops being irrigated, leakage from canals, and other diverted water that percolates to the groundwater table by any process.

The Lower Colorado River Accounting System (LCRAS) is a water budget tool currently being tested for application to decree accounting[HH] calculations of consumptive use of Colorado River water from Hoover Dam to SIB. LCRAS calculates consumptive use based upon evapotranspiration and estimates of domestic use, assuming that the diverted water unconsumed by these processes returns to the Colorado River and becomes available for diversion and consumptive use by other users in the United States or the satisfaction of the Mexican treaty obligation. This assumption generally holds true along the lower Colorado River upstream of Morelos Dam, near Yuma, Arizona.

Downstream of Morelos Dam, a considerable fraction of water applied for irrigation flows into Mexico through the groundwater system and is not returned to the river (underflow to Mexico). Because this

[HH] See, "Compilation of Records in Accordance with Article V. of the Decree of the Supreme Court of the United States in Arizona v. California dated March 9, 1964."

underflow to Mexico is not available for delivery to other users in the United States or in accordance with the Mexican treaty, it is a consumptive use. This underflow to Mexico, sometimes referred to as loss to Mexico, must be credited as a consumptive use to the entitlement of the district which diverted the water from the Colorado River.

In previous reports, LCRAS used 62,000 acre-feet as the initial estimate of underflow to Mexico across SIB (a final estimate of underflow to Mexico is made when a portion of the water balance residual is added to the initial estimate). The Yuma Mesa Irrigation and Drainage District (YMIDD), the Unit B Irrigation and Drainage District (Unit B), and the University of Arizona (U of A) have been credited with the underflow to Mexico across SIB as consumptive use in proportions based upon the number of acres of crops irrigated by each district (87%, 12%, and 1% respectively in 1998).

This technique assumes that 100% of the underflow to Mexico is a consequence of excess irrigation by the YMIDD, the Unit B, and U of A. While this may be a reasonable assumption in the absence of other information, the particle tracking study does provide more detailed information regarding the movement of groundwater in the Yuma area than has been available previously, and has the potential to refine the assumptions used in previous LCRAS reports.

Difference Between the Particle Tracking Study's Focus and LCRAS' Focus

The particle tracking study's general focus is the fractions of water pumped from drainage wells, and which appear in drainage ditches, that originated from excess irrigation within the districts near Yuma, Arizona. The source of the irrigation water is not a major concern. LCRAS focuses on the consumptive use of water by each district. A part of this consumptive use is the fraction of the water each district diverts and applies which becomes the underflow to Mexico across SIB.

The significant difference between these two focuses is that LCRAS does not treat the excess irrigation from the Hillander "C" Irrigation District (Hillander "C") and the area south of the Yuma Mesa (South Yuma Mesa wells) as "sources" of water, because these areas irrigate with pumped groundwater not surface diversions from the Colorado River. This pumped groundwater is primarily excess irrigation from the up-gradient applications of surface diversions from the Colorado River.

The problem that must be solved for LCRAS' needs is therefore, how to use the particle tracking study to calculate the fraction of the underflow to Mexico across SIB that is contributed by each district that applies water diverted at Imperial Dam.

Process

The goal of this process is to identify the fraction of the underflow to Mexico at SIB which comes from excess irrigation of water each district diverted at Imperial Dam. These fractions are referred to as independent components.

The process described below attempts to mitigate for the particle tracking study's treatment of Hillander "C" and the south Yuma Mesa in the same fashion as the other districts even though they do not divert water at Imperial Dam. The premise is that the fractions of the underflow to Mexico at SIB, which the particle tracking study attributes to Hillander "C" and the south Yuma Mesa, are themselves made up of fractions of the other identified components of the underflow at SIB. Hillander "C" and the south Yuma Mesa are therefore referred to as dependent components.

The identification and quantification (in acre-feet) of the components of the underflow to Mexico at SIB, and the pumping by the Hillander "C" and the south Yuma Mesa wells are all identified by the particle tracking study. The data used in this analysis are taken from tables 9, 15, 16, and 17 of particle tracking study.

The most appropriate value of flow for each component is herein considered to be the average of the flow calculated by assuming that the particles stop in non-well weak-sink cells (as defined in the particle tracking study), and the flow calculated by assuming that particles pass through non-well weak-sink cells. The spreadsheets referred to by the following process description are shown at the end if this attachment.

To begin;

1. Observe that the components of the underflow across SIB are listed with their respective acre-foot volumes (first block on first spreadsheet),

2. Set the flow of the dependent components of the underflow to Mexico across SIB (Hillander "C" and the south Yuma Mesa) to zero (first block on first spreadsheet),

3. Calculate a single acre-foot volume for each independent component of the underflow to Mexico across SIB by averaging the acre-foot volumes derived from the analysis of particles which stop or pass through non-well weak-sink cells (column labeled "Average" on the first block on first spreadsheet),

4. Observe that the components of the water pumped by Hillander "C" and the south Yuma Mesa are listed with their respective acre-foot volumes (second and third blocks on first spreadsheet),

5. Set the dependent components of the water pumped by Hillander "C" and the south Yuma Mesa (the water pumped by Hillander "C" and the south Yuma Mesa components) to zero (second and third blocks on first spreadsheet),

6. Calculate a single acre-foot volume for each independent component of the water pumped by Hillander "C" and the south Yuma Mesa by averaging the acre-foot volumes derived from the analysis of particles which stop or pass through non-well weak-sink cells (column labeled "Average" on the second and third blocks on first spreadsheet),

7. Adjust the average acre-foot volumes of each independent component of the water pumped by Hillander "C" and the south Yuma Mesa (from 6), in proportion to their magnitudes, to equal the pumping assumed by the particle tracking study (column labeled "Average Adjusted to Equal 17,842" and "Average Adjusted to Equal 36,169" on the second and third blocks on first spreadsheet),

8. Approximate the acre-foot volume of each independent component of the water pumped (and presumably applied) on Hillander "C" and the south Yuma Mesa, which contributes to the underflow to Mexico at SIB by,

   A) calculating the percentage each independent component is of the totals from 7, above and,

   B) applying these percentages to the contribution Hillander "C" and the South Yuma Mesa are identified to make to the underflow to Mexico at SIB (columns labeled "adjusted average %" and "Average Volume of SIB Underflow 'Contributed' by Hillander 'C'" and "Average Volume of SIB Underflow 'Contributed' by South Yuma Wells" on the second and third blocks on first spreadsheet),

9. Transfer the acre-foot volumes from 8, above, to the first block of the first spreadsheet representing the underflow to Mexico at SIB. (columns labeled “Adjustments From Hillander ‘C’” and “Adjustments from South Yuma Mesa”),

10. Calculate the total contribution from each independent component of the underflow to Mexico at SIB by summing the independent components of the underflow to Mexico at SIB and the adjustments from Hillander “C” and the south Yuma Mesa (column labeled “Total Average Contributions” on the first block on the first spreadsheet),

11. Calculate the “best fit” acre-foot volumes for the independent components of the underflow to Mexico at SIB by adjusting the values from 10, above, in proportion to their magnitude, to equal the assumed volume of underflow to Mexico at SIB (column labeled “Average Adjusted to Equal 62,443).

The independent components of the underflow to Mexico at SIB have now been identified and the fraction each independent represents of the total underflow to Mexico at SIB has been approximated. The independent components, their respective acre-foot volumes, and the percent fraction each represents of the total underflow are listed on the second spreadsheet (columns labeled “Adjusted Acre-Feet” and “Percentage” respectively). The column labeled “Revised Value” on the second spreadsheet is simply a tool to distribute an estimated value of underflow to Mexico at SIB different from 62,443 acre feet. A revised value would be calculated in LCRAS by adding a portion of the residual from the water budget from Imperial Dam to Mexico to an initial estimate of 62,443.

Conclusion

This study presents an alternate way to estimate the fractions of the “loss of water to Mexico” across SIB that must be credited to the diverters of the water as consumptive use. The results are considerably different from values used in previous LCRAS reports. The study does recognize that even if there was no irrigation in the Yuma area south of Morelos Dam, there would still be underflow to Mexico as part of the natural system. This recognition is missing from the previous method.

At this time, the type of process documented herein cannot be used for the underflow to Mexico across the Limitrophe section. This conclusion is based upon the particle tracking study conclusion that its results for the underflow across the Limitrophe section are unreliable.

FIRST SPREADSHEET							
Contributions to underflow across the Southerly International Boundary with Mexico (SIB) from irrigation in Arizona.							
Data Source: "Determination of the Contributions of Recharge from Six Irrigated Areas near Yuma Arizona to Drainage Wells and Drains and to Underflow Across International Boundaries into Mexico Using Particle Tracking" by William Greer, Yuma Area Office, Bureau of Reclamation.							
Note: Ranges in values represent differences from assuming particles stop in, or pass through, non-well weak-sink (NWWS) cells.							
Total flow across SIB assumed to be 62,443 acre-feet annually.							
FIRST BLOCK:							
Source of Water	Particles Stop in NWWS Cells (Acre-Feet)	Particles Pass Through NWWS Cells (Acre-Feet)	Average	Adjustments from Hillander "C"	Adjustments from South Yuma Mesa	Total Average Contributions	Average Adjusted to Equal 62,443
Unit B	83	83	83	1,617	99	1,799	1,665
YMIDD	24,952	26,750	25,851	2,340	1,707	29,898	27,665
Yuma Mesa Canals	1,670	1,701	1,686	82	0	1,768	1,636
YCWUA	5,978	17,486	11,732	1,446	0	13,178	12,194
Yuma Valley Canals	6,169	10,804	8,487	856	0	9,343	8,645
Yuma Irrig. Dist. (YID)	0	0	0	0	0	0	0
Hillander "C" (HC) *	Included in others	Included in others		0	0	0	0
South Yuma Mesa *	Included in others	Included in others		0	0	0	0
River (Mor. - SIB)	5,570	7,547	6,559	0	0	6,559	6,069
Other Sources	9,873	0	4,937	0	0	4,937	4,568
Total	54,295	64,371	59,335	6,341	1,806	67,482	62,442
* - Deep percolation from irrigation water applied in these areas is not considered a source because it is pumped water derived from other sources in this list, see breakouts below.							

SECOND BLOCK:							
Contributions to water pumped by Hillander "C" wells (pumping assumed to be 17,842 acre-feet).							
Source of Water	Particles Stop in NWWS Cells (Acre-Feet)	Particles Pass Through NWWS Cells (Acre-Feet)	Average	Average Adjusted to Equal 17,842	Adjusted Average % (Rounded)	Average Volume of SIB Underflow "Contributed" by Hillander "C"	
Unit B	3,892	3,892	3,892	4,549	25.5%	1,617	
YMIDD	5,387	5,887	5,637	6,589	36.9%	2,340	
Yuma Mesa Canals	190	196	193	226	1.3%	82	
YCWUA	2,806	4,164	3,485	4,074	22.8%	1,446	
Yuma Valley Canals	1,733	2,380	2,057	2,404	13.5%	856	
Yuma Irrig. Dist. (YID)	0	0	0	0	0.0%	0	
Hillander "C" (HC)*	Included in others	Included in others	0	0	0.0%	0	
South Yuma Mesa *	Included in others	Included in others	0	0	0.0%	0	
River (Mor. - SIB)	0	0	0	0	0.0%	0	
Other Sources	0	0	0	0	0.0%	0	
Total	14,008	16,519	15,264	17,842	100.0%	6,342	
						6,341	Check Total
* - Deep percolation from irrigation water applied in these areas is not considered a source because it is pumped water derived from other sources in this list, see breakout below.							

THIRD BLOCK:

Contributions to water pumped by US Wells south of the Yuma Mesa (pumping assumed to be 35,169 acre-feet).

Source of Water	Particles Stop in NWWS Cells (Acre-Feet)	Particles Pass Through NWWS Cells (Acre-Feet)	Average	Average Adjusted to Equal 35,169	Adjusted Average %	Average Volume of SIB Underflow "Contributed" by South Yuma Wells	
Unit B	1,765	1,765	1,765	1,938	5.5%	99	
YMIDD	30,259	30,259	30,259	33,231	94.5%	1,707	
YCWUA	0	0	0	0	0.0%	0	
Yuma Irrig. Dist. (YID)	0	0	0	0	0.0%	0	
Hillander "C" (HC) *	Included in others	Included in others	0	0	0.0%	0	
South Yuma Mesa *	Included in others	Included in others	0	0	0.0%	0	
Canal leakage	0	0	0	0	0.0%	0	
Other sources	0	0	0	0	0.0%	0	
Total	32,024	32,024	32,024	35,169	100.0%	1,806	
						1,806	Check Total

* - Deep percolation from irrigation water applied in these areas is not considered a source because it is pumped water derived from other sources in this list.

SECOND SPREADSHEET					
Source of underflow to Mexico across the Southerly International Boundary					
Source of Water	Adjusted Acre-Feet	Percentage	Rounded Percentage	Revised Value From From Rounded %	
Unit B	1,665	2.7%	3.0%	1,873	
YMIDD & Yuma Mesa Canals	29,301	46.9%	47.0%	29,348	
YCWUA & Yuma Valley Canals	20,839	33.4%	33.0%	20,606	
YID	0	0.0%	0.0%	0	
River (Mor. - SIB)	6,069	9.7%	10.0%	6,244	
Other Sources	4,568	7.3%	7.0%	4,371	
Total	62,442	100.0%	100.0%	62,443	
				62,442	Check Value

Attachment 6

Revised Reference ET and Crop Groupings for 1999

Introduction

This attachment documents the reference evapotranspiration (reference ET) values used in the development of this LCRAS Demonstration of Technology report and how they differ from the reference ET values reported by the Arizona Meteorological Network (AZMET) and the California Irrigation Management Information System (CIMIS) stations sited along the lower Colorado River used in previous LCRAS Demonstration of Technology reports. This attachment also documents the disparity between reference ET values reported by the AZMET and CIMIS networks, the problem that this disparity presents to the LCRAS program, the investigations undertaken to identify and understand its source, and the development of a solution for the LCRAS program.

This attachment also documents improvements made in crop groups, used to calculate crop ET, implemented in this report.

Reference ET for 1999

This report is compiled using reference ET values calculated using the standardized reference evapotranspiration equation (standardized equation) recommended by the American Society of Civil Engineers, Evapotranspiration in Irrigation and Hydrology Committee and data collected by the AZMET and CIMIS stations sited along the lower Colorado River.

In 1999 area-wide reference ET values for the Palo Verde/Parker valleys and the Yuma valley were developed by averaging the reference ET values for stations sited within these two areas. The area-wide reference ET values for the Palo Verde/Parker area were developed by averaging the reference ET values calculated using the standardized equation and data collected by the three CIMIS stations sited in the Palo Verde Valley (Blythe North East, Palo Verde, and Ripley) and the Parker AZMET station sited in the Parker Valley. The area-wide reference ET values for the Yuma area were developed similarly, using data collected by the three AZMET stations sited in Yuma area (North Gila, Yuma Valley, and Yuma Mesa). The reference ET calculated using the standardized equation and data collected by the single

AZMET station sited in the Mohave Valley was used for the Mohave Valley area. Table Att 6.A lists the annual summation of the averaged daily reference ET values for the years 1998 and 1999.

Table Att 6.A — Annual Summation of Area-Wide Averaged Daily Reference ET Values Used for this LCRAS Demonstration of Technology Report

(Units: inches)

Year	Mohave	Palo Verde/Parker	Yuma	Average
1999	76.89	76.25	76.67	76.60
1998	74.17	71.38	74.66	73.40

The values presented for 1998 are included for comparison with the overall average reference ET value of 74.49 inches used in the 1998 LCRAS Demonstration of Technology report.

The Disparity in Reference ET Values Reported by the AZMET and CIMIS Stations and the Need for Consistent Reference ET Values for the LCRAS Program

During the compilation of data for the 1997 LCRAS Demonstration of Technology Report in 1998, Reclamation noted that the average annual summation of daily reference ET values reported by the AZMET stations differed by as much as 17 inches from that of the CIMIS stations during the period 1995 through 1997. Average annual reference ET calculated by AZMET was approximately 18 percent higher than CIMIS during this same period.

Table Att 6.B lists the annual summation of daily reference ET values reported by the AZMET and CIMIS stations along the lower Colorado River for the years 1995 through 1999.

Table Att 6.B — Annual Summation of Daily Reference ET Values
Reported by AZMET and CIMIS Stations

(Units: inches)

Year	Mohave	Parker	Blythe NE	Palo Verde	Ripley	N. Gila	Yuma Mesa	Yuma Valley
1999	84.99	88.35	71.67	69.83	68.88	82.87	83.40	88.97
1998	80.68	82.20	66.07	66.96	NA	78.51	81.71	89.20
1997	84.99	91.06	69.66	68.34	NA	82.25	82.39	88.72
1996	86.76	93.32	NA	72.10	NA	87.26	83.23	92.04
1995	76.66	89.06	NA	71.63	NA	82.94	78.94	89.51

This disparity in reference ET values reported by the AZMET and CIMIS networks presents a problem for LCRAS because a consistent set of ET coefficients is used to calculate the ET of crop and phreatophyte groups on both sides of the River (in California, Nevada and Arizona). Therefore, consistent reference ET values are required from the CIMIS and AZMET networks. To meet this need; Reclamation discussed the problem with representatives from the CIMIS and AZMET networks and Reclamation's consultant. The result of this discussion was a recommendation to use an average of the reference ET values reported by the CIMIS and AZMET networks to calculate crop and phreatophyte ET as an interim solution until the disparity could be fully analyzed and a solution developed and implemented.

The use by LCRAS of an average reference ET calculated from the reference ET values reported by the AZMET and CIMIS stations sited along the lower Colorado River was discussed at length at the LCRAS public meeting in Henderson, Nevada, in October 1998. Subsequently, an average of the reference ET values reported by the AZMET and CIMIS stations sited along the lower Colorado river was used to prepare the LCRAS Demonstration of Technology Reports for calendar years 1997 and 1998.

Analysis of the reference ET reported by the AZMET and CIMIS stations located along the lower Colorado River

Analysis by the University of Arizona (operators of AZMET), the California Department of Water Resources (operators of CIMIS), and Reclamation's consultant identified four potential sources of the disparity in the reference ET values reported by the AZMET and CIMIS stations sited along the lower Colorado River,

1) the equation used to calculate reference ET,
2) crop conditions at the station sites,
3) equipment maintenance and calibration, and
4) micro-climatic differences between station sites.

This analysis concluded that,

1) Net radiation is the most significant component of the methods used by the AZMET and CIMIS networks to calculate reference ET and that each network uses a slightly different method to calculate net radiation[II],

2) micro-climatic differences between AZMET and CIMIS station sites contribute no more than 5 percent to the variation in reported reference ET values between individual sites.

3) how crop conditions at the station affect the variations in reported reference ET values at individual sites is not fully quantified and,

4) the equipment used at AZMET and CIMIS stations, and the maintenance and calibration procedures for this equipment, are very similar.

[II] The CIMIS and AZMET networks do not measure net radiation directly because of the cost and maintenance requirements of the instruments.

Net Radiation

The University of Arizona recently completed a study to identify the impact that the different methods used to calculate net radiation have on reported reference ET values. The study concludes that the difference in methods used to calculate net radiation is the major source of the disparity in reported reference ET values between the two networks.

The methods used to calculate net radiation by AZMET and CIMIS differ in the approximation of cloud cover. The cloud cover approximation used by AZMET typically yields higher net radiation values during the daytime than the cloud cover approximation used by CIMIS. The result is generally higher reported reference ET values from AZMET stations when compared to CIMIS stations.

When the reference ET values reported by AZMET and CIMIS networks are compared to reference ET values calculated using the Penman-Monteith equation and measured net radiation, the CIMIS stations appear to significantly underestimate reference ET in the summer and fall which leads to an annual reference ET that is low by an average of about 9%. The AZMET stations appear to overestimate reference ET during the fall, winter and spring which leads to an annual reference ET that is high by an average of about 6%.

Micro-climatic Differences Between Station Sites

Micro-climatic differences between AZMET and CIMIS station sites contribute no more than 5% of the variation in reported reference ET between individual the stations. The data also does not indicate a geographic trend from north to south as might be expected. The disparity in reference ET values reported by the AZMET and CIMIS stations exceed 5%. Therefore, the disparity in the reference ET values reported by the CIMIS and AZMET sites along the lower Colorado River is greater than micro-climatic differences between the sites alone can explain.

Station Siting Conditions

Siting conditions, including crop conditions, at a weather station site most likely have an impact on the accuracy of the calculated reference ET, however the full impact has not been quantified. Reclamation and the University of Arizona are cooperating in a study to identify the impact station siting conditions at individual stations have on reported reference ET values. This two-year study is targeted for completion in August 2001.

Equipment Used at AZMET and CIMIS Stations

The consultation concluded that the equipment used by both networks is standard for the industry and calibrated to the manufacturer's specifications during installation and site visits for periodic maintenance. Both networks perform regularly scheduled maintenance to the best of their abilities, typically on a monthly basis. Additional maintenance is performed when equipment fails. Data is reviewed daily by both entities to identify anomalies and problems with sensors. It is doubtful that differences in equipment maintenance and calibration contribute significantly to the disparity in the reference ET values reported by the AZMET and CIMIS networks.

The Standardized Reference Evapotranspiration Equation Solution

The University of Arizona, the California Department of Water Resources, and Reclamation's consultant have recommended a solution to the problem the disparity between the reference ET values presents to the LCRAS program. The recommended solution is to calculate reference ET using the standardized reference ET equation, recommended by the American Society of Civil Engineers, Evapotranspiration in Irrigation and Hydrology Committee (ASCE-ET), and the data collected by the AZMET and the CIMIS stations sited along the lower Colorado River. To implement this solution, a reference ET, calculated using the standardized equation, must be calculated for each AZMET and CIMIS station site based upon the data collected by each station. This solution has been implemented beginning with this report as explained at the beginning of this attachment.

The development of the standardized reference ET equation resulted from a request made by the Irrigation Association (IA) of the ASCE-ET to help establish and define a benchmark reference ET equation. "The purpose of the equation is to bring commonality to the various reference ET equations and crop coefficients now in use. IA envisioned an equation that would be accepted by the U.S. scientific community, engineers, courts, policy makers, and end-users. An equation that would be applicable to agricultural and landscape irrigation and would facilitate the use and transfer of crop and landscape coefficients."[KK]

[KK] Walter, et. al., 2000, proceedings of the ASCE-EWRI Watershed Management 2000 Symposium, Ft. Collins, Co.

ASCE-ET empaneled the Task Committee on Standardization of Reference Evapotranspiration (TC) consisting of leading scientists in the field of reference ET and vegetative water use, including Ivan Walter P.E. and Drs. Marvin Jensen, Richard Allen, Paul Brown and Simon Eching. The TC developed several evaluation criteria which provided that the standardized equation should be understandable, defensible, simple, accepted by the science/engineering communities, facilitate the use of existing data and be based on measured or experimental data. An important element of the evaluation criteria states that if the standardized equation resulted from the simplification of a currently accepted equation that there should be no significant loss of accuracy from the simplification.

The TC evaluated equations preferred by the scientific/engineering community including the ASCE-Penman Monteith, FAO-56 Penman Monteith, 1982 Kimberly Penman, CIMIS Penman, NARCS Chapter 2 Penman Monteith, and the 1985 Hargreaves. The TC selected the ASCE Penman Monteith ET values as the measure against which to evaluate equations proposed for use as the standardized equation. The performance of the proposed equations was evaluated using data from 49 sites in 16 States, covering 82 site-years, spanning a wide range of elevation and including most of the States of the West. Evaluations were also performed to compare the variance of summed hourly ET to daily ET for each equation.

The Standardized Equation

The equation recommended by TC for use as the standardized equation is a reduced version of the ASCE Penman Monteith (ASCE P-M) equation. The standardized equation is a simplified version of the ASCE Penman Monteith (ASCE P-M) equation in which constants (C_n and C_d) are used to represent a tall or short reference crop and the time step of the ET calculation (hourly or daily). The standardized equation used to calculate the reference ET values used in this report is shown below.

$$ET_{ref} = [0.408\Delta(R_n - G) + \gamma(C_n / T+273)u_2 (e_s - e_a)] / [\Delta + \gamma(1 + C_d u_2)]$$

Where:

ET_{ref} = short (ET_{os}) or tall (ET_{rs}) standardized reference evapotranspiration (mm/day),

*R_n = net radiation at crop surface (MJ m^{-2}/day or hour),

*G = soil heat flux density at the soil surface (MJ m^{-2}/day or hour),

*T = mean daily or hourly air temperature at 1.5 to 2.5m height (°C),

*u_2 = mean daily or hourly wind speed at 2 m height (m/s),

$*e_s$	= mean saturation vapor pressure at 1.5 to 2.5 m height (kPa),
$*e_a$	= mean actual vapor pressure at 1.5 to 2.5 m height (kPa),
*)	= slope of the vapor pressure-temperature curve (kPa $^\circ C^{-1}$),
(	= the psychrometric constant (kPa $^\circ C^{-1}$),
C_n	= constant for reference type and calculation time step,
C_d	= constant for reference type and calculation time step.

* calculated from data collected at each of the AZMET and CIMIS sites.

Dr. Paul Brown of AZMET performed the calculations required to develop daily reference ET values for calendar years 1998 and 1999 using the standardized equation and data collected at each of the AZMET and CIMIS stations along the River.

The annual summations of the daily reference ET values calculated by Dr. Brown are shown in Table Att 6.C.

Table Att 6.C — Annual Summation of Daily Reference ET Values calculated using the Standardized equation

(Units: inches)

Year	Mohave	Parker	Bly. NE	P. Verde	Ripley*	N. Gila	Y. Mesa	Y. Valley	Average
1999	76.89	82.96	76.55	72.87	72.62	75.20	72.92	81.90	76.49
1998	74.17	75.88	69.48	68.78	NA	69.64	73.58	80.75	73.18

*The Ripley CIMIS station was installed in November of 1998.

The 1998 values displayed in table 2 are presented for comparison with the averaged reference ET value of 74.49 inches used to compile the 1998 LCRAS Demonstration of Technology report. The average reference ET value of 73.18 inches for 1998 (shown in table 1) differs from the averaged reference ET value used to compile the 1998 LCRAS Demonstration of Technology report by less than 2%.

Impact of Using the Standardized Equation on ET Coefficients

Reclamation asked Dr. Marvin Jensen to evaluate the need to adjust the ET coefficients used by LCRAS for use with the standardized equation. Dr. Jensen performed an analysis comparing evapotranspiration calculated using the 1999 LCRAS ET coefficients and reference ET from the standardized equation with crop studies performed in arid climates worldwide. The comparison studies included ET values calculated by various equations and ET measured in lysimeter studies. As expected the ET calculated using reference ET from the standardized equation and 1999 LCRAS ET coefficients did not differ significantly from the average water use by the subject crops determined by the previous studies. The consensus is that the 1999 LCRAS ET coefficients do not need to be adjusted for the use of the standardized equation.

This exercise did however indicate that the ET coefficients developed for Citrus and Alfalfa may eventually need some adjustment. This conclusion stems not as a result of useing the standardized equation for reference ET, but from trends that are beginning to appear in the LCRAS water balance. This will be studied over the next year to see if the trends identified in the 1995 - 1998 water balances continue through 2000.

New Crop Groups for 1999

As noted in chapter 2, the section titled ***ET Coefficients for Crop and Phreatophyte Groups*** of this report, a number of new crop groups have been added to the suite of crop groups used by LCRAS, and individual crops have been moved from one crop group to another to more accurately group crops with like water use and growing seasons. For example, many of the crops formerly within the crop group called Other Vegetables have been moved into other existing or new crop groups which now contain crops with similar water use and growing seasons.

Crop groups that have changed are: Field Grain (replaces Corn) and Legume/Solanum Vegetables (replaces Other Vegetables). Crop groups that have been added are: Deciduous Orchards, Small Vegetables, Root Vegetables, Perennial Vegetables, Sugar Beets, and Grapes. Many crops formerly included in the Other Vegetables group have been reassigned to these new groups. Each of these crop groups have been assigned a unique set of daily ET coefficients. In addition, crop subgroups, each with a unique set of ET coefficients, have been added to the Bermuda Grass, Sugar Beets, and Citrus crop groups. The Bermuda grass crop group now includes subgroups to represent Bermuda grass dormant in the winter and Bermuda grass over seeded with rye in the winter. The sugar beets crop group includes subgroups to represent winter and summer planting. The Citrus crop group now includes subgroups which represent three stages of development, young 1-2 meters, mature 2+ meters and declining. Table Att 6.D shows the distribution of crops within the new crop groups developed for 1999.

Table Att 6.D — Changes to Crop Groupings in the 1999 LCRAS Report

5-Field Grain	**7-Melons**	**12- Legume Vegetables**	**13-Crucifers**	**17-Deciduous Orchards**	**18-Small Vegetables**	**19-Root Vegetables**	**20-Perennial Vegetables**
field corn	squash	beans	okra	pecans	carrots	beets-table	artichokes
sorghum		beans (dry)		peaches	celantro	parsnip	asparagus
milo		garbonzo			celery	turnips &rutabaga	
		peas			garlic		
		peanuts			onions-dry		
		peppers			onions		
		potatoes			parsley		
					radishes		

The changes discussed above were made to improve the accuracy of evapotranspiration values calculated by the LCRAS method. Reclamation has made every effort to use methods that are accepted by the scientific and engineering community or that have been reviewed and accepted by scientists and engineers in the field of crop water use.