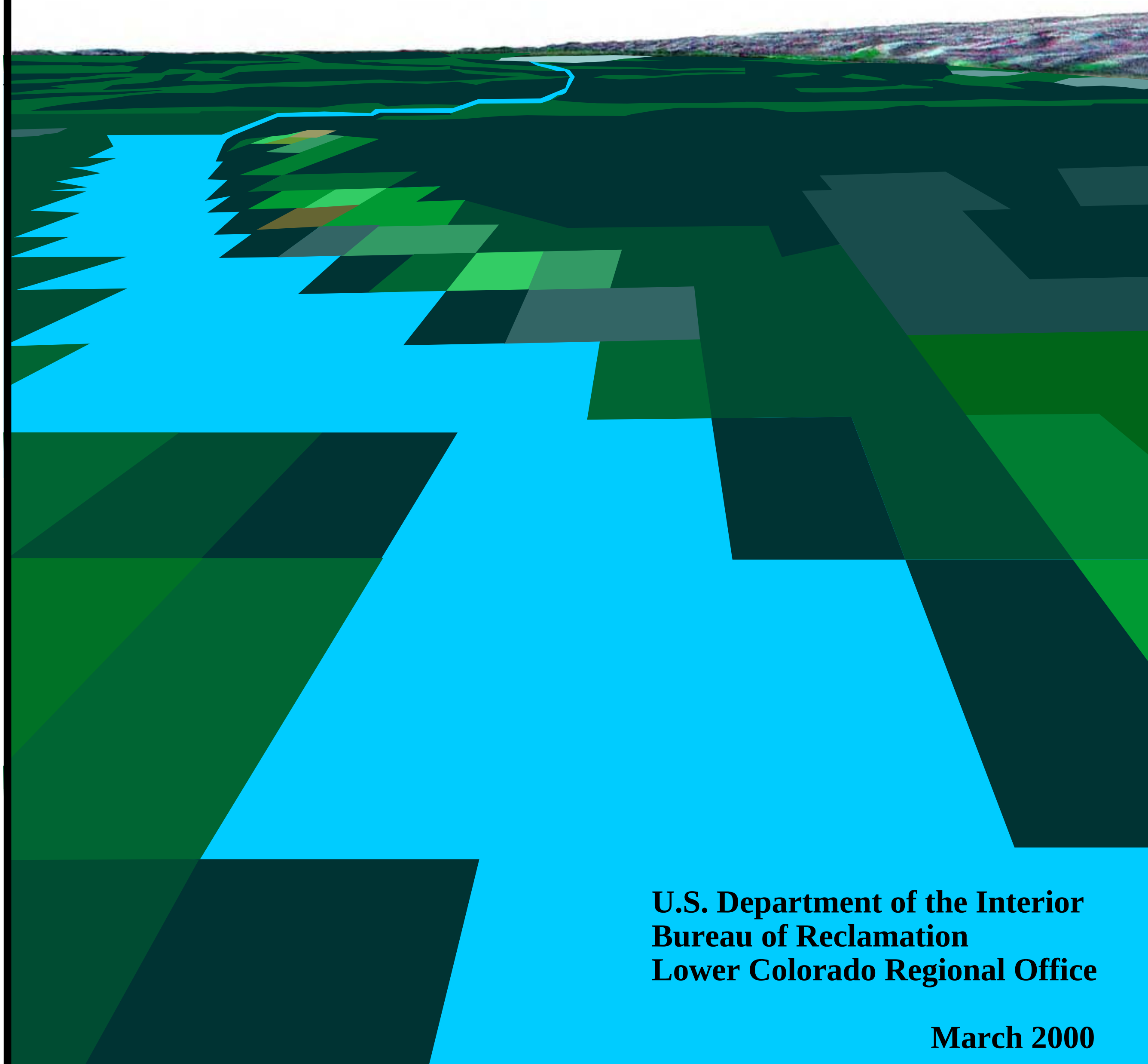
Lower Colorado River Accounting System
Demonstration of Technology

Calendar Year 1998



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

March 2000

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

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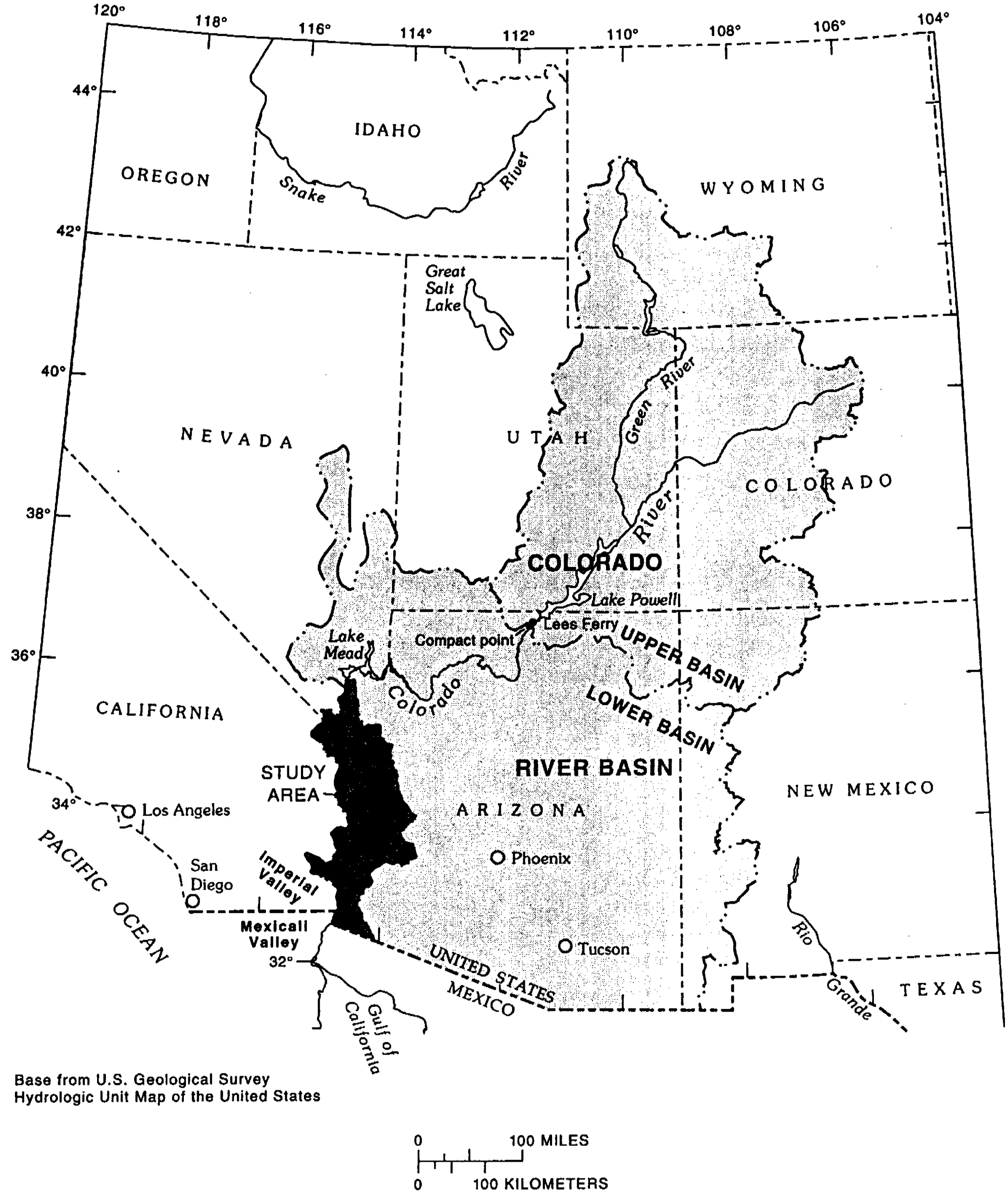

COLORADO RIVER BASIN AND STUDY AREA

Executive Summary

The Colorado River is the principal source of water for irrigation and domestic use in Arizona, southern California, and southern Nevada. Within this area, accounting for the use and distribution of water from the 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). This report focuses on determining values of consumptive use.

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 the request of the lower Basin States to account for return flows in addition to those measured as surface flows, a limitation of 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 flows. 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, and 1997 (Bureau of Reclamation 1997, 1998a, and 1999).

This report documents the application of LCRAS to calendar year 1998 and the changes made to the LCRAS method since the report for calendar year 1997 was issued.

The LCRAS Method

LCRAS is an accounting method that estimates and distributes consumptive use to diverters along the lower Colorado River. LCRAS uses a water balance in which all the inflows, outflows, and water uses are calculated or 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 values for short grass (ET_0) provided by the California Irrigation Management Information System (CIMIS) and Arizona Meteorological Network (AZMET) stations located in irrigated areas along the Colorado River,

2) vegetation-class-specific ET coefficients, and

3) the acreage of each crop and phreatophyte classes that appeared along the lower Colorado River developed from the classification of remotely sensed data (image classification).

The initial estimate of domestic consumptive use not associated with vegetation 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 the remaining domestic diverters along the mainstream of the lower Colorado River. 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 a question left open by this report.

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

Image Classification Results

The image classification results are excellent using Landsat 5 image data to discriminate crop classes. Reliable results are obtained using single-date image classification processes. Post-classification accuracy assessment shows that, overall, the crops can be mapped with an average accuracy of approximately 93 percent for each image classification date (four dates in calendar year 1998).

The initial phreatophyte coverage developed by Reclamation for the 1995 LCRAS report (Bureau of Reclamation, 1997) was developed in 1994. Discrimination between phreatophyte classes, while not as well defined as crops, 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 1998, 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 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.

Distributing the residual is considered optional if the value of the residual is about equal to or less than the presumed measurement error of the mainstream flow entering the reach. The residual is distributed in all reaches for 1998 to show the impact of the residual distribution on the final results, even though the residual is less than the presumed measurement error of the flow entering all of the reaches.

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 (unadjusted 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})	12,774,700	12,940,300	10,380,000	9,095,557	12,774,700
Flow at the downstream boundary (Q_{ds})	12,940,300	10,380,000	9,095,557	4,800,885	4,800,885
Residual	-114,548	-81,568	175,118	31,365	10,367
Residual as a percentage of the mainstream flow entering the reach (Q_{us})	-0.90%	-0.63%	1.69%	0.34%	0.08%
Difference between upstream and downstream flow (Q_{dif})	-165,600	2,560,300	1,284,443	4,294,672	7,973,815
Measured Tributary inflow (Trm)	0	7,443	0	7,988	15,431
Unmeasured Tributary inflow (Trum)	6,480	36,290	33,750	3,000	79,520
Exported flow (Q_{ex})	0	2,300,878	0	3,837,381	6,138,259
Evaporation (E)	112,552	97,970	61,193	5,061	276,776
Domestic consumptive use [1] (CU_d)	510	33,836	5,175	27,398	66,919
Crop evapotranspiration (ET_{crop})	0	72,611	729,919	337,689	1,140,219
Phreatophyte evapotranspiration (ET_{pht})	866	171,406	342,750	66,766	581,788
Change in reservoir storage (**)** S_r)	-158,500	8,900	4,038	0	-145,562
Change in aquifer storage (**)** S_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 1998.

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[1]Decree of the Supreme Court in Arizona v. California, Article I(I), “Domestic use includes 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.

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 1998 Decree Accounting Report)		227,683	227,683	Uses above Hoover Dam
Uses below Hoover Dam	19,616	16,926	17,621	Uses below Hoover Dam
			794	Unmeasured return flow credit
Nevada Total	19,616	244,609	244,510	Nevada Total
California				
			5,045,232	Sum of individual diverters
			91,996	Unmeasured return flow credit
California Total	167,769	4,953,357	4,953,236	California Total
Arizona				
Subtotal (below Hoover Dam, less Wellton-Mohawk IDD)	395,082	2,063,146	2,347,725	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (1998 Decree Accounting Report)		151	151	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (1998 Decree Accounting Report)		290,355	290,355	Wellton-Mohawk IDD
			71,515	Pumped from South Gila wells (drainage pump outlet channels [DPOCs]).
			143,842	Unmeasured return flow credit
Arizona Total	395,082	2,353,652	2,422,874	Arizona Total
Lower Basin Total				
Total Lower Basin Use	582,467	7,551,618	7,620,620	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})	12,840,311	12,891,428	10,251,035	9,137,278	12,840,311
Flow at the downstream boundary (Q_{ds})	12,891,428	10,251,035	9,137,278	4,871,386	4,871,386
Residual	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	-51,117	2,640,393	1,113,757	4,265,892	7,968,925
Measured Tributary inflow (Trm)	0	7,447	0	7,988	15,435
Unmeasured Tributary inflow (Trum)	6,484	36,361	33,503	2,999	79,347
Exported flow (Q_{ex})	0	2,299,605	0	3,839,470	6,139,075
Evaporation (E)	112,520	97,956	61,216	5,061	276,753
Domestic consumptive use (CU_d)	510	33,836	5,175	27,398	66,919
Crop consumptive use (CU_{crop})	0	72,603	733,132	338,045	1,143,780
Phreatophyte water use (CU_{pht})	866	171,362	343,458	66,780	582,466
Change in reservoir storage ()S_r)	-158,504	8,899	4,038	0	-145,567
Change in aquifer storage ()S_a)	-25	-60	241	125	281

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 becomes available and potential improvements are identified through reviews and experience. An outstanding question that must be resolved is the appropriate assessment 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 the lower Colorado River basin.

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 1999 and 2000 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 Supreme Court Decree of 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, in 1984 the task force chose to develop and apply a water balance approach to the lower Colorado River. 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 1998 documents the processes and data used to apply the LCRAS method to determine consumptive use along the lower Colorado River below Hoover Dam for calendar year 1998.

The LCRAS Method

LCRAS is an accounting method that estimates and distributes consumptive use to diverters along the lower Colorado River. LCRAS uses a water balance in which all the inflows, outflows, and water uses are calculated or 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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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.

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 1998

Reclamation's activities for the 1998 LCRAS Demonstration of Technology began with scheduled ground reference data collection to record crop and field conditions. Reclamation purchased satellite imagery and processed it using standard image classification methods, incorporating recent improvements to procedures developed in previous years. Reclamation also finalized the district boundaries that would be used in 1998, after consultation with several irrigation districts to confirm and update the district boundaries that were used in 1997.

Reclamation gathered reference ET and precipitation data from AZMET and CIMIS stations along the lower Colorado River and finalized the ET coefficients for each crop and phreatophyte class and open-water evaporation that would be used in 1998. Reclamation averaged the ET_0 values provided by the AZMET and CIMIS networks and developed one set of ET_0 values for the entire lower Colorado River as was done in the 1997 report. Reclamation compiled domestic uses and changes in reservoir storage during 1998 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 1998 data was performed as the data became available throughout the year. The acreage of each crop class grown, each phreatophyte class 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 1998 and calculated the number of acres occupied by each crop and phreatophyte class within the boundary of each irrigator, wildlife refuge, or other reservation of land along the river.

With the information described above, Reclamation calculated the evapotranspiration of each crop and phreatophyte class 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 1998, 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 1998.

Remote Sensing and Geographic Information Systems

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

The flood plain boundary (shown in exhibits 2 through 8) used in 1998 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 crop areas included in this analysis are located within the flood plain boundary along the mainstream of the lower Colorado River 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 diverters are not part of this GIS coverage. They, and their service areas, will be incorporated in the future.

Remote sensing involves the processing of satellite imagery to identify and quantify the type and area of crop classes, fallow classes, phreatophyte communities, and open water along the lower Colorado River. Field surveys are also used to obtain information for vegetative 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 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 (image data). GIS database management tools are used to calculate, summarize, and generate reports defining the area of each crop class and phreatophyte communities for each diverter and open water along the lower Colorado River.

Satellite Image Processing

Multispectral analysis is performed on image data to classify and map vegetation and open water along the mainstream of the lower Colorado River. Vegetation and open-water classification processes have been developed for image data acquired by the Thematic Mapper (TM) sensor mounted onboard the

Landsat 5 satellite. This sensor detects and records reflected and emitted energy (light) 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 25 meters. TM image data were acquired for analysis during calendar year 1998 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	February 28, 1998	Path 39, row 36	March 3, 1998
Path 38, rows 36 and 37	April 29, 1998	Path 39, row 36	May 6, 1998
Path 38, rows 36 and 37	July 18, 1998	Path 39, row 36	July 25, 1998
Path 38, rows 36 and 37	November 7, 1998	Path 39, row 36	November 14, 1998

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. The February TM image for Path 38, rows 36 and 37, was not usable in 1998 because of cloud cover. A multispectral image from the Indian Remote Sensing Satellite using the Linear Imaging Self Scanning III sensor (path 245, row 47) was substituted. IRS LISS III images are equivalent to Landsat 5 TM images for the needs of LCRAS. The IRS LISS III path 245, row 47, encompasses the LCRAS study area covered by Landsat TM path 38, rows 36 and 37.

Ground Reference Data Collection

Correct identification and mapping of crop and phreatophyte classes by image data processing requires a detailed understanding of the spectral characteristics and irrigation practices of representative sites

[2] Landsat 5 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 V has 233 paths corresponding to the number of orbits required to cover the earth in one 16-day cycle. 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.

throughout the study area. TM image data contain digital values that represent the spectral reflectance of land-cover types as detected and recorded by the TM sensor. These digital values can be analyzed to generate spectral statistics (signatures) that represent specific land cover types on the Earth's surface. Ground reference data is required to understand unique relationships between the spectral signatures derived from the image data and crop and phreatophyte classes on the ground.

Ground reference data are collected for approximately 1,900 of the 12,800 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 identification and mapping of crop and phreatophyte classes. Selection of ground reference sites is based on the vegetation distribution in each major irrigated area along the mainstream of the lower Colorado River. Irrigated fields are selected randomly from a database of the irrigated fields and their borders. Additional sample fields are added to the random sample where necessary to ensure all crop types are adequately represented. 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 is a critical factor in the selection of image data-collection dates.

Table 2 presents the crop classes sampled. Classes such as Other Vegetables, Small Grains, and Crucifers are general class names that consist of a variety of specific crop types.

Table 2 — Crop classes

Alfalfa	Corn	Bermuda Grass	Sudan Grass	Fallow
Cotton	Lettuce	Citrus	Other Vegetables	Dates
Small Grains	Melons	Tomatoes	Crucifers	Safflower

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

Table 3 — Phreatophyte classes

Class 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, Phreatophyte, 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 Crop 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. All the ground reference data collected for image classification is 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 1998. Reclamation also uses 5-meter Indian Remote Sensing satellite data to update field borders on an annual basis below Imperial Dam and every three to four years north of Imperial Dam. More frequent field border updates are required below Imperial Dam due to the greater variability in cropping patters in that area. Field borders will continue to be routinely updated using these two practices.

All areas along the mainstream of the lower Colorado River 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 classes listed in table 2 using a single-date image classification process several times per year. Post-classification accuracy assessment shows that, overall, the crops 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 1997 and May 1998 were used to perform the update for this report.

Delineation of Open Water

A separate class is developed, and image classification processes are used to quantify areas of open water. A single-image classification process is performed on Landsat 5 images acquired for this purpose. Images acquired July 25 and July 18, 1998, were used for the Hoover Dam to Davis Dam; and Davis Dam to Parker Dam, Parker Dam to Imperial Dam, and Imperial Dam to Mexico reaches respectively. In 1995, area of open water within reservoirs quantified by image classification processes were 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 1998 uses the same equation that was used for 1997 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
)S_r	=	The change in reservoir storage
)S_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 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).

[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.

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.

Export Flow (Q_{ex})

Flows into the California 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 California 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 1998, 30,004 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.

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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 1998.*

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	1,072,645	1,072,052	-593	-0.10%
CAP	1,228,233	1,227,553	-680	-0.06%
Wellton-Mohawk	372,577	372,646	69	0.02%
IID & Coachella	3,434,800	3,436,819	2,019	0.06%

The sum of the final estimates of export flows accounts for about 84 percent of the total lower Colorado River basin consumptive use (crop, domestic, and export).

Measured Tributary Inflow Data (T_{rm})

The flows on two tributaries to the lower Colorado River 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 was 15,431 acre-feet in 1998, or about 0.12 percent of the flow below Hoover Dam. After distribution of residual from the water balance, the final value of measured tributary inflow increased to 15,435 acre-feet, a change of about 0.03 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 decreased to 79,347 acre-feet, a change of about 0.22 percent. Unmeasured tributary flow values can be found in attachment 2.

Evapotranspiration

The LCRAS method calculates evapotranspiration for all vegetation within the flood plain and on the Palo Verde and Yuma Mesas as an initial estimate of crop consumptive use and phreatophyte water use. Evapotranspiration calculations require the following:

1) Daily ET_0
2) Daily crop and phreatophyte class ET coefficients

3) Number of acres covered by each crop and phreatophyte class
4) Effective precipitation (used to develop crop ET only)

Daily ET_0 values are reported by two CIMIS and five AZMET automated weather stations along the lower Colorado River. These stations are located in irrigation districts within the flood plain and continuously collect maximum, minimum, and average temperature and relative humidity; 2- and 4-inch average soil temperature, wind speed, precipitation; and calculate net solar radiation. These parameters, with the exception of precipitation, are used to calculate hourly and daily ET_0 values. This report used a weighted average of the daily ET_0 values from the CIMIS and AZMET stations. The purpose of using a weighted average is to mitigate for the variation in reported ET_0 values between the two networks and within each network. The technique used to develop the weighted average ET_0 is explained below.

The daily ET coefficients used in 1998 for each vegetation class are the same as those used in 1997[6]. Reclamation developed the acreage covered by each vegetation class by applying the analysis described above in "Delineation of Crop, Phreatophyte, and Open-Water Areas."

Weighted Average ET_0 Values

Reclamation has noted that the annual summation of daily ET_0 values reported by the AZMET stations has differed by as much as 23 inches from that of the two CIMIS stations during a 4-year period (1995 - 1998). The variation in the annual summation of daily ET_0 values reported by the AZMET stations themselves has been as much as nearly 13 inches during this same period.

Table 5 lists the annual summation of daily ET_0 values (inches) for the stations along the lower Colorado River.

[6] Daily ET coefficients were developed specifically for the LCRAS program (Jensen, Marvin E., 1996) and updated for the 1997 report based upon changes in growing season patterns observed since Dr. Jensen's initial work for LCRAS.

Table 5 — Annual Summation of Daily ET_0 Values
(Units: inches [rounded])

Year	Mohave	Parker	Blythe NE	Palo Verde	North Gila	Yuma Mesa	Yuma Valley
1998	80.68	82.20	66.07	66.96	78.51	81.71	89.20
1997	84.99	91.06	69.66	68.34	82.25	82.39	88.72
1996	86.76	93.32	NA	72.10	87.26	83.23	92.04
1995	76.66	89.06	NA	71.63	82.94	78.94	89.51

Consultation with the University of Arizona (operators of AZMET), the California Department of Water Resources (operators of CIMIS), and Reclamation's consultant identified three potential sources of the variation of reported ET_0 values along the lower Colorado River:

1) local climatic conditions
2) siting conditions and
3) the method used to calculate ET_0

This consultation also concluded that variation in local climatic conditions contribute to variations in ET_0, but probably not much more than about 5 percent, nor do the data indicate a geographic trend from north to south as might be expected. In other words, the variation in the ET_0 values shown in table 5 is greater than differences in local climatic variation along the lower Colorado River can explain.

This consultation also concluded there is uncertainty with respect to the effect siting has on the variations in reported ET_0 values. Reclamation and the University of Arizona are cooperating in a siting study in order to identify the effect siting has on the variation of reported ET_0 values. This study is targeted for completion in August 2000.

The most significant component of the methods used by the CIMIS and AZMET networks to calculate ET_0 is net solar radiation. The University of Arizona recently completed a study of the impact the different methods used to calculate net solar radiation used by the AZMET and CIMIS networks have on the reported ET_0 values. A conclusion of this study is that the method used to calculate net solar radiation appears to be a major source of the variation in reported ET_0 values between the CIMIS and AZMET networks[7]. The equations used to calculate net radiation by the CIMIS and AZMET networks differ in the method used to approximate cloud cover. The method used by AZMET typically yields higher net radiation during the daytime than the method used by CIMIS. The result is generally a higher reported ET_0 from AZMET stations when compared to CIMIS stations.

LCRAS uses a single set of vegetation ET coefficients along the lower Colorado River. Therefore, consistent ET_0 values are required from the CIMIS and AZMET networks. To meet this need, representatives of the CIMIS and AZMET networks and Reclamation's consultant recommended using an average ET_0 based upon values reported by the CIMIS and AZMET networks. This average will be used until the planned use of equivalent methods for calculating net solar radiation is implemented or identical ET_0 equations are adopted. This issue was discussed at length at the LCRAS public meeting in Henderson, Nevada, in October 1998.

Reclamation currently applies a weighted-average method to daily ET_0 values reported by the CIMIS and AZMET networks to calculate an average daily ET_0. Average daily ET_0 values are calculated by

1) calculating average values from the two CIMIS stations (Palo Verde and Blythe NE) and average values from the five AZMET stations (Mohave, Parker, North Gila, Yuma Mesa and Yuma Valley), and

2) calculating the average of the two average values from the CIMIS and AZMET networks from step 1. This calculation is shown below:

$$\text{Daily Average } ET_0 = (\text{daily avg. CIMIS } ET_0 + \text{daily avg. AZMET } ET_0) \div 2.$$

This process yields a single set of average daily ET_0 values which are applied from Hoover Dam to Mexico. The ET_0 and precipitation values reported by each automated weather station and the average ET_0 used in this report are shown on figure 1.

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

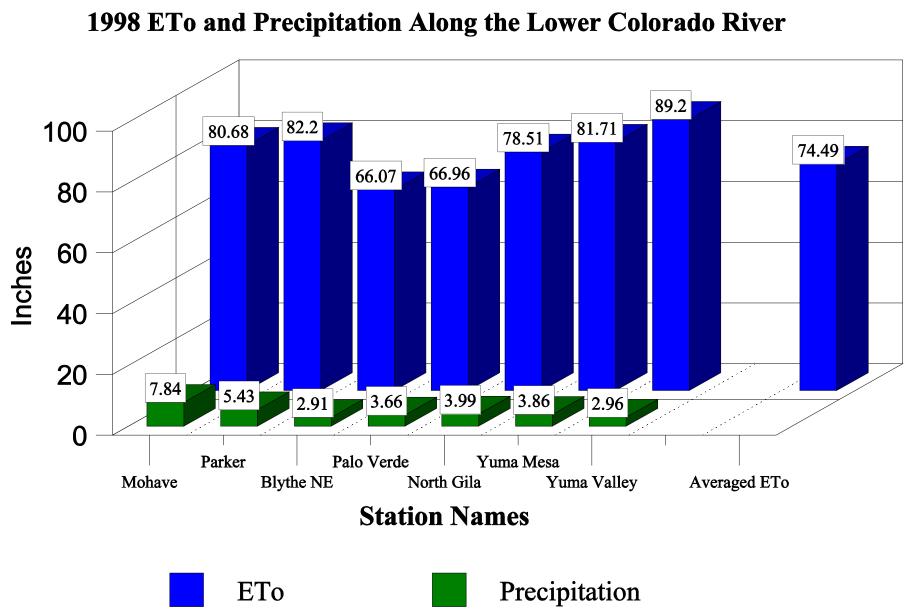


Figure 1. — ET_0 and Precipitation Reported By AZMET and CIMIS Stations, and the Average ET_0 used in this report.

Crops (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 class. Average daily ET_0 values (inches) are multiplied by daily crop coefficients unique to each crop class (dimensionless), to develop the daily ET rate for each crop class. The impact of rainfall on crop water use is considered by subtracting effective precipitation (inches) from the ET rate for each crop class to yield a net ET rate (inches).

LCRAS calculates effective precipitation by multiplying precipitation recorded by a rain gauge (usually, but not necessarily, at a CIMIS or AZMET station) by an effective precipitation coefficient. 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 1998 ranged from 7.84 inches, measured at the Mohave AZMET station, to 2.91 inches measured at the Blythe NE CIMIS station. The unweighted precipitation average recorded across the lower Colorado River valley for 1998 is 4.38 inches.

In parallel with the calculations of ET rate, the number of acres covered by each crop class within the diverter boundary must be calculated. This is done using remotely sensed data and field surveys. Satellite images are used to identify each crop class. GIS coverages are used to identify diverter boundaries within which the crops fall and to quantify the area covered by each crop class within each diverter boundary. There are 15 crop classes, some with numerous subclasses, for which this calculation is performed. These crop classes are listed in table 2 in the "Ground-Reference Data Collection" section.

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 class within each diverter boundary and dividing by 12 (inches/foot). Monthly ET for each diverter is summed for the year to yield the annual ET for each diverter.

An example using cotton is shown below:

$$ET_{cotton} = \Sigma_{n} [(\text{avg. } ET_0 \times K_{cotton}) - \text{Effective PPT}] \, AC_{cotton} \div 12$$

Where:

ET_{cotton} = The monthly or annual ET by cotton for the diverter in question (acre-feet)

Σ_{n} = Summation for $_{n}$ time (monthly or annually)

Avg. ET_0 = Weighted daily ET_0 value from AZMET and CIMIS stations (inches)

K_{cotton} = Daily crop 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 1998 from Hoover Dam to Mexico is 1,140,219 acre-feet. After distribution of the residual from the water balance, the final calculation of crop consumptive use increased to 1,143,780 acre-feet, a change of about 0.3 percent. Crop consumptive use accounts for about 16 percent of the total lower Colorado River basin consumptive use (crop, domestic, and export).

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.

Phreatophytes (ET_{pht})

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

Using the same process applied to crop evapotranspiration, the summation of ET for all phreatophyte classes 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 figures for each phreatophyte class used to calculate ET_{pht} in the 1995 LCRAS report. Phreatophytes were grouped into the 14 classes listed in table 3 in the section "Ground Reference Data Collection." Beginning in 1996 and continuing in 1998, phreatophyte acreage figures 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 1998 from Hoover Dam to Mexico is 581,788 acre-feet. After distribution of the residual from the water balance, the final calculation of phreatophyte water use increased to 582,466 acre-feet, a change of 0.12 percent. Phreatophyte water use accounts for about 7 percent of the combined lower Colorado River basin use and loss from crops, domestic uses, exports, evaporation, and phreatophytes.

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. Beginning in 1998, the evaporation from 34 acres of fish ponds within the Palo Verde Irrigation District is added to the total evaporation in the Parker Dam to Imperial Dam reach. These values are used in the water balance.

LCRAS calculates a monthly open-water evaporation rate as the product of a monthly summation of average daily ET_0 times a monthly evaporation coefficient. Monthly precipitation measured at the appropriate AZMET or CIMIS station 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, from remote sensing) to yield the monthly open-water evaporation (acre-feet).

Open-water area is developed by analyzing images acquired July 25, 1998, for the Hoover Dam to Davis Dam reach and images acquired July 18, 1998, 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 1998 is 276,776 acre-feet. After distribution of the residual from the water balance, the final calculation of evaporation decreased to 276,753 acre-feet, a change of 0.01 percent. Evaporation accounts for about 3.4 percent of the combined lower Colorado River basin water use and loss from crops, domestic uses, exports, phreatophytes, and evaporation.

Domestic Consumptive Use (CU_d)

This section describes how domestic consumptive use along the mainstream of the lower Colorado River, 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 1998 is 66,919 acre-feet. After distribution of the residual from the water balance, the final estimate of domestic consumptive use remained unchanged. Domestic consumptive use accounts for about 1 percent of the total lower Colorado River basin consumptive use (crop, domestic, and export).

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 calendar year 1998 (as was done in previous reports). Currently, no network of wells exists that would give consistent current water-level data throughout the study area. Beginning with this report, a non-zero value for the standard error of estimate is used. 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 impact of this modification is small and can be seen on table 8.

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 accurately measured or otherwise quantified, the residual would be zero. In the real-world system of the lower Colorado River, the residual of a water balance cannot reasonably 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 6.

Table 6 — Water balance summary (unadjusted 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})	12,774,700	12,940,300	10,380,000	9,095,557	12,774,700
Flow at the downstream boundary (Q_{ds})	12,940,300	10,380,000	9,095,557	4,800,885	4,800,885
Residual	-114,548	-81,568	175,118	31,365	10,367
Residual as a percentage of the flow entering the reach (Q_{us})	-0.90%	-0.63%	1.69%	0.34%	0.08%
Difference between upstream and downstream flow (Q_{dif})	-165,600	2,560,300	1,284,443	4,294,672	7,973,815
Measured Tributary inflow (Trm)	0	7,443	0	7,988	15,431
Unmeasured Tributary inflow (Trum)	6,480	36,290	33,750	3,000	79,520
Exported flow (Q_{ex})	0	2,300,878	0	3,837,381	6,138,259
Evaporation (E)	112,552	97,970	61,193	5,061	276,776
Domestic consumptive[1] use (CU_d)	510	33,836	5,175	27,398	66,919
Crop evapotranspiration (ET_{crop})	0	72,611	729,919	337,689	1,140,219
Phreatophyte evapotranspiration (ET_{pht})	866	171,406	342,750	66,766	581,788
Change in reservoir storage (ΔS_r)	-158,500	8,900	4,038	0	-145,562
Change in aquifer storage (ΔS_a)	0	0	0	0	0

[1] Domestic use includes the use of water for household, stock, municipal, mining, milling, industrial, and other like purposes, but shall exclude the generation of electrical power. Domestic use also includes water use on wildlife refuges.

The residuals in 1998 are less than the presumed standard error of estimate in all reaches. 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. The residual is less than the standard error of estimate of the mainstream inflow in all of the reaches in 1998. However, 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 1998 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 7 shows the calculation and resultant values 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 7 — Adjustments to flow at or below the major dams 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	12,774,700	12,940,300	10,380,000	9,095,557	4,800,885	
Amount of residual apportioned to Q_{dif} of the reach below each dam from the water balance	-114,483	-80,092	170,686	28,781	N/A	
Initial adjustment value (start with zero at most upstream dam and add cumulative to most downstream flow)	0	-114,483	-194,575	-23,889	4,892	-65,611
Initial adjusted flow (measured flow + initial adjustment)	12,774,700	12,825,817	10,185,425	9,071,668	4,805,777	
Final adjusted flows below each dam and to Mexico (initial adjusted flow - average of initial adjustment values)	12,840,311	12,891,428	10,251,035	9,137,278	4,871,386	
Final adjustments to measured flows (final adjusted value - measured value)	65,611	-48,872	-128,965	41,721	70,501	
Final adjustments to measured flows in percent	0.51%	-0.38%	-1.24%	0.46%	1.47%	

By solving this boundary problem, a table of adjusted values for the whole water balance can be made which yields a residual of zero for all reaches of the lower Colorado River. The final results of the water balance are shown on table 8.

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

Table 8 — 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})	12,840,311	12,891,428	10,251,035	9,137,278	12,840,311
Flow at the downstream boundary (Q_{ds})	12,891,428	10,251,035	9,137,278	4,871,386	4,871,386
Residual	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	-51,117	2,640,393	1,113,757	4,265,892	7,968,925
Measured tributary inflow (Trm)	0	7,447	0	7,988	15,435
Unmeasured tributary inflow (Trum)	6,484	36,361	33,503	2,999	79,347
Exported flow (Q_{ex})	0	2,299,605	0	3,839,470	6,139,075
Evaporation (E)	112,520	97,956	61,216	5,061	276,753
Domestic consumptive use	510	33,836	5,175	27,398	66,919
Crop consumptive use	0	72,603	733,132	338,045	1,143,780
Phreatophyte water use	866	171,362	343,458	66,780	582,466
Change in reservoir storage (ΔS_r)	-158,504	8,899	4,038	0	-145,567
Change in aquifer storage (ΔS_a)	-25	-60	241	125	281

Sample Calculation

This sample calculation uses the Colorado River Indian Reservation in Arizona (CRIR, AZ) as an example to display the steps undertaken to calculate consumptive use by crops and phreatophyte water use for a diverter. From this point on in the example, CRIR, AZ will be referred to simply as CRIR. The calculation for consumptive use by crops and phreatophyte water use has four steps.

1. Calculate the ET for each crop and phreatophyte class using ET_0, vegetation coefficients, and crop and phreatophyte acreages. The ET for all crop and phreatophyte classes is summed to provide the total crop and phreatophyte ET for CRIR.

2. Calculate the residual of the water balance by summing all inflows, outflows, and water uses for the Parker Dam to Imperial Dam reach.

3. Distribute the residual to crop and phreatophyte ET, and all the other inflows, outflows, and water uses within the Parker Dam to Imperial Dam reach proportional to the product of their variance and magnitude.

4. Apportion the distributed values of crop consumptive use and phreatophyte water use to CRIR and all other irrigators within the Parker Dam to Imperial Dam reach.

Detailed explanations of each of the four steps described above is 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 ET for Each Crop and Phreatophyte Class

The average daily ET_0 is calculated as noted in the section titled "Evapotranspiration" in Chapter 2. Daily ET_0 values reported by individual CIMIS and AZMET stations along with the average daily ET_0 values used in this report can be found in appendix I. An annual summary of ET_0 and precipitation values reported by individual CIMIS and AZMET stations and the average ET_0 used in this report can be found on figure 1 and in the Average ET_0 table in appendix I, Part 1.

Below is an example of the average ET_0 calculation for January 1, 1998. The ET_0 values reported by each of the AZMET and CIMIS stations is shown in table 9 below (rounded to 3 decimals for this example). These values of ET_0 can be found in the Average ET_0 table in appendix I, Part 1.

[10] The crop acreage data are calculated using Reclamation's remote sensing process; they are not provided by the districts in crop reports.

Table 9 — ET_0 values for January 1, 1998

AZMET/CIMIS Station Name	Reported ET_0 (Inches) for January 1, 1998 (rounded)
Mohave AZMET station	0.095
Parker AZMET station	0.091
Palo Verde CIMIS station	0.049
Blythe NE CIMIS station	0.054
Yuma North Gila AZMET station	0.095
Yuma Valley AZMET station	0.098
Yuma Mesa AZMET station	0.098

The average ET_0 for January 1st is calculated in a three part process as show below:

Part 1 (average of AZMET network): (0.095+ 0.091 + 0.095 + 0.098 + 0.098) ÷ 5 = 0.095
Part 2 (average of CIMIS network): (0.049 + 0.054) ÷ 2 = 0.051
Part 3 (average of parts 1 and 2 from above): (0.095 + 0.051) ÷ 2 = 0.073

This sample calculation proceeds using alfalfa_1a as the sample crop, referred to hereafter simply as alfalfa. The daily ET rate for alfalfa at CRIR is calculated by multiplying the average daily ET_0, times the daily crop coefficient (K_c) for alfalfa; then subtracting the effective precipitation from the Parker AZMET station (located within the CRIR in Arizona).

The average daily ET_0 values, crop coefficients, precipitation, effective precipitation, and resultant ET values for each crop and phreatophyte class are listed in appendix I, Part 1, Parker Crops Table. Note the following values on sheet D for January 1 (shown below rounded to 3 decimals):

Average ET_0 = 0.073 inch
K_c for alfalfa = 1.020 (listed on page 2 of 2, sheet E)
Precipitation = 0.0 (listed on sheet B)

ET for alfalfa, in inches, is calculated as the product of the average ET_0 and K_c values less the effective precipitation. This calculation is shown below:

(0.073 * 1.020) - 0.000 = 0.0745 inches

This value can be found on sheet E, page 1 of 2.

Let us look at January 9 for an example of an ET rate calculation when precipitation is not zero. The effective precipitation (the portion of the precipitation that contributes to crop ET requirement) is the product of an effective precipitation coefficient and the measured precipitation in inches.

For January 9, the effective precipitation coefficient is 0.4 (monthly value for January from sheet C), and the precipitation is 0.12 inches (from sheet B); therefore, the effective precipitation is calculated as 0.4 × 0.12, which results in 0.05 inches as shown on sheet C.

The ET rate[11] of alfalfa for January 9 is calculated as shown below:

ET = ET_0 (0.027 from sheet D) * K_c for alfalfa (1.020 from sheet E, page 2 of 2), - effective precipitation (0.05 from sheet C) = -0.02 inches (shown on sheet E).

A value of zero means the soul moisture gain from the precipitation is the same as the ET requirement of the plant. A negative ET indicates a net gain in soil moisture from the precipitation.

Let us continue our example with the month of January. The ET for alfalfa in January is the product of the January ET rate for alfalfa (1.57 inches, from the Parker Crops Table, sheet E, page 1 of 2) and the acreage of alfalfa on CRIR listed for January 1998 (49,410 acres, from the Parker Dam to Imperial Dam Water-Balance Table, sheet O, page 2 of 3 in appendix I, Part 2).

[11] The ET rate displayed in the tables of appendix I, Part 1, includes the effects of precipitation. These tables do not display an ET value uncorrected for effective precipitation.

This calculation is shown below:

1.57 (inches) * 49,410 (acres) ÷ 12 (inches/foot) = 6,464 acre-feet of ET.

The calculation shown above results in 6,464 acre-feet while 6,451 acre-feet is shown on sheet O, page 1 of 3 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 and phreatophyte classes (except that effective precipitation is not subtracted from phreatophyte ET). The annual crop and phreatophyte ET for CRIR is calculated by summing the monthly ET for each crop and phreatophyte class.

The sample calculation, as described thus far, has provided the crop and phreatophyte ET (ET_{crop} and ET_{pht}) for CRIR. The same process is repeated to obtain the crop and phreatophyte ET for each diverter between Parker and Imperial Dams.

Calculate the Residual of the Water Balance

The water balance is performed on annual values between Parker and Imperial Dams to produce the residual. A portion of the residual is distributed to each diverter's crop and phreatophyte ET to yield each diverter's crop consumptive use and phreatophyte water use. 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 consists of many parts. Each part used in 1998 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 (10,380,000 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 value between Parker and Imperial Dams (33,750 acre-feet) is provided by the Geological Survey on page 46 of Owen-Joyce, Sandra J., and Raymond, Lee H., 1996, as shown and summed on sheet C of the Parker Dam to Imperial Dam Water-Balance Table.

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 (9,095,557 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 (6,740,000 acre-feet), Station 30 on the Gila Gravity Main Canal (812,961 acre-feet), the inflow to Mittry Lake (11,196 acre-feet), and the Colorado River sluiceway (1,531,400 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 the 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 total becomes the evaporation for the Parker Dam to Imperial Dam reach. The evaporation calculation for January in River Section 1 in the Parker Dam to Imperial Dam reach is shown below.

E (373 acre-feet) = [[monthly sum of daily ET_0 (2.46 inches) * monthly evaporation coefficient (0.52)] - precipitation (0.16 inches)] * area of open water (4,000 acres) ÷ 12 (inches/foot)

E, ET_0, the evaporation coefficient, the precipitation, the area of open water, and the total evaporation for January (713 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 consists of 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 (C_{ud})” 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, 1997) is 2,937 acre-feet and end-of-month storage (measured midnight January 31, 1998) is 4,559 acre-feet. The difference is a gain of 1,622 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 (4,038 acre-feet in 1998).

To this point, this sample calculation has described how the totals for each inflow, outflow, and water use needed for the water balance are calculated.

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 1998 is 175,118 acre-feet, or about 1.7 percent of the flow below Parker Dam. The resulting values are termed a distributed annual value (DAV). Consumptive use and the final estimate of all other water uses is the DAV.

The residual is calculated as shown below (see the above section entitled “Water Balance” for definitions of terms),

$$\text{Residual } (175{,}118) = Q_{dif}\ (1{,}284{,}443) + Q_{Trum}\ (33{,}750) - S_r\ (4{,}038) - C_{ud}\ (5{,}175) - ET_{crop}\ (729{,}919) - ET_{pht}\ (342{,}750) - E\ (61{,}193)$$

Distribute the Residual

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 UAV times its variance (the square of the presumed standard error of estimate). Using the crop ET as an example, the DAV is calculated as shown below:[12]

$$DAV_{ETcrop} = UAV_{ETcrop} + [(VAR_{ETcrop} \div TVAR) \times Q_{res}]$$

Where:

DAV_{ETcrop}	=	The distributed annual value of crop ET for the reach
UAV_{ETcrop}	=	The undistributed annual value of crop ET
VAR_{ETcrop}	=	The variance of the crop ET
TVAR	=	The sum of the variances for all parts of the water balance
Q_{res}	=	The residual

The UAV of crop ET in the Parker Dam to Imperial Dam reach is 729,919 acre-feet, and the SEE is presumed to be 5 percent, yielding a variance of 1,331,958,016 acre-feet squared. The TVAR of the reach is 72,599,943,645 acre-feet squared, and the residual is 175,118 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:

$$DAV_{ETcrop} = 729{,}919 + [(1{,}331{,}958{,}016 \div 72{,}599{,}943{,}645) \times (175{,}118)]$$
$$DAV_{ETcrop} = 733{,}132 \text{ acre-feet}$$

Apportion the Distributed Values to Individual Diverters

The residual is distributed to the crop ET of each diverter based on each diverter's proportion of the total UAV of crop ET in the reach. Continuing the sample calculation for CRIR, the distributed crop ET (consumptive use) for CRIR is calculated as shown below.

[12] The DAV is added to outflows and subtracted from inflows. ET_{crop} is an outflow in the water balance.

$DDET_{crop\ CRIR}$ = $UAV_{crop\ CRIR} \div UAV_{cropT} * DAV_{cropT}$)

Where:

$DDET_{crop\ CRIR}$	=	The distributed annual value of crop ET for CRIR
$UAV_{crop\ CRIR}$	=	The undistributed annual value for crop ET in CRIR
UAV_{cropT}	=	The total of the undistributed annual crop ET value for all diverters
DAV_{cropT}	=	The distributed annual value crop ET for all diverters, calculated as DAV_{ETcrop} above

Values for the variables defined above can be found on sheet A of the Parker Dam to Imperial Dam Water-Balance Table. Substituting values into the above equation yields the proportion of residual distributed to crop ET in CRIR:

$DDET_{crop\ CRIR}$ = 325,326 acre-feet ÷ (729,919 acre-feet ÷ 733,132 acre-feet)
$DDET_{crop\ CRIR}$ = 326,758 acre-feet [13] = Consumptive Use

The distributed value for phreatophytes for each diverter is calculated in the same fashion using the UAV and DAV for phreatophytes. The final estimate of phreatophyte water use for CRIR is 132,025 acre-feet. These values are considered to be the crop consumptive use and the final estimate of phreatophyte water use[14] at CRIR. The distributed values of domestic consumptive use are calculated in a similar manner.

An explanation of how the water balance calculations are performed is found in the beginning of appendix I, Part 2. The values and results of the actual calculations are displayed on the Water-Balance Tables in appendix I, Part 2.

Results

The results of LCRAS for Calendar Year 1998 are presented in the tables and charts found on the following pages and in attachment 3. Table 10 presents a summary of the water use values calculated using LCRAS and the consumptive use values reported in the Decree Accounting Report.

[13] Differences between the results shown in the example and those displayed in appendix I are due to rounding.

[14] The amount, if any, of the identified phreatophyte water use within CRIR that should be applied to CRIR's entitlement has not been determined, and is left open in this report.

Some of the differences in reported consumptive uses between LCRAS and the Decree Accounting report shown in the table 10 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.

Table 10 — 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 1998 Decree Accounting Report)		227,683	227,683	Uses above Hoover Dam
Uses below Hoover Dam	19,616	16,926	17,621	Uses below Hoover Dam
			794	Unmeasured return flow credit
Nevada Total	19,616	244,609	244,510	Nevada Total
California				
			5,045,232	Sum of individual diverters
			91,996	Unmeasured return flow credit
California Total	167,769	4,953,357	4,953,236	California Total
Arizona				
Subtotal (Below Hoover Dam, less Wellton-Mohawk IDD)	395,082	2,063,146	2,347,725	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (from the 1998 Decree Accounting Report)		151	151	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (from 1998 Decree Accounting Report)		290,355	290,355	Wellton-Mohawk IDD
			71,515	Pumped from South Gila wells (DPOCs): returns
			143,842	Unmeasured return flow credit
Arizona Total	395,082	2,353,652	2,422,874	Arizona Total
Lower Colorado River Basin Total				
Total Use	582,467	7,551,618	7,620,620	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 the following chapter.

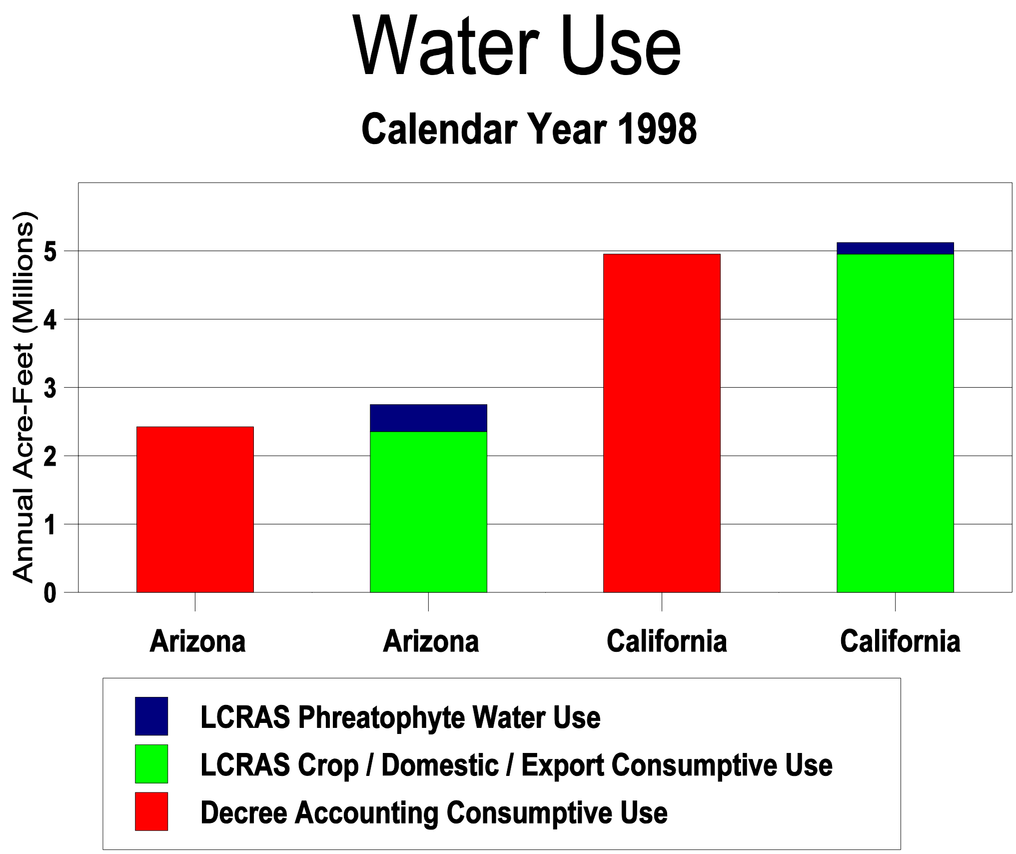


Figure 2. — State water use totals for Arizona and California (calendar year 1998).

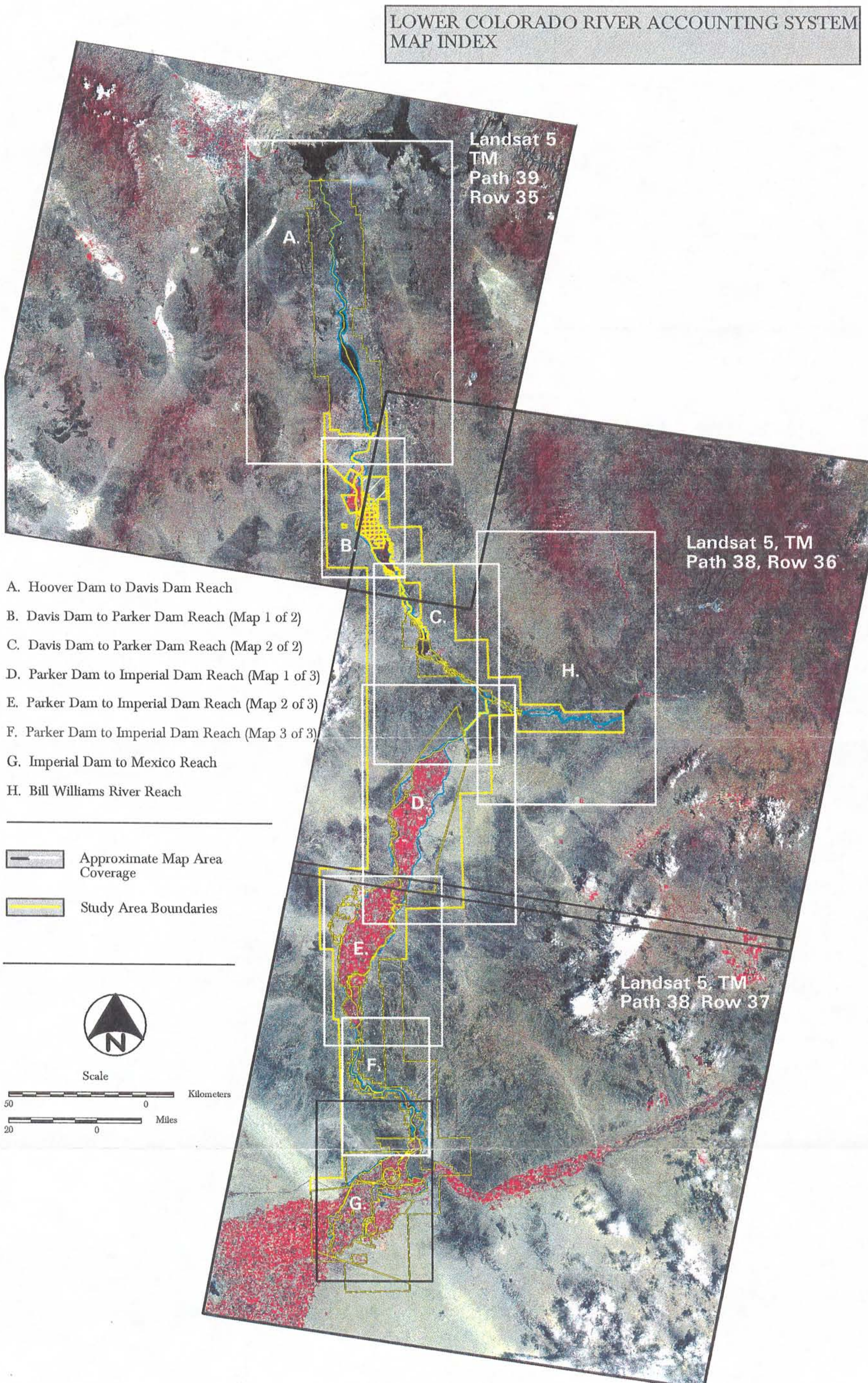
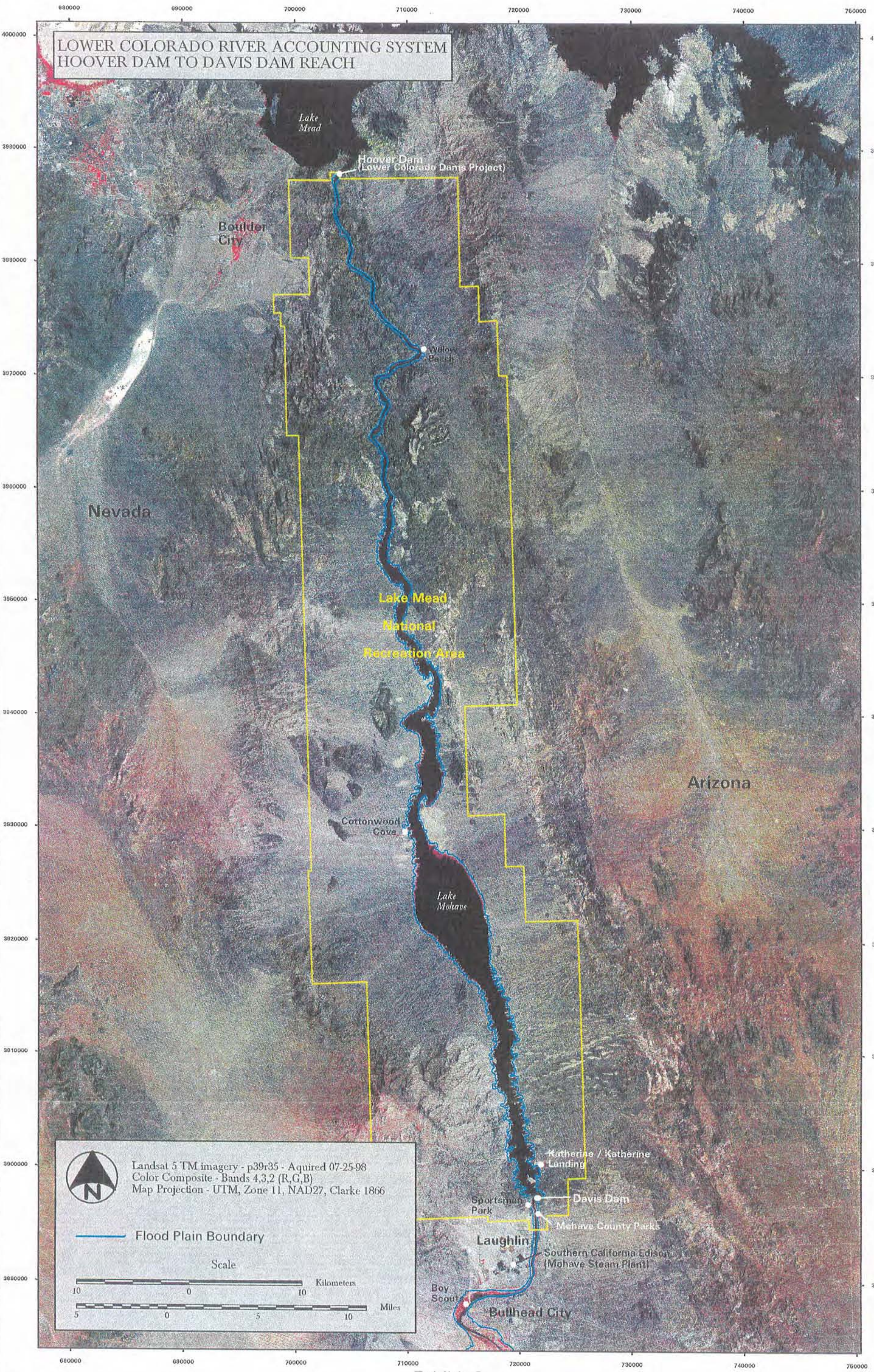

LOWER COLORADO RIVER ACCOUNTING SYSTEM
MAP INDEX
Landsat 5 TM Path 39 Row 35
Landsat 5, TM Path 38, Row 36
Landsat 5, TM Path 38, Row 37
A.
B.
C.
D.
E.
F.
G.
H.
A. Hoover Dam to Davis Dam Reach
B. Davis Dam to Parker Dam Reach (Map 1 of 2)
C. Davis Dam to Parker Dam Reach (Map 2 of 2)
D. Parker Dam to 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
N
Scale
Kilometers
50
0
Miles
20
0

Exhibit 1



LOWER COLORADO RIVER ACCOUNTING SYSTEM
HOOVER 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 Scout
Bullhead City
Landsat 5 TM imagery - p39r35 - Aquired 07-25-98
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 2

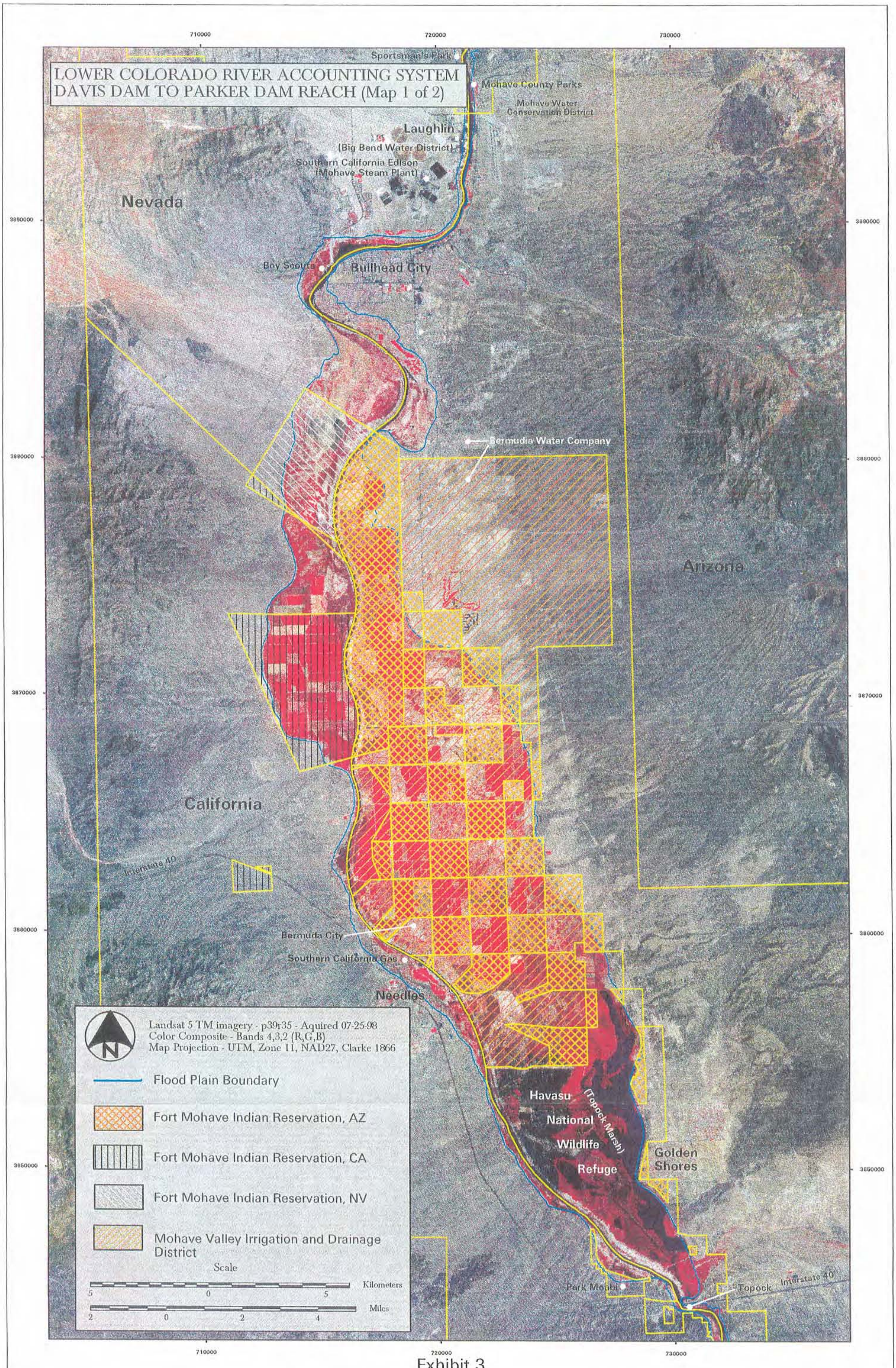

LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 1 of 2)
710000
720000
730000
Sportsman's Park
Mohave County Parks
Mohave Water Conservation District
Laughlin
(Big Bend Water District)
Southern California Edison (Mohave Steam Plant)
Nevada
Boy Scouts
Bullhead City
Bermudia Water Company
Arizona
California
Interstate 40
Bermuda City
Southern California Gas
Needles
Havasu National Wildlife Refuge
(Topock Marsh)
Golden Shores
Park Moabi
Topock
Landsat 5 TM imagery - p39r35 - Aquired 07-25-98
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
Kilometers
Miles

Exhibit 3

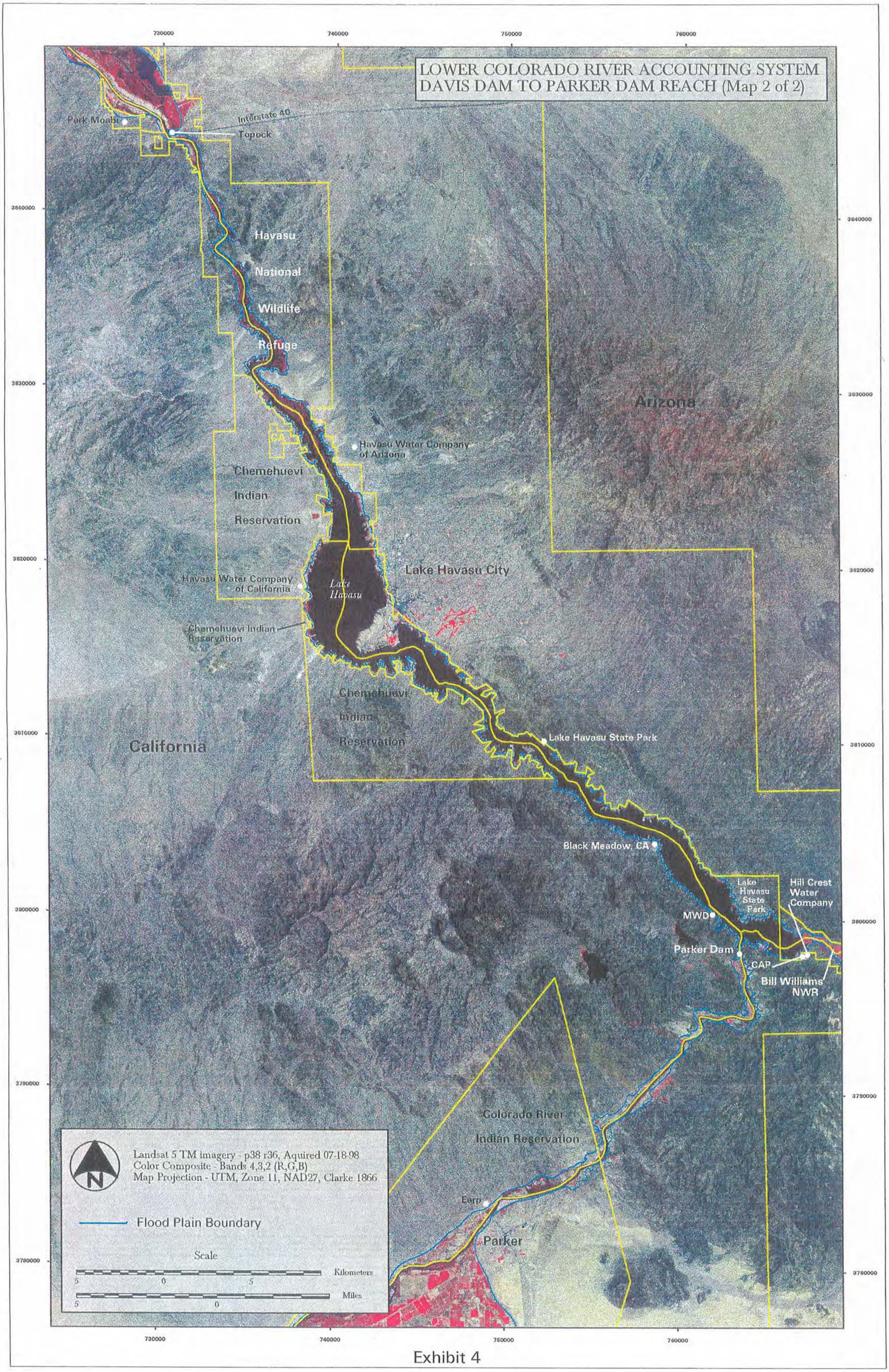
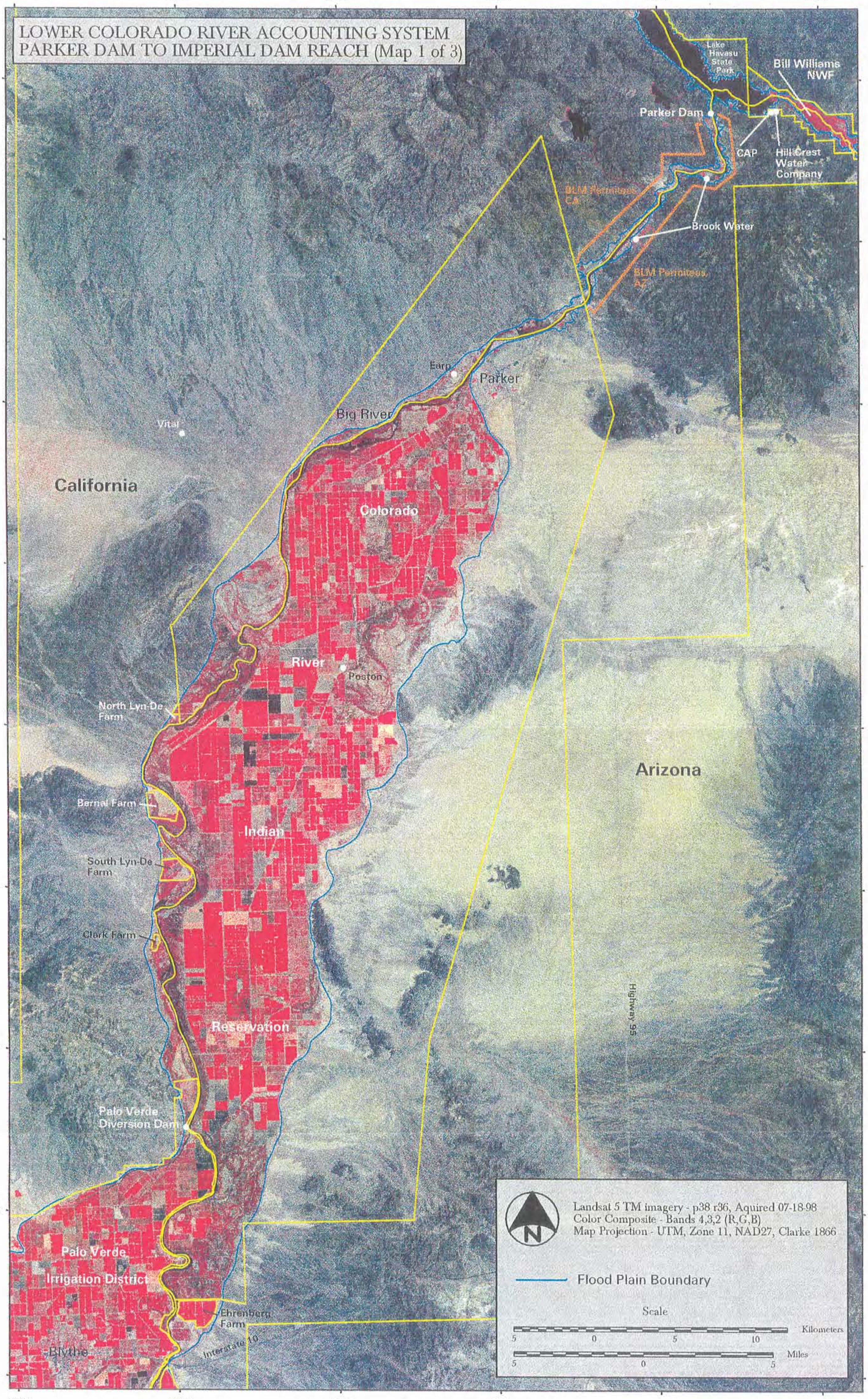

LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 2 of 2)
Park Moabi
Interstate 40
Topock
Havasu
National
Wildlife
Refuge
Havasu Water Company
of Arizona
CA
Chemehuevi
Indian
Reservation
Lake Havasu City
Havasu Water Company
of California
Lake
Havasu
Chemehuevi Indian
Reservation
Arizona
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 07-18-98
Color Composite - Bands 4,3,2 (R,G,B)
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
Flood Plain Boundary
Scale
Kilometers
Miles
N
730000
740000
750000
760000
3840000
3830000
3820000
3810000
3800000
3790000
3780000

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
CAP
Hill Crest Water Company
BLM Permitees, CA
Brook Water
BLM Permitees, AZ
Earp
Parker
Big River
Vidal
California
Colorado
River
Poston
North Lyn-De Farm
Bernal Farm
Indian
South Lyn-De Farm
Clark Farm
Reservation
Arizona
Highway 95
Palo Verde Diversion Dam
Palo Verde
Irrigation District
Blythe
Ehrenberg Farm
Interstate 10
Landsat 5 TM imagery - p38 r36, Aquired 07-18-98
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 5

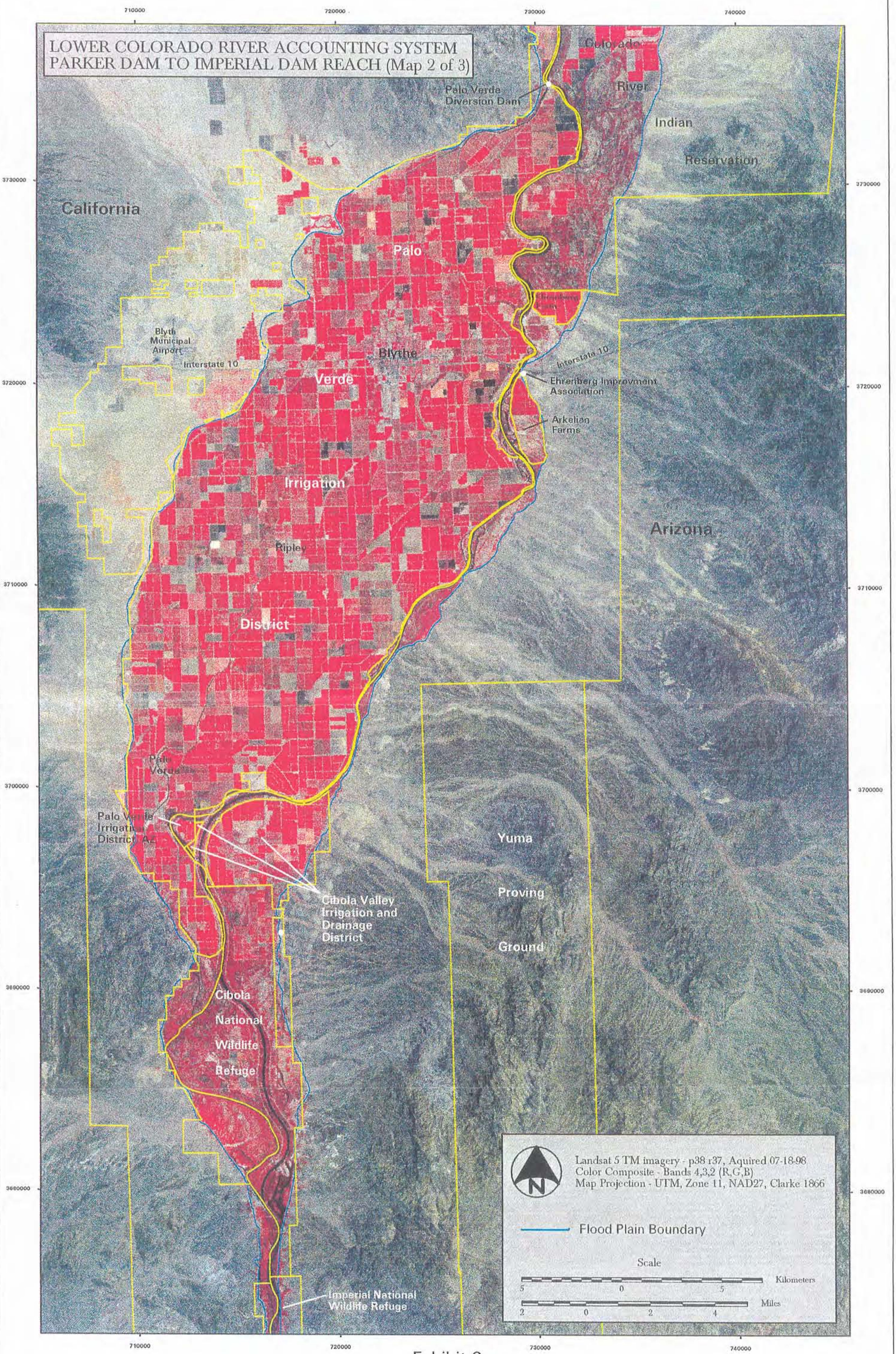

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 2 of 3)
710000
720000
730000
740000
3730000
3720000
3710000
3700000
3690000
3680000
Colorado
River
Indian
Reservation
Palo Verde
Diversion Dam
California
Palo
Verde
Irrigation
District
Blythe
Blyth
Municipal
Airport
Interstate 10
Ehrenberg Improvment
Association
Arkelian
Farms
Ripley
Arizona
Palo
Verde
Palo Verde
Irrigation
District
Cibola Valley
Irrigation and
Drainage
District
Yuma
Proving
Ground
Cibola
National
Wildlife
Refuge
Imperial National
Wildlife Refuge
Landsat 5 TM imagery - p38 r37, Aquired 07-18-98
Color Composite - Bands 4,3,2 (R,G,B)
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
N
Flood Plain Boundary
Scale
5
0
5
Kilometers
2
0
2
4
Miles

Exhibit 6

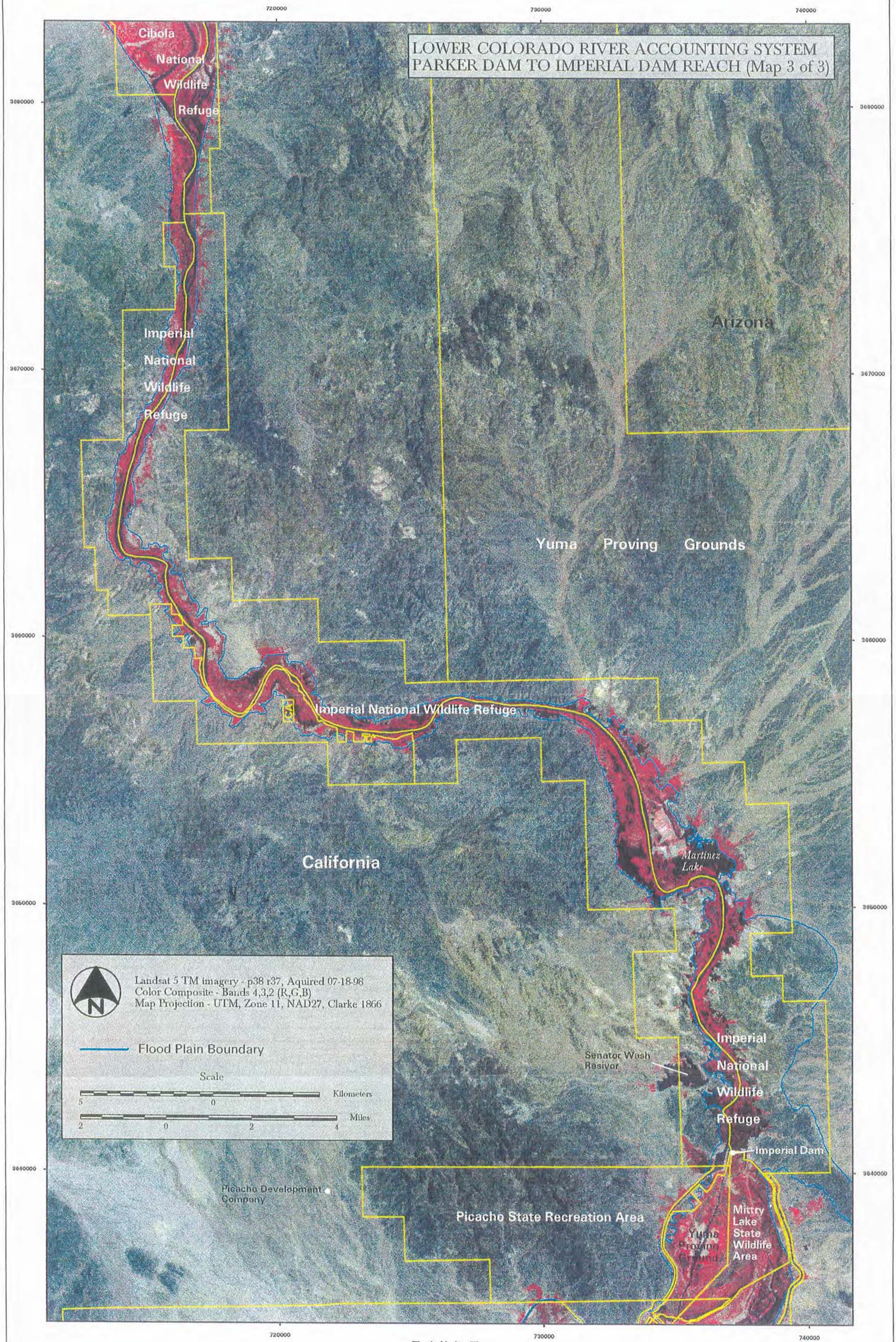

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 3 of 3)
720000
730000
740000
3680000
3670000
3660000
3650000
3640000
Cibola National Wildlife Refuge
Imperial National Wildlife Refuge
Arizona
Yuma Proving Grounds
Imperial National Wildlife Refuge
California
Martinez Lake
Imperial National Wildlife Refuge
Senator Wash Resivor
Imperial Dam
Picacho Development Company
Picacho State Recreation Area
Yuma Proving Grounds
Mittry Lake State Wildlife Area
N
Landsat 5 TM imagery - p38 r37, Aquired 07-18-98
Color Composite - Bands 4,3,2 (R,G,B)
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
Flood Plain Boundary
Scale
5
0
Kilometers
2
0
2
4
Miles

Exhibit 7

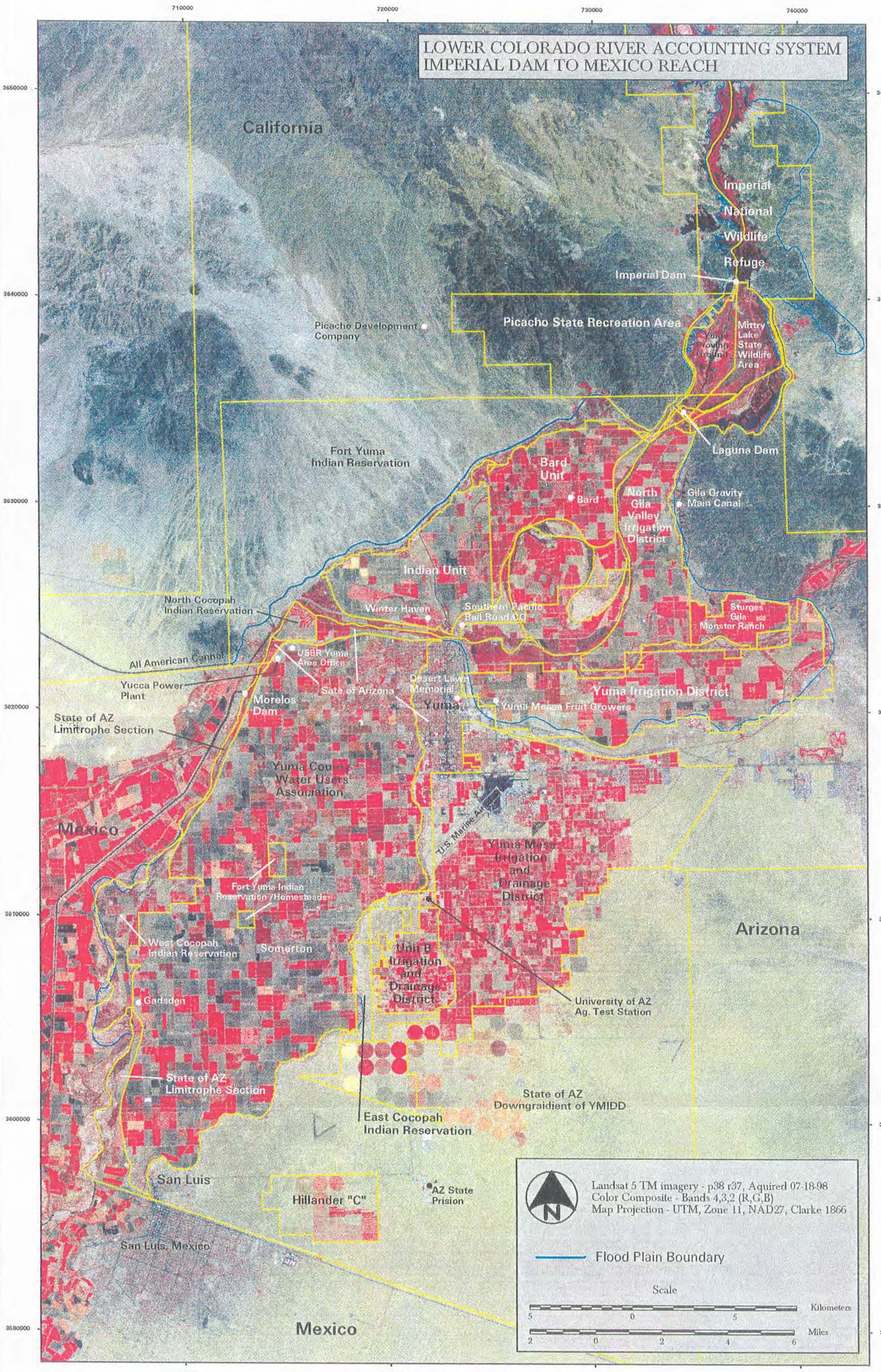

LOWER COLORADO RIVER ACCOUNTING SYSTEM
IMPERIAL DAM TO MEXICO REACH
California
Imperial
National
Wildlife
Refuge
Imperial Dam
Picacho Development Company
Picacho State Recreation Area
Mittry Lake State Wildlife Area
Laguna Dam
Fort Yuma Indian Reservation
Bard Unit
Bard
North Gila Valley Irrigation District
Gila Gravity Main Canal
Indian Unit
North Cocopah Indian Reservation
Winter Haven
Southern Pacific Rail Road CO.
Sturges Gila Monster Ranch
All American Canal
USBR Yuma Area Office
Yucca Power Plant
State of Arizona
Desert Lawn Memorial
Yuma
Yuma Irrigation District
Morelos Dam
Yuma Mesa Fruit Growers
State of AZ Limitrophe Section
Yuma County Water Users Association
Mexico
U.S. Marine Air
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 07-18-98
Color Composite - Bands 4,3,2 (R,G,B)
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
N
Flood Plain Boundary
Scale
Kilometers
Miles
710000
720000
730000
740000
3650000
3640000
3630000
3620000
3610000
3600000
3590000

Exhibit 8

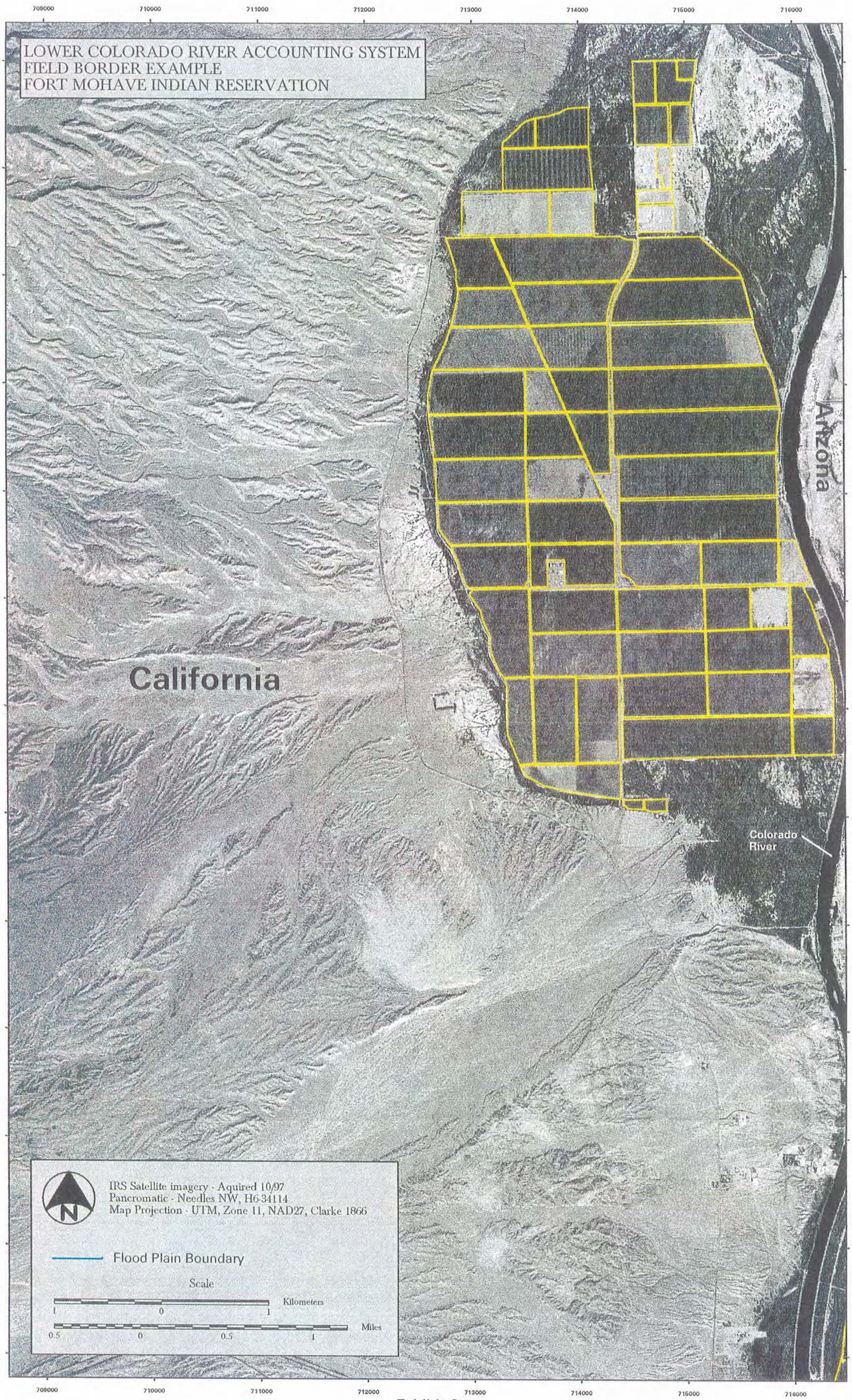

LOWER COLORADO RIVER ACCOUNTING SYSTEM
FIELD BORDER EXAMPLE
FORT MOHAVE INDIAN RESERVATION
California
Arizona
Colorado River
IRS Satellite imagery - Aquired 10/97
Pancromatic - Needles NW, H6-34114
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
Flood Plain Boundary
Scale
Kilometers
Miles

Exhibit 9

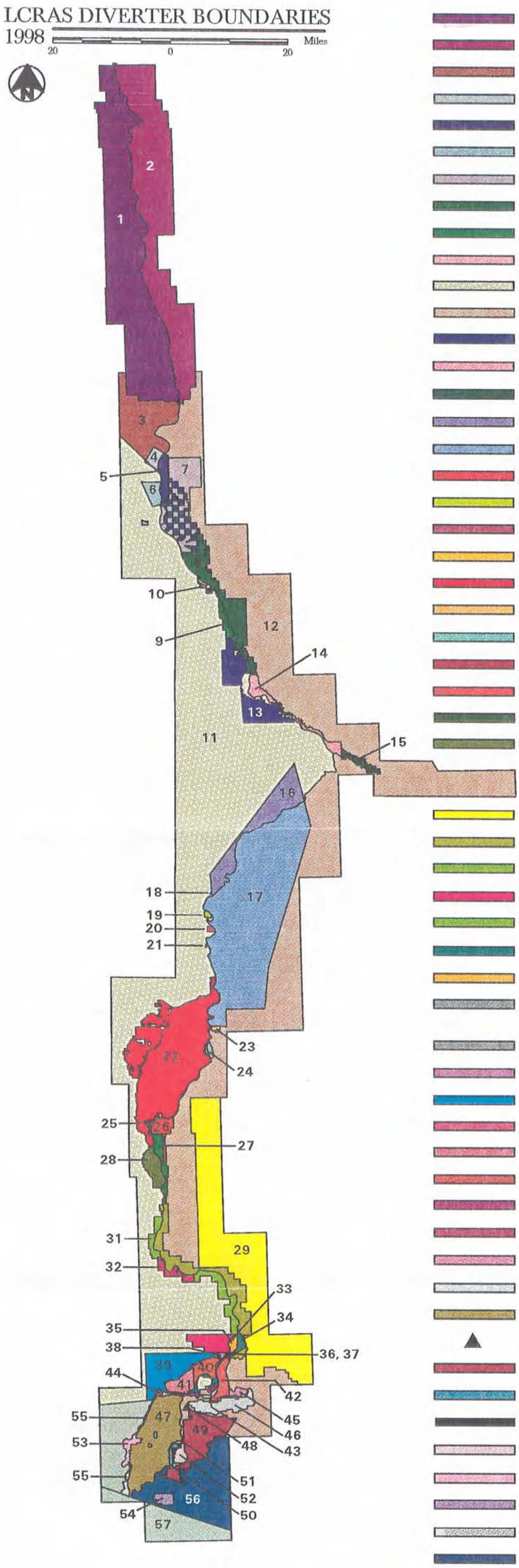

LCRAS DIVERTER BOUNDARIES
1998
Miles
20 0 20
(1) Lake Mead National Recreation Area, NV
(2) Lake Mead National Recreation Area, AZ
(3) State of Nevada
(4) Fort Mohave Indian Reservation, NV
(5) Fort Mohave Indian Reservation, AZ
(6) Fort Mohave Indian Reservation, CA
(7) Mohave Valley Irrigation and 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 Wilflife 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

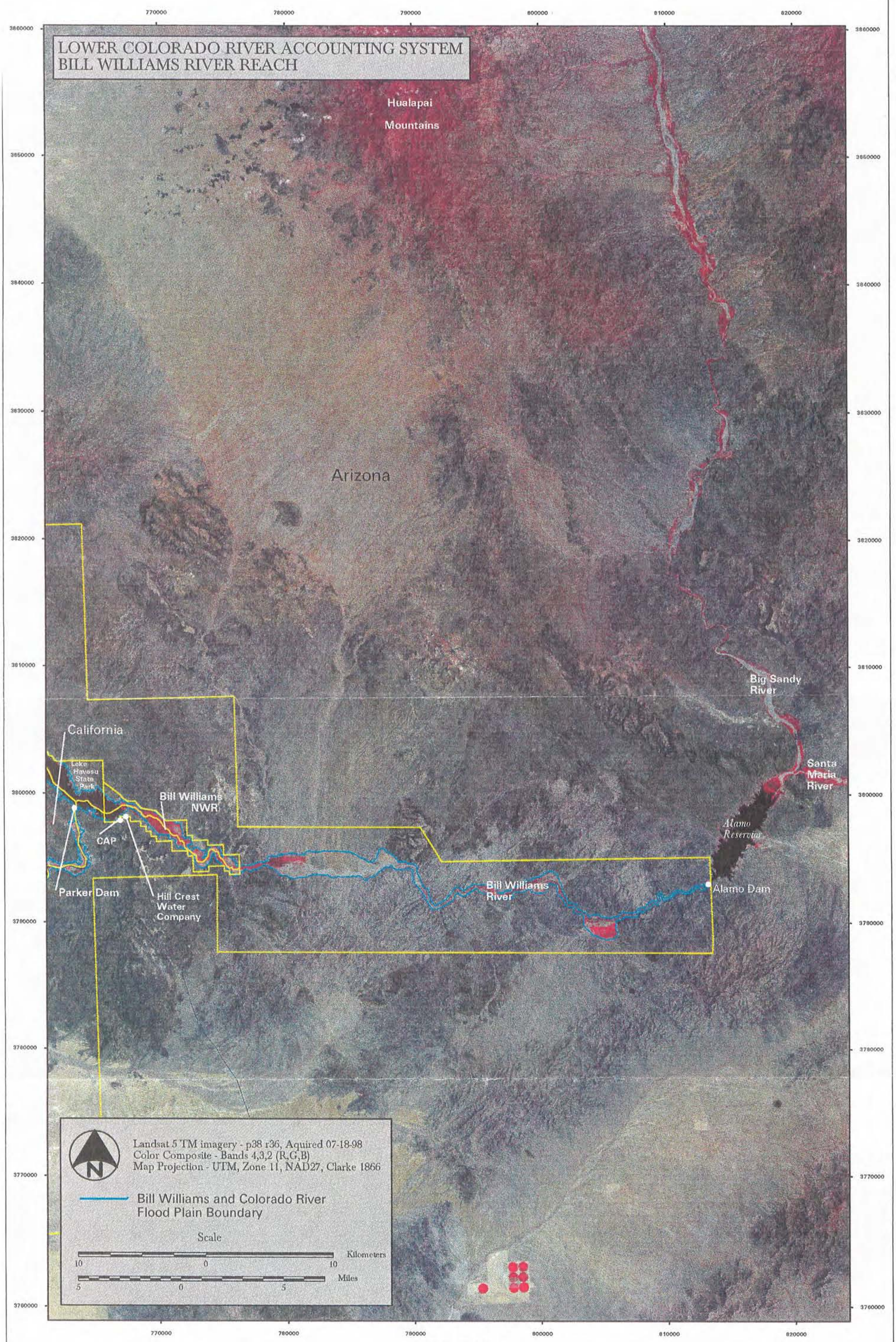

LOWER COLORADO RIVER ACCOUNTING SYSTEM
BILL WILLIAMS RIVER REACH
Hualapai Mountains
Arizona
Big Sandy River
Santa Maria River
Alamo Reservoir
Alamo Dam
Bill Williams River
California
Lake Havasu State Park
Bill Williams NWR
CAP
Parker Dam
Hill Crest Water Company
Landsat 5 TM imagery - p38 r36, Aquired 07-18-98
Color Composite - Bands 4,3,2 (R,G,B)
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
Bill Williams and Colorado River Flood Plain Boundary
Scale
Kilometers
Miles
N

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 into the foreseeable future and is a normal function of improving technology.

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.

The following diverter boundary change was made for 1998:

> The north boundary of the Mesa Verde development (located across I-10 from the Blythe airport) was moved to the south of I-10.

Crop Consumptive Use

The crop coefficient values used for 1998 remain the same as used for 1997. The crop coefficient values and growth windows used in 1998 can be found in appendix I, Part 1, Evapotranspiration Rate Calculations. The Lower Colorado River Accounting System Demonstration of Technology Report for Calendar Year 1999 will use revised crop coefficients. Revisions are based upon field observations and comments brought to Reclamation through the LCRAS public process.

Phreatophyte Water Use

What portion, if any, of the phreatophyte water use within the boundary of an irrigator, a wildlife refuge, a State park, a domestic diverter, or other reservation of land 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 1998.

The evaporation and phreatophyte water use associated with the operation of the Gila Gravity Main Canal are reported by the 1998 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 4,200 acre-feet in 1998. 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 is investigating the use of additional meteorological information to supplement the information available from the six AZMET and CIMIS stations (see the above sections describing crop ET and evaporation) on a regular basis. Reclamation currently supplements precipitation data reported by the CIMIS and AZMET networks with data from other sources only when the CIMIS and/or AZMET precipitation records are not complete. Reclamation is specifically interested in additional information that might more fully represent conditions over open water.

Reclamation is planning an evaporation study along the lower Colorado River. Plans currently include placing meteorological stations over water. Evaporation and precipitation 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 11, below, displays the residuals for the reaches of the water balance for this and from previous applications of LCRAS.

Table 11 — 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%

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 with the accounting for calendar year 2000, pending a 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. 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 years 1999 through 2000 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, as well as to examine any trends that may appear in the differences of the results provided by the two methods.

BIBLIOGRAPHY

Bureau of Reclamation, 1997. Report, “Lower Colorado River Accounting System Demonstration of Technology Calendar Year 1995,” Bureau of Reclamation, Lower Colorado Region, Boulder City, Nevada.

Bureau of Reclamation, 1998a. Report, “Lower Colorado River Accounting System Demonstration of Technology Calendar Year 1996,” Bureau of Reclamation, Lower Colorado Region, Boulder City, Nevada.

Bureau of Reclamation, 1998b. Decree Accounting Report, Compilation of Records in Accordance with Article V of the Supreme Court of the United States in *Arizona* v. *California*, dated March 9, 1964, Calendar Year 1998, Bureau of Reclamation, Lower Colorado Region, Boulder City, Nevada.

Bureau of Reclamation, 1999. Report, “Lower Colorado River Accounting System Demonstration of Technology Calendar Year 1997,” Bureau of Reclamation, Lower Colorado Region, Boulder City, Nevada.

Jensen, Marvin E., 1993. "Evaluating Effective Rainfall in CVWD," October 1, 1993. Appendix 3 of "Appendix Prepared for Water Use Assessment, Coachella Valley Water District and Imperial Irrigation District," Phase I Report from the Technical Work Group, Stephen M. Jones, Charles M. Burt, Albert J. Clemmens, Marvin E. Jensen, Joseph M. Lord, Jr., Kenneth H. Solomon, Draft April 1994 (copies of appendix 3 are available from the Bureau of Reclamation, Boulder Canyon Operations Office, Boulder City, Nevada) (see page A3-13).

Jensen, Marvin E., 1996. "Coefficients for Vegetative Evapotranspiration and Open-Water Evaporation for the Lower Colorado River Accounting System," Report Final Draft, July 15, 1996, Fort Collins, CO (a draft report available from the Bureau of Reclamation, Boulder Canyon Operations Office, Boulder City, Nevada).

Lane, W. L., 1998. Statistical Analysis of the 1995 Lower Colorado River Accounting System, An Assessment of Current Procedures with Recommended Improvements, February 1998. W. L. Lane Consulting, Hydrology and Water Resources Engineering, 1091 Xenophon Street, Golden, Colorado 80401-4218 (available from the Bureau of Reclamation, Boulder Canyon Operations

Office, Boulder City, Nevada).

Owen-Joyce, Sandra J., 1987. "Estimates of Average Annual Tributary Inflow to the Lower Colorado River, Hoover Dam to Mexico," U.S. Geological Survey Water-Resources Investigation Report 87-4078.

Owen-Joyce, Sandra J., and Raymond, Lee H., 1996. "An Accounting System for Water and Consumptive Use Along the Colorado River, Hoover Dam to Mexico," United States Geological Survey Water-Supply Paper 2407.

Supreme Court Decree. Supreme Court of the United States, No. 8, Original, State of Arizona, *Plaintiff* v. *State of California*, et. al., Defendants, Decree, March 9, 1964.

Wilson, Richard P., and Owen-Joyce, Sandra J. 1994. "Method to Identify Wells That Yield Water That Will be Replaced by Colorado River Water in Arizona, California, Nevada, and Utah, "U.S. Geological Survey Water-Resources Investigation Report 94-4005.

Attachment 1

Colorado River History and Legal Framework

The lower Colorado River 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	12,774,700	09421500
	Change in storage, Lake Mohave [A]	-158,500	09422500
Davis Dam to Parker Dam			
	Colorado River below Davis Dam	12,940,300	09423000
	Colorado River Aqueduct [B]	1,072,645	09424150
	Bill Williams River below Alamo Dam	25,364	09426000
	Central Arizona Project Canal [B]	1,228,233	09426650
	Change in storage, Lake Havasu [A]	8,900	09427500
Parker Dam to Imperial Dam			
	Colorado River below Parker Dam	10,380,000	09427520
	Change in storage, Senator Wash [A]	4,038	
	Colorado River at Imperial Dam	9,095,557	09429490
Imperial Dam to Mexico			
	Diversion to Mittry Lake	11,196	09522400
	All-American Canal	6,740,000	09523000
	All-American Canal below Pilot Knob	3,434,800	09527500
	Gila Gravity Main Canal [C]	812,916	09522500
	Wellton-Mohawk Canal [C]	372,577	09522700
	Colorado River below Imperial Dam	1,531,400	09429500
	Gila River near Dome	7,988	09520500
	Colorado River at NIB [D]	4,587,500	09522000
	Eleven Mile wasteway [D]	4,721	09525000
	Cooper wasteway [D]	1,846	09531850
	Twenty-one Mile wasteway [D]	2,084	09533000
	Main drain + 242 wells [D]	109,534	09534000
	West Main Canal wasteway [D]	6,688	09534300
	East Main Canal wasteway [D]	6,512	09534500

A. Geological Survey - December 1997 minus December 1998.
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.	299	0	312	Lake Mead National Recreation Area, diversion from Lake Mohave (Cottonwood). Reported as a diversion.
Cottonwood Cove (domestic consumptive use).		187		
Southern California Edison (domestic consumptive use).		12,851	12,851	Southern Nevada Water Authority (Southern California Edison), pumped from Sec 24 T32S R66E. Diversion = consumptive use.
Big Bend Water District (domestic consumptive use).		2,034	2,035	Big Bend Water District Diversion Sec 12 T32S R66E. Reported as a consumptive use.
Sportsman's Park.		10	10	Sportsman's Park.
Boy Scouts (domestic consumptive use).		4	7	Boy Scouts of America. Reported as a diversion.
Fort Mojave Indian Reservation, NV.	8,002	970	2,406	Fort Mohave Indian Reservation (Avi), 2 wells, sections 27 & 5. Reported as a diversion.
Fort Mojave Indian Reservation, NV (Avi) (domestic consumptive use).		870		
State of Nevada[F].	11,315	0		Not reported.
Subtotal: Uses below Hoover Dam.	19,616	16,926	17,621	Subtotal: Uses below Hoover Dam.
Uses above Hoover Dam [G].		227,683	227,683	Uses above Hoover Dam.
			794	Unmeasured return flow credit to Nevada.
Nevada Total.	19,616	244,609	244,510	Nevada Total.

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

[G] From 1998 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.	4,622	14,464	26,276	Fort Mohave Indian Reservation, pumped from river and wells. Reported as a diversion.
Needles (domestic consumptive use).		1,235	1,159	City of Needles, 4 wells NW SW Sec 29 T9N R23E SBM. Reported as a consumptive use.
Havasu Water Company.		2	3	Havasu Water Company. 1 well, T5N/R25E Sec31.
Colorado River Aqueduct (export).		1,072,052	1,073,125	Metropolitan Water District, diversion from Lake Havasu. Reported as a consumptive use.
Parker Dam/Gov't. Camp (domestic consumptive use).		66	115	Parker Dam and Government Camp, diversion at Parker Dam. Reported as a diversion.
Total Colorado River Indian Reservation, CA[H].	35,986	2,747	10,937	Colorado River Indian Reservation, pumped from 11 pumps and wells, 4 pumps from river. Reported as a diversion[I].
Colorado River Indian Reservation, CA.	34,703	0		
North Lyn-De Farm, CA[J].	0	750		
South Lyn-De Farm, CA.	2	1,551		
Bernal Farm, CA.	1,150	0		
Clark Farm, CA.	131	446		
Total Chemehuevi Indian Reservation, CA.	46	101	664	Chemehuevi Indian Reservation, Diversions from Pumps.
Chemehuevi Indian Reservation, CA.	46	101		
Chemehuevi Indian Reservation, CA. (domestic use not reported in 1998).		0		

[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**		
Park Moabi, CA.	253	0			Not Reported.
Havasu National Wildlife Refuge, CA.	5,868	0			Not reported.
BLM-Black Meadow (Domestic Consumptive Use)	0	118			Included in BLM Permittees (LHFO & YFO) below.
BLM Permittees, CA.		183	493		BLM Permittees (LHFO & YFO).
Total Palo Verde Irrigation District, CA.	8,567	378,189	427,113		Palo Verde Irrigation District, diversion from Palo Verde Dam. Reported as a consumptive use.
Palo Verde Irrigation District, CA.	8,016	374,413			
Palo Verde Irrigation District, AZ.	551	772			
Blythe (city, domestic consumptive use).		2,905			
Ripley (domestic consumptive use).		53			
Palo Verde (domestic consumptive use).		46			
Cibola National Wildlife Refuge, CA.	18,035	0			Not reported.
Imperial National Wildlife Refuge, CA.	19,034	0			Not reported.
Winterhaven (domestic consumptive use).		81	135	135	City of Winterhaven, 1 well, SE SE NE Sec 27 T16S R22E SBM.
					Town of Winterhaven, 1 well, 6S-22E 27DAA (No Report).
					Reported as diversions.
Fort Yuma Indian Reservation and Picacho State Recreation Area, CA.	1	0			Not reported.
Picacho State Recreation Area, CA.	4,477	0			Not reported.
Picacho Development Corp., CA (domestic consumptive use).		34	6		Picacho Development Corp. Reported as a diversion.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
All-American Canal below Pilot Knob[K].		3,436,819	3,439,014	3,101,548	Imperial Irrigation District, diversion at Imperial Dam.
				337,466	Coachella Valley Water District, diversion at Imperial Dam.
				Reported as consumptive uses.	
Earp (domestic consumptive use).		133		Not reported.	
Vidal (domestic consumptive use).		5		Not reported.	
Big River (domestic consumptive use).		99		Not reported.	
Southern California Gas (domestic consumptive use).		37	61	Southern California Gas. Reported as a diversion.	
Imperial National Wildlife Refuge and Yuma Proving Ground, CA.	46	0		Not reported.	
Yuma Proving Ground, CA.	8,119	0		Not reported.	
Fort Yuma Indian Reservation and Yuma Proving Ground, CA .	819	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.	13,724	38,950	49,025		31,163	Yuma Projects, Reservation Division Indian Unit, diversion at Imperial Dam (consumptive use).
Fort Yuma Indian Reservation, Indian Unit, CA.	487	14,202			49,564	Yuma Projects, Reservation Division Bard Unit, diversion at Imperial Dam (consumptive use).
Fort Yuma Indian Reservation, Bard Unit, CA.	814	21,400			35,724	Returns from Yuma Project, Reservation Division returns.
Bard (domestic consumptive use).		214		45,003	Sum Yuma Projects, Reservation Division (consumptive use).	
Fort Yuma Indian Reservation, CA.	12,423	3,134		276	Valdez, Mike, Sec 35 T15S R23E DDC.	
				100	Living Earth Farm, Sec 02 T16S R23E BBC.	
				1,355	MivCo Packing, (C-16S-23E) 9CCA.	
				11	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].	48,172	8,042	17,106	2,724	Ida Cal, 11N/22W -31BAB.
				985	Ida Cal, 11N/21E -36ADD.
				494	Ida Cal, 11N/21E -36CDA.
				The above Ida Cal wells irrigate lands north of Fort Mohave Irrigation District in CA.	
				121	Lye, C.L., 1S/24E -16ACB.
				600	Harp, P. (R. Harp), (C-8-23) 13AAD.
				2,673	Horizon Farms, (08S/R22W) 6CDA.
				225	Horizon Farms, (10S/R22W) 7ABD.
				940	Horizon Farms, (08S/R22W) 7BAB.
				225	Horizon Farms, (10S/R22W) 6DCB.
				225	Horizon Farms, (08S/R22W) 6BBD.
				0	Horizon Farms, (08S/R22W) 6BCD.
				225	Horizon Farms, (10S/R22W) 6CBB.
				1,097	Horizon Farms, (C-8-23) 1DCC.
				133	Horizon Farms, (C-8-23) 12CDB.
				1,138	Horizon Farms, (C-8-22) 6CBA.
				32	Living Earth Farm, (C-8-23) 2ADC.
					Ed Weavers Farms, (C-8-22) 6BCD (No Report).
				150	Horizon Farms, (C-8-22) 1BBA.
				715	Ed Weavers Farms, (C-8-23) 1BAD.

[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**		
				4	Horizon Farms (C-8-23) 12AAC
				0	Valdez, Mike, Sec T16S R23E 30 ACC.
				183	Valdez, Mike, Sec T16S R23E 30 ADD.
				1,145	Power, O.L., (C-8-23) 11 DCA.
				180	Harp, Robert, (C-8-23) 12 DAC.
				1,956	Dees, Alex, (C-8-23) 1 DAC.
				38	Wilson Farms, (C-8-23) 12 BBA.
				889	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.
				1	Williams, Jerry.
				3	Lindeman, William H. and Hazel D., Carney, Jerome D., and Phillips, Dorothy L. (3 wells).
			91,996	Unmeasured return flow credit to California.	
California Total.	167,769	4,953,357	4,953,236	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.	1,026	291	486	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).	670	0		
Lake Mead National Recreation Area, AZ (Davis Dam to Parker Dam).	356			
Katherine Landing and Willow Beach (domestic consumptive use).		291		
Lower Colorado Region Dams Project (domestic consumptive use).		32	32	Lower Colorado Region Dams Project (Davis Dam), Diversion at Davis Dam. Reported as a consumptive use.
Bullhead City (domestic consumptive use).		4,455	7,322	Bullhead City, Pumped from wells. Reported as a diversion.
Mohave County Parks (domestic consumptive use).		62	104	Diversion at Davis Dam, Mohave Co. Parks. Reported as a diversion.
Arizona State Parks (Windsor Beach)		5	8	Arizona State Parks (Windsor Beach)
Total Mohave Valley Irrigation and Drainage District	32,774	23,105	31,668	Mohave Valley Irrigation and Drainage District, Pumped from wells. Reported as a diversion[M].
MVIDD (domestic consumptive use)[N].		2,653		
Mohave Valley Irrigation and Drainage District, AZ (includes no domestic use).	32,774	20,452		
Fort Mojave Indian Reservation, AZ.	32,480	35,619	61,888	Fort Mohave Indian Reservation, 6 pumps and wells in flood plain. Reported as diversions.

[M] Includes 4,474 acre-feet of municipal and industrial use.

[N] 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**	
Golden Shores (domestic consumptive use).		300	501	Golden Shores Water Conservation District, pumped from wells. Reported as a diversion.
Topock (domestic consumptive use).		126		Not reported.
Crystal Beach Water Conservation District		54	90	Crystal Beach Water Conservation District Reported as a diversion
Havasu Water Company, AZ (domestic consumptive use).		254	423	Havasu Water Co. of AZ (Citizens Utilities). Reported as a diversion.
Mohave Water Conservation District (domestic consumptive use).		363	606	Mohave Water Conservation District; pumped from wells. Reported as a diversion.
Brook Water (domestic consumptive use).		229	382	Brook Water, (was Consolidated Water Utilities), pumped from river. Reported as a consumptive use.
Havasu National Wildlife Refuge, AZ[O].	49,023	0	36,641	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).		8,278	13,797	Lake Havasu City, pumped from wells. Reported as diversions.
Bill Williams National Wildlife Refuge (Lake Havasu).	599	0		Not reported.
Central Arizona Project Canal (export).		1,227,553	1,228,233	Central Arizona Project; pumped from Lake Havasu. Reported as a diversion.
Town of Parker (domestic consumptive use).		615	1,025	Town of Parker; pumped from river, 1 well-NW NW NW Sec 7 T9N R19W G&SRM. Reported as a consumptive use.
Lake Havasu State Park, AZ[P].	3,510	0		Not reported.

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

[P] May have missed a golf course.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Poston (domestic consumptive use).		67			Not reported.
Colorado River Indian Reservation, AZ.	132,025	326,758	351,668		Colorado River Indian Reservation; diversion at Headgate Rock Dam, 1 pump from river (B-04-22) 14BBD. Reported as a consumptive use.
Ehrenburg Improvement Association (domestic consumptive use).		262	427		Ehrenburg Improvement Association, 1 pump SW Sec 3 T3N R22W G&SRM. Reported as a diversion.
Cibola (domestic consumptive use).		26			Not reported.
Ehrenberg Farm, AZ.	0	2,511	4,015	3,821	Jack Rayner (B-04-22) 34 DCC (CDD).
				194	Jack Rayner (B-04-22)34 DCC (DCD).
					Reported as diversions.
Arkelian Farms, AZ.	2,141	1,908	2,808	0	George Arkelian (B-03-22)16 DBD (DAD).
				2,808	George Arkelian (B-03-22)16 DBD (DAD).
					Reported as diversions.
Total Bureau of Land Management permittees (domestic consumptive use).	0	519	865		Bureau of Land Management permittees (LHFO & YFO). Reported as a diversion.
Bureau of Land Management permittees (Davis Dam to Parker Dam).		81			
Bureau of Land Management permittees (Parker Dam to Imperial Dam).		438			
Hillcrest Water Company (domestic consumptive use).		13	21		Hillcrest Water Co. Reported as a diversion.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Total Yuma Proving Ground.	355	498	830		Yuma Proving Ground, diversion at Imperial Dam, wells X,Y,M. Reported as a consumptive use.
Yuma Proving Ground.	355	0			
Yuma Proving Ground (domestic consumptive use).		498			
Fort Yuma Indian Reservation, Mittry Lake State Wildlife Area and Yuma Proving Ground, AZ.	855	0			Not reported.
Fort Yuma Indian Reservation and Homesteads, AZ.	3,746	1,467	3,911	579	Dulin, A (C-8-22) 9 CCC.
				191	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.
				1,581	Glen Curtis Cit, (C-8-22) 7 CCD.
				960	Yowelman, R., Sec 17 T08S/ R22W CBC.
					Reported as diversions.
Martinez Lake (domestic consumptive use).		1			Not reported.
Cibola Valley Irrigation and Drainage District, AZ.[Q]	6,057	16,175	28,952		Cibola Valley Irrigation District, 5 pumps Sections 20, 21, and 26T1N R23W. Reported as a diversion.
Cibola National Wildlife Refuge, AZ.	44,900	6,906	6,915	6,435	Cibola National Wildlife Refuge, 4 pumps, Secrion 2 T1S R24W, Section 31 T1S, R23W. Reported as a diversion.
				480	Cibola Sportsman

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

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Imperial National Wildlife Refuge, AZ.	31,303	0	7,000	Imperial National Wildlife Refuge, 2 wells, Sec 13 T5S R22W G&SRM. Reported as a diversion.
Mittry Lake State Wildlife Area, AZ.	9,802	0	360	Pumper L. Pratt Sec 14 T7S R22W ABC.
Sturges Gila Monster Ranch, AZ.	47	6,386	11,702	Sturges, diversions at Imperial Dam (Warren Act). Reported as a consumptive use.
City of Yuma (domestic consumptive use).		16,474	16,474	City of Yuma, diversion at Imperial Dam (All-American Canal), diversion at Imperial Dam (Gila). Reported as a consumptive use.
Marine Corps Air Station [R] (domestic consumptive use).		1,126	1,876	Marine Corps Air Station (Yuma), diversion at Imperial Dam. Reported as a diversion.
Southern Pacific Company (domestic consumptive use).		29	48	Southern Pacific Company, diversion at Imperial Dam. Reported as a diversion.
Yuma Mesa Fruit Growers (domestic consumptive use).		7	12	Yuma Mesa Fruit Growers Association, diversion at Imperial Dam. Reported as a diversion.
University of Arizona.	0	985	1,044	University of Arizona, diversion at Imperial Dam (Warren Act). Reported as a diversion.
University of Arizona crop CU & Phreatophyte water use.	0	332		
Underflow to Mexico from the application of water by the U. of A.[S]	0	653		
Yuma Union High School (domestic consumptive use).		136	226	Yuma Union High School, diversion at Imperial Dam. Reported as a diversion.

[R] Located within Yuma Mesa Irrigation and Drainage District, AZ polygon.

[S] 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, Unit B I&DD, and the Yuma Mesa I&DD. The underflow to Mexico across SIB is therefore distributed as a consumptive use to these diverters. The portion of the underflow at SIB assigned to each of these diverters is based upon the number of acres of crops grown by each diverter. U of A grew 97 acres of crops (1 percent of the total), Unit B grew 2,454 acres of crops (12 percent of the total), and Yuma Mesa I&DD grew 17,308 acres of crops (87 percent total). The final estimate of underflow to Mexico across the SIB (after distribution of the residual from the water balance for the Imperial Dam to Mexico reach) is 65,258 acre-feet. Therefore, 653 acre-feet is assigned to the University of Arizona, 7,831 acre-feet is assigned to the Unit B I&DD, and 56,774 acre-feet is assigned to the Yuma Mesa I&DD.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Desert Lawn Memorial.		272	448		Desert Lawn Memorial, diversion at Imperial Dam. Reported as a diversion.
North Gila Valley Irrigation District, AZ.	815	16,075	19,532		North Gila Valley Irrigation District, diversion at Imperial Dam. Reported as a consumptive use.
Yuma Irrigation District, AZ.	311	26,734	51,504	50,736	Yuma Irrigation District, diversion at Imperial Dam and pumped from private wells. Reported as a consumptive use.
				146	Cameron Bros Sec 24 T08S R22W CCB.
				225	Cameron Bros Sec 24 T08S R22W CAD.
				397	Judd T. Ott Sec 30 T08S R22W BAB.
					Individual wells are reported as diversions.

Diverter name	Phreatophyte water use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Total	0	141,863	179,134	Yuma Mesa Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use[T].
Yuma Mesa Irrigation and Drainage District, AZ.	0	67,088		
Underflow to Mexico[U].		56,774		
Consumptive use by down gradient users[V].	0	10,366		
Hillander "C" Irrigation District, AZ .	0	7,623		
The Prison (domestic consumptive use).	0	12		

[T] 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.

[U] 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 87% of 65,250 acre-feet). See footnote S for more detailed information.

[V] 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.	4,773	155,914	227,407	221,057	Yuma County Water Users Association, diversion at Imperial Dam and pumped from wells[W].
Yuma County Water Users Association, AZ.	28	130,492		300	Burrell, Sec 33 T08S R24W BAB.
Underflow to Mexico[X].		20,629		46	Farmland Management Sec 19 T09S R24W BAD.
State of Arizona - Limitrophe Section.	4,745	2,549		128	Farmland Management, Sec19 T09S/ R24W BDD.
City of Somerton (domestic use).		720		46	Farmland Management, Sec19 T09S/ R24W BDA
City of Gadsden (domestic use).		24		829	Waymon Farms, Sec 36 T09S/R24W AAA.
City of San Luis (domestic use).		1,500		1,235	Waymon Farms Sec 31 T09S R24W BBB.
				901	J.W. Cumings, (C-10-25) 1BBA.
				State of Arizona Limitrophe Section:	
				950	J.W. Cumings (C-10-25), 14ADB.
				480	C & J Cummings, (C-10-25) 26BAB.
				480	J. Barkley, (C-10-25) 35CBA.
				600	Brown, Rodger S., (C-11-25) 2BBA.
				355	Earl Huges, (C-11-25) 3DAC.

[W] Also 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 into Mexico. Reported as a consumptive use. Individual wells are reported as diversions.

[X] The underflow to Mexico across the Limitrophe section presumed to result from the application of water within Yuma County Water Users Association's service area (about 98 percent of 21,050 acre-feet).

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	16,713	20,971	20,969	Unit "B" Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use[Y].
Unit B Irrigation and Drainage District, AZ.	0	8,882		2	Camille, Alec, Jr., diversion at Imperial Dam (Warren Act). Reported as a diversion. (Located with Unit B's diverter boundary)
Underflow to Mexico[Z].		7,831			
Total West Cocopah Indian Reservation, AZ.	5,897	6,004	15,473	12,893	Cocopah Indian Reservation, diversion at Imperial Dam. Pumped from wells (includes return flows). Reported as a consumptive use[AA].
West Cocopah Indian Reservation, AZ.	5,897	5,583			
Underflow to Mexico[BB].		421		630	W. Brand, D. Donnely (C-9-25) 35 ABA.
				1,950	P. Sibley, (C-10-25) 2CDA.
				Wells reported as diversions.	
Yuma Area Office, Bureau of Reclamation (Domestic consumptive use).		968	968	Yuma Area Office, diversion from Mode and Well No.8. Reported as a consumptive use.	

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

[Z] 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 12 percent of 65,258 Acre-feet). See footnote S for more detailed information.

[AA] 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).

[BB] 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 (21,050 acre-feet), or about 421 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 [CC](domestic consumptive use).		597	597	Yucca Power Plant. Sec 36 T16S R21E CBA. Reported as a diversion.	
Total North Cocopah Indian Reservation, AZ.	701	1,038	1,450	339	Huerta Packing 16S/22E-30CDA.
North Cocopah Indian Reservation, AZ.	701	834		771	Huerta Packing 16S/21E-25DAA.
Cocopah Bend RV (domestic consumptive use)[DD].		204		340	Cocopah Bend RV. 1 well, Sec 30 T16S R22E BDB.
				Reported as diversions.	
East Cocopah Indian Reservation, AZ. (domestic consumptive use + bingo)		14		Not reported.	
Yuma County (domestic consumptive use).		4,794		Not reported.	

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

[DD] 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[EE].	31,942	8,565	7,881	432	Hall, Ansil (Sec 36 T16S R21E BCB
				113	Texas Hill Farm (Sec 28 T16S R22E CDA
				0	Curry Family LTD (Sec 29 T16S R22E DAC
				2,850	R.E. & P. Power (Sec 30 T16S R22E ACC
				499	Ogram, George, Sec 24 T08S R23W DCC
				0	Ogram, George, Sec23 T08S R23W CDA (Indeterminate location)
				352	Peach, Sec 22 T08S R23W DCC
					AZ prod, Sec 23 T08S R23W CDA (No Report)
				515	Ott, Judd T., (C-8-22) 19CCA
				300	Glen Curtis Cit (C-8-22) 24BDD
				2,078	Glen Curtis Cit (C-8-22) 24BDD
				742	Ott, Lee & Larry (no location reported).
				Reported as diversions.	

[EE] 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).	395,082	2,063,146	2,347,725		Arizona Subtotal (Below Hoover Dam, less Wellton-Mohawk Irrigation and Drainage District).
			71,515		Pumped from South Gila Wells (drainage pump outlet channels): Returns.
Arizona uses above Hoover Dam[FF].		151	151		Arizona uses above Hoover Dam.
				133	Lake Mead Nat'l Recreation, AZ. Diversions from Lake Mead (Temple Bar).
				18	Marble Canyon Company.
Wellton-Mohawk Irrigation and Drainage District [EE].		290,355	290,355		Wellton-Mohawk Irrigation and Drainage District.
			143,842		Unmeasured return flow credit to Arizona.
Arizona Total.	395,082	2,353,652	2,422,874		Arizona Total.
Total Lower Basin Use.	582,467	7,551,618	7,620,620		Total Lower Basin Use[GG].

[FF] From 1998 Decree Accounting Report.

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

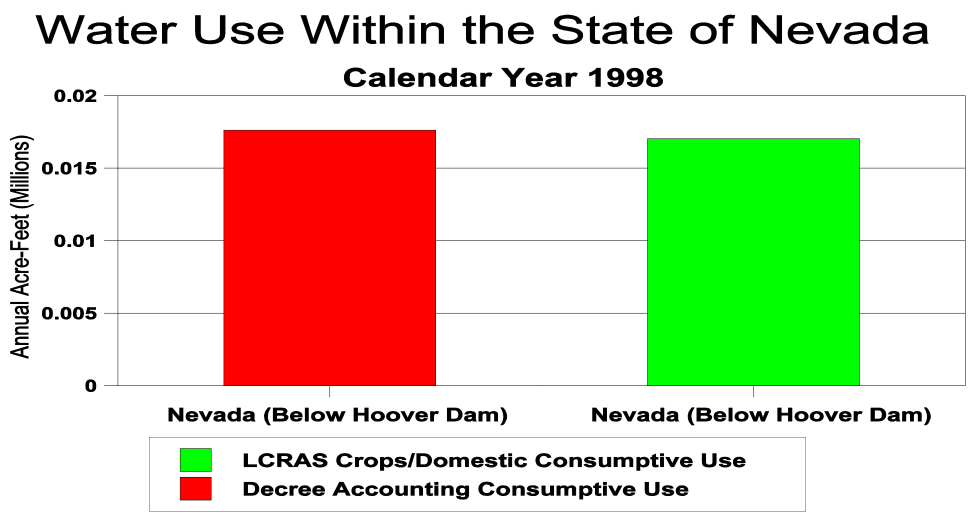
Selected Results in Graphic Form

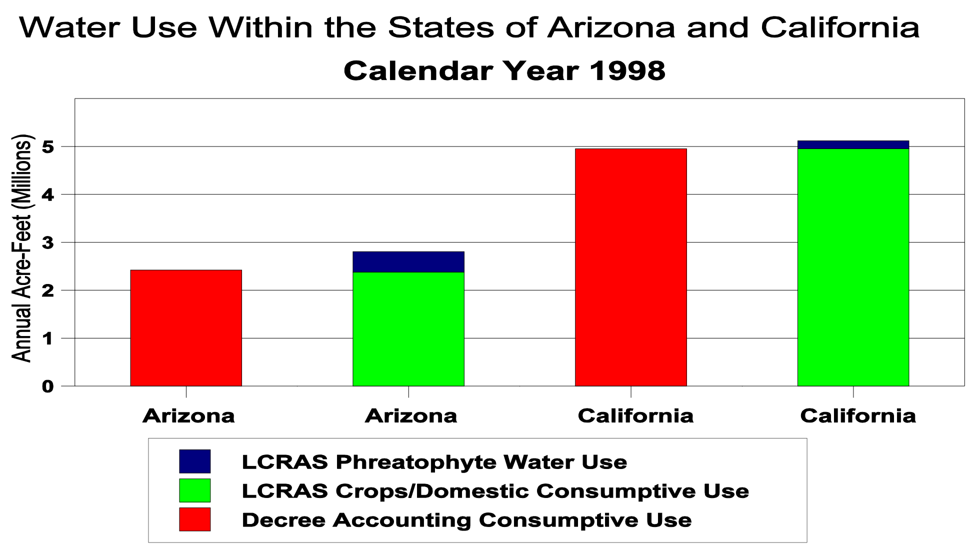
A list of the bar charts included on the following pages and a short interpretation of the information displayed upon them are presented below:

Water Use within 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)

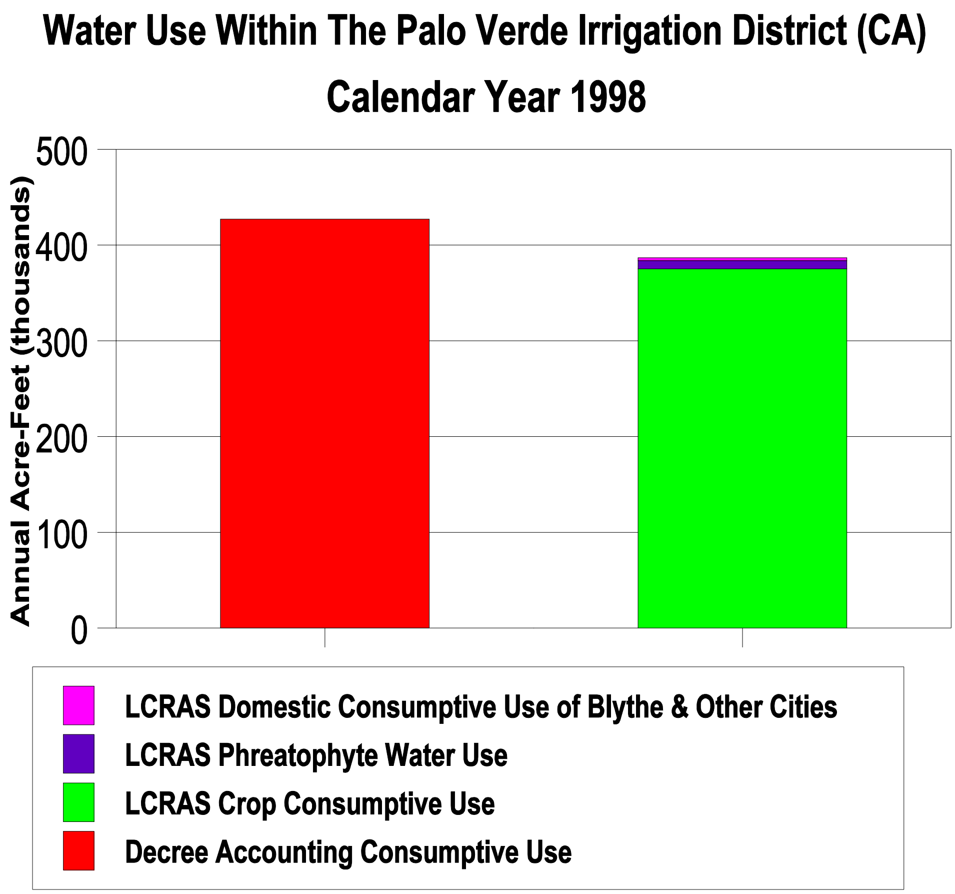
The following bar charts show the consumptive use reported for 1998 by Decree Accounting, and crop and domestic consumptive uses, and phreatophyte water uses produced by LCRAS for State totals and selected irrigation districts and wildlife refuges. These bar charts highlight the importance of determining the amount of phreatophyte water use, if any, that should be reported as part of a diverter's consumptive use[HH].

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

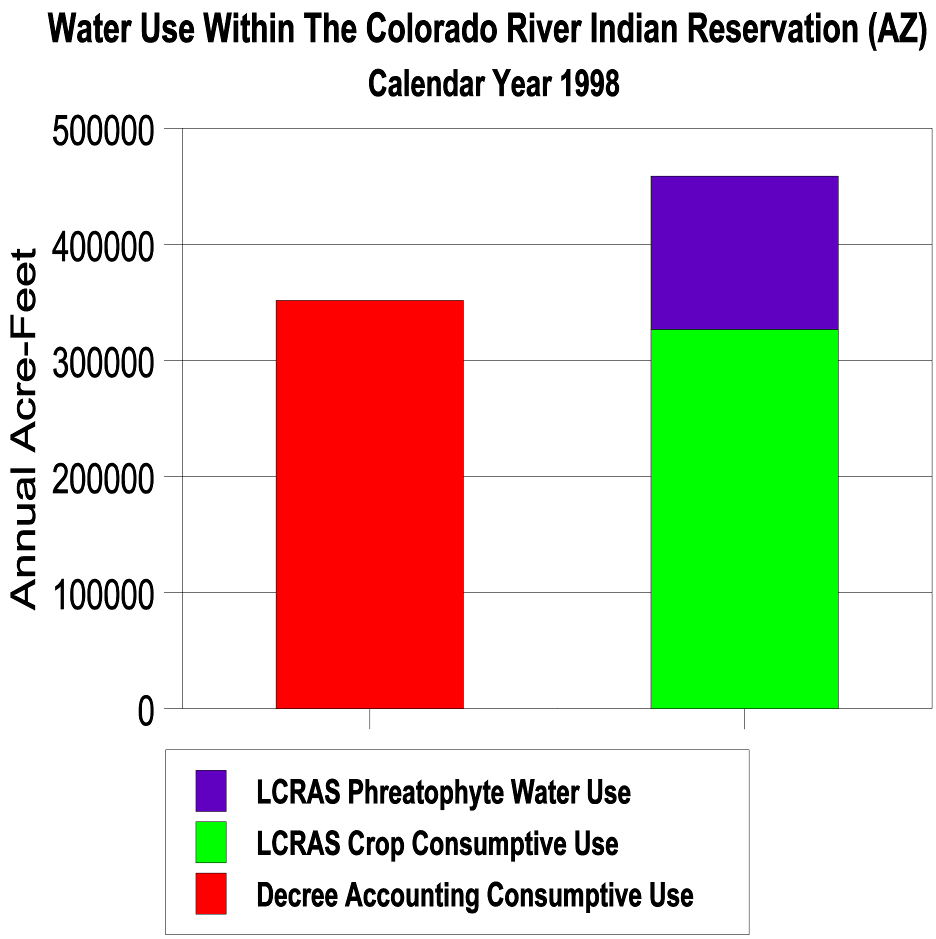




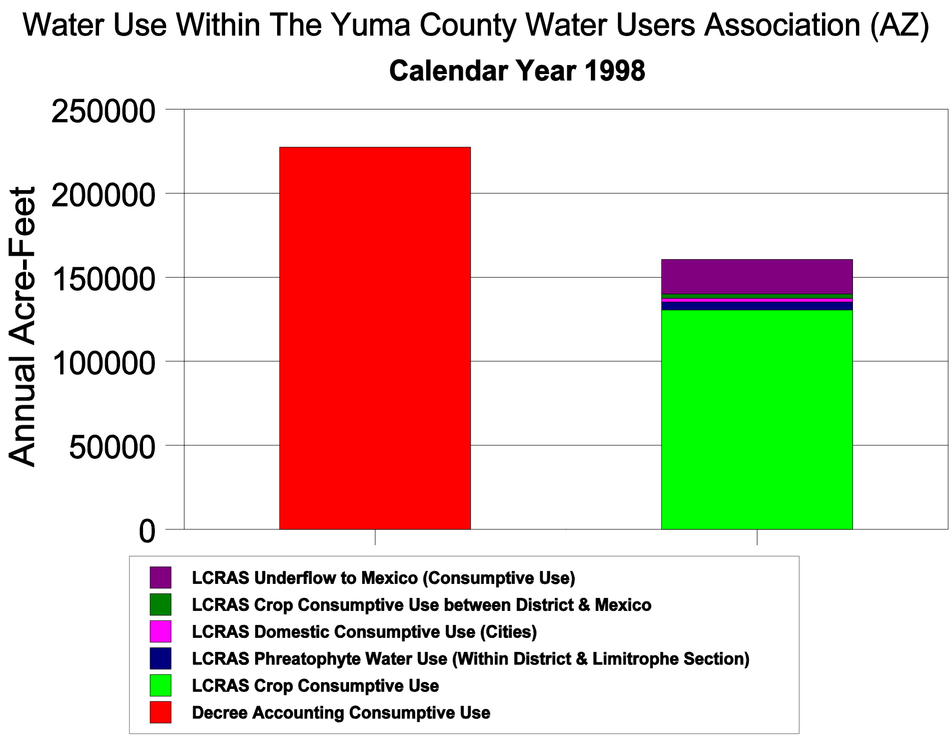
The bar chart for the State of Nevada shows the minor impact LCRAS has on consumptive use calculations in Nevada. LCRAS has a minor impact because there was no irrigation in Nevada in 1998. The bar chart for the States of California and Arizona shows a good comparison between the consumptive uses of crops 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.

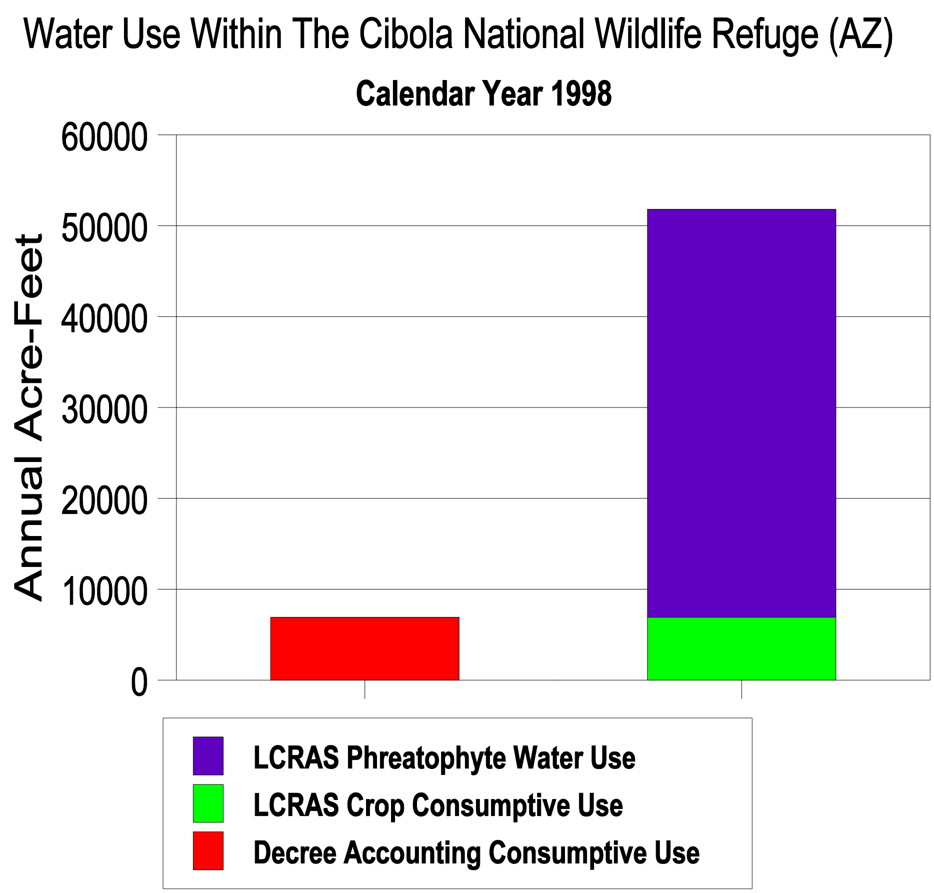


The bar chart for the Colorado River Indian Reservation (AZ) shows the crop consumptive use and phreatophytes water use, and the consumptive use reported by Decree Accounting. The consumptive use reported for the Colorado River Indian Reservation by Decree Accounting does not include the estimate of 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.

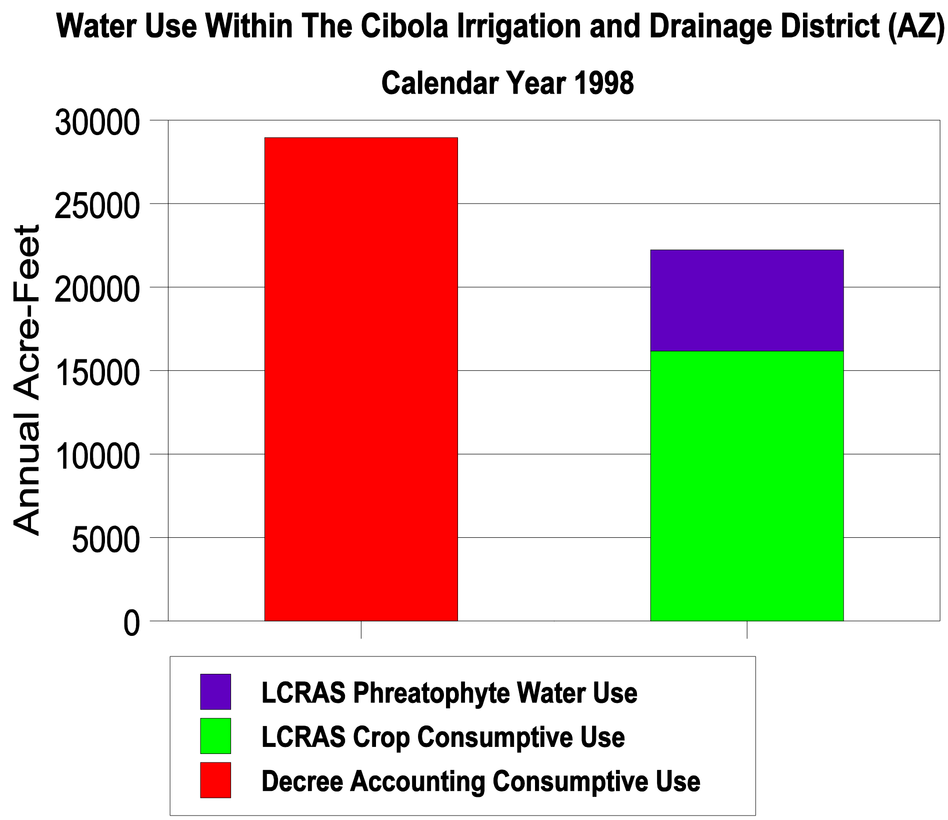


The bar chart for the Yuma County Water Users Association shows the crop and domestic consumptive uses and the phreatophyte water use within the district boundary developed by LCRAS, plus an estimate of the underflow to Mexico that results from applied but unconsumed water within the district, plus crop 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."

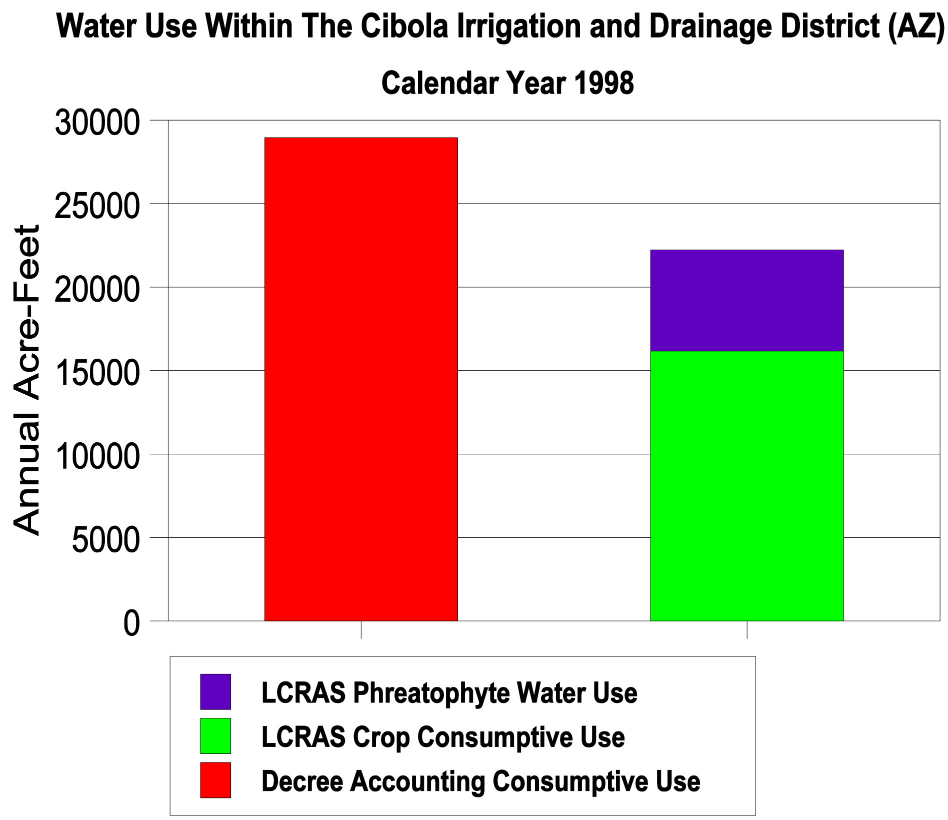
The underflow to Mexico, the domestic consumptive use, the crop consumptive use, and the phreatophyte water use between the district boundary and Mexico should be considered part of the Yuma County Water Users Association's consumptive use because these quantities represent diversions from the Colorado 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.



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 generate acreage amounts for crops, phreatophytes, and open water within the project area. These technologies are used to classify crop types, phreatophytes, and open water, and to populate a complete digital database(s) representing the areal extent of these land cover types. Annual acreage summaries are generated for each land-cover type by diverter boundary, river reach, and State. Accuracy assessment is performed for crop and phreatophyte classes.

Field Border Database

Refer to page 8 in this report for an explanation of how this database was created. Refer to Table Att-4.A for metadata on this 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 class assigned by the spectral classification process. "CROP-TYPE" is populated with a crop class 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. This comprehensive field border update is used for this report.

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

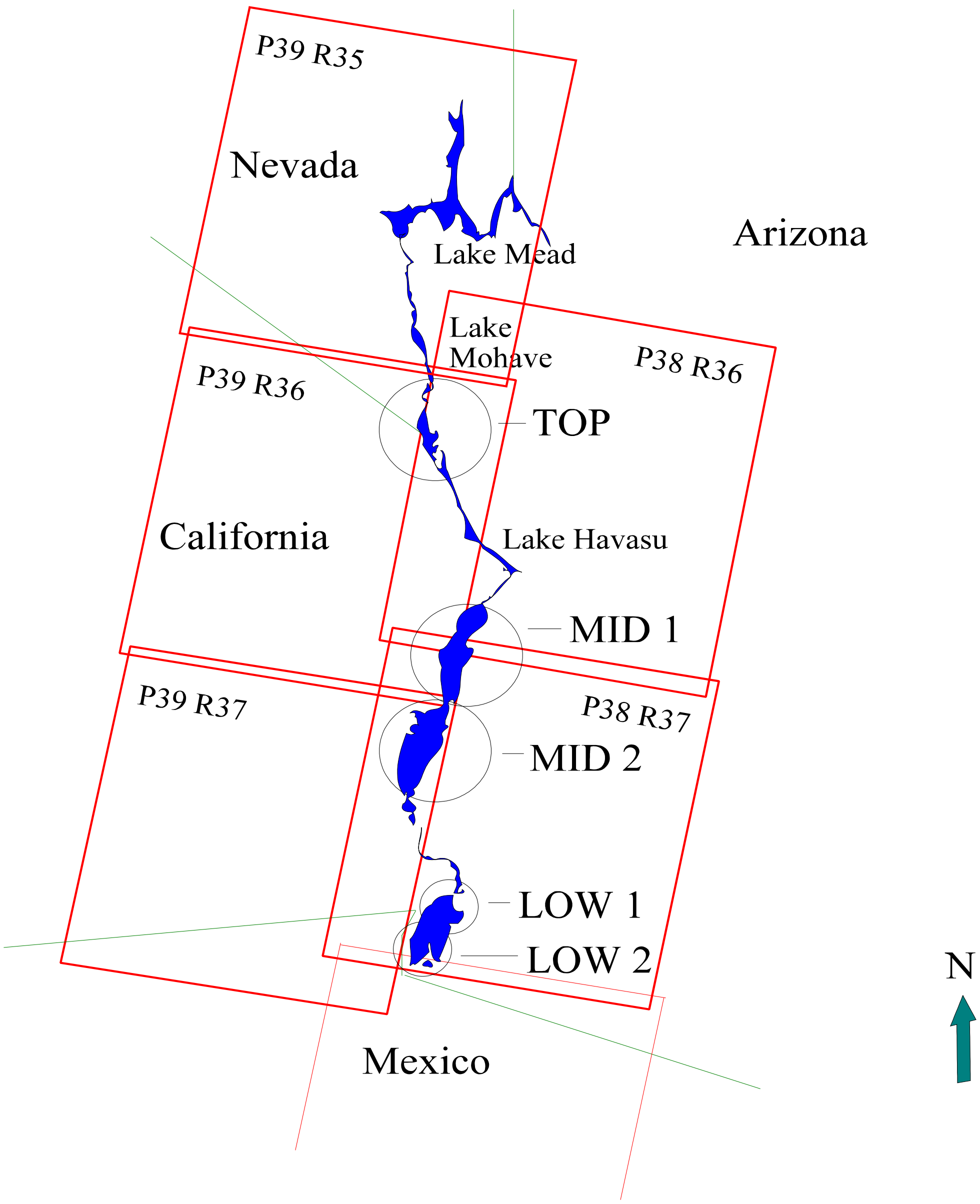


Figure Att-4.1 — Image Processing Areas and Landsat Scene Boundaries.

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 boundary files. 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. 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, and Japanese (JERS) LISS-III multi-spectral data. Ground reference data for training the spectral classifier are collected during a 2-week 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 in crop types, 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 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 crop conditions as possible to assure that the majority of spectral variability within the satellite imagery is considered. Approximately 17 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 crop types 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 location, and colors indicate the crop that was present during the last ground reference visit. This 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 type and field-id on a hard-copy form while the data coder records all attributes in digital format. Field id's and crop type 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 Type	See Table Att-4.D for complete crop 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 (Furrow orientation)	North, west, uniform (leveled), pivot
Furrow moisture	Dry/Semi moist, saturated, ponding
Bed moisture	Dry/Semi moist, saturated, ponding
Photo	Roll/Frame # if photo taken for reference
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, approximately 30 percent 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. Note that these fields are not buffered to the inside. When the field is not buffered to eliminate edge effects, the region-growing algorithm often generates "border" regions that reflect the unique spectral conditions caused by mixed pixels at the boundaries of the irrigated fields.

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 attributes collected in the field are included in the ERDAS signature file with each spectral training signature.

Table Att-4.D — 1998 Crop List

Crop Type	Code	Crop Type	Code	Crop Type	Code
Alfalfa	1.00	Cotton	2.00	Unknown Crop	3.00
Small Grains	**4.00**	**Lettuce**	**6.00**	**Melons**	**7.00**
Oats	4.01	Head Lettuce	6.01	Watermelon	7.01
Rye	4.02	Leaf Lettuce Green	6.02	Honeydew Melon	7.02
Barley	4.03	Leaf Lettuce Red	6.03	Cantaloupe Melon	7.03
Milo	4.04	Other Lettuce	6.04		
Wheat	4.05				
Corn	**5.00**	**Bermuda Grass**	**8.00**	**Citrus**	**9.00**
Tomatoes	**10.00**	**Sudan Grass**	**11.00**	**Dates**	**15.00**
Other Vegetables	**12.00**	**Other Vegetables**	**12.00**	**Other Vegetables**	**12.00**
Beans	12.01	Potatoes	12.09	Garbanzo Beans	12.17
Peas	12.02	Okra	12.10	Squash	12.18
Sorghum	12.03	Radish	12.11	Celantro	12.19
Millet	12.04	Commercial Flowers	12.12	Celery	12.21
Peppers	12.05	Artichokes	12.13	Pecans	12.22
Carrots	12.06	Asparagus	12.14	Peaches	12.23
Onions	12.07	Peanuts	12.15		
Garlic	12.08	Jojoba Beans	12.16		
Crucifers	**13.00**	**Fallow**	**14.00**	**Safflower**	**16.00**
Broccoli	13.01	Idle with green weeds	14.01		
Cauliflower	13.02	Idle with senescent weeds	14.02		
Cabbage	13.03	Cultivated bare soil	14.03		
Bok-choy	13.04	Not cultivated. Bare	14.04		

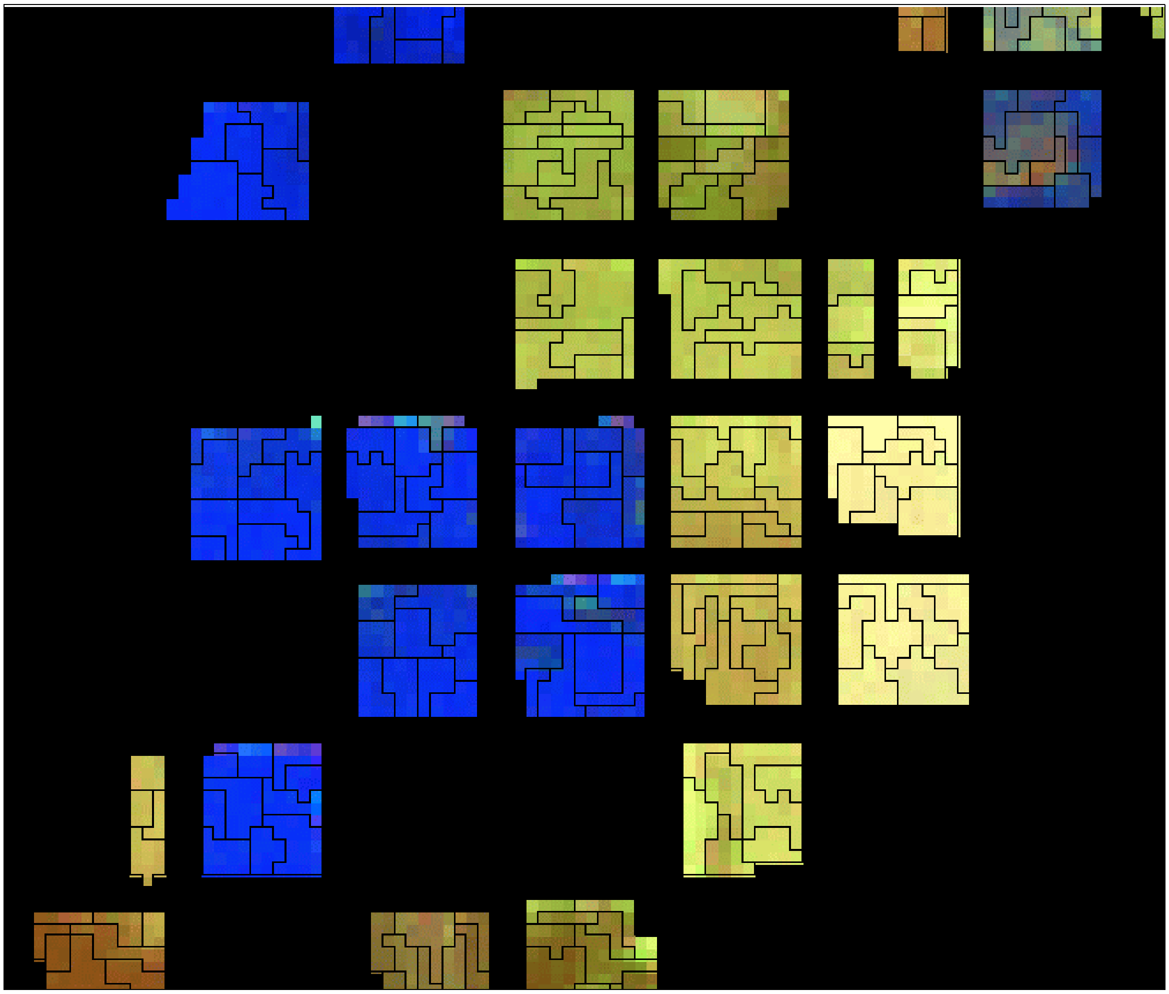


Figure Att-4.5 — Ground Reference Fields - masked and partitioned into spectral regions for signature generation. Black lines denote spectral regions plotted on Landsat bands 4, 3, 2.

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 types. 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 irrigated fields. The resulting pixel classification is then “overlaid” with the field border database and each field is given a single crop label based on the distribution of classified pixels within that field. A simple plurality rule is used (the field label is given to the class 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 classes. 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 acreage and number of fields correct. For each classification time, approximately 30 percent of the ground reference fields are reserved as an independent sample for accuracy assessment purposes. This is a random stratified sample representing the relative proportions of crop classes being grown at each classification time. Due to crop rotation practices, some crop classes for a particular classification time are under-sampled with respect to accuracy assessment needs. However, these crop classes 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 classes 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 crops are being confused in the classifier and are useful in determining ways of improving the classification process and the creation of annual crop 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 class 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 class to which it actually belongs (reported in the columns of the error matrix). A commission error occurs when an area is included into a class to which it does not belong (reported in the rows of the error matrix). Every error of omission from the correct class is also an error of commission to a wrong class.

These error matrices also contain additional information specific to this project. Some reported accuracy percentages are adjusted for expected spectral confusion. These adjustments are specific to two conditions:

1. Confusion between any crop class and a fallow condition.
2. Confusion between bermuda and alfalfa.

In the first type of confusion, it is expected that at an immature growth stage, a given crop will not have a great enough crown closure to spectrally differentiate it from a fallow field. In the second case, the confusion between bermuda and alfalfa is primarily due to the fact that a certain percentage of alfalfa fields have bermuda grass growing in them. Both adjustments consider this confusion to be acceptable and adjust the accuracy percentages accordingly. Even though this does not correct the error in each crop classification, much of this error is accounted for when all four classification times are used for calculating the annual crop summary (discussed in the next section).

Table Att-4.E — March 1998 Accuracy Assessment Error Matrix (Units: Acres)																		
Ground Reference Fields																		
		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Other Vegs.	Crucifers	Fallow	Dates	Safflower	**TOTALS**	
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**		
Alfalfa	**1**	**7114.00**		148.23							110.8			4.69			**0.00**	??
Cotton	**2**																**0.00**	
Small Grain	**4**	263.40		**2774.05**		80.44	10.1				18.49	90.17	165.29	55.76			**3457.70**	80.23%
Corn	**5**																**0.00**	
Lettuce	**6**	25.72		62.41		**559.24**							64.92	11.38			**723.67**	77.28%
Melons	**7**																**0.00**	
Bermuda Grass	**8**	52.21						**120.76**									**172.97**	69.82%
Citrus	**9**								**1016.39**								**1016.39**	100.00%
Tomatoes	**10**																**0.00**	
Sudan Grass	**11**																**0.00**	
Other Vegs.	**12**	12.04		38.55		26.33						**137.89**					**214.81**	64.19%
Crucifers	**13**					27.47						54.4	**175.92**				**257.79**	68.24%
Fallow	**14**	54.86		385.18		143.33	18.37					5.58		**3806.45**			**4413.77**	86.24%
Dates	**15**														**384.4**		**384.36**	100.00%
Safflower	**16**																**0.00**	
TOTALS		**7522.23**	**0.00**	**3408.42**	**0.00**	**836.81**	**28.47**	**120.76**	**1016.39**	**0.00**	**129.29**	**288.04**	**406.13**	**3878.28**	**384.36**	**0.00**	**18019.18**	Total Samples
%correct by crop		95%		81%		67%	0%	100%	100%		0%	48%	43%	98%	100%		**16089.06**	Total Correct
																	89%	**% correct**
Total w/ fallow correction		7467.37	0	3023.24	0	693.48	10.1	120.76	1016.39	0	129.29	282.46	406.13	4485.60	384.4	0	18019.18	
%correct w/ fallow correction		95%		92%		81%	0%	100%	100%		0%	49%	43%	98%	100%		**93%**	
Total berm. OR alf. correct		7,166.21						120.76									**7286.97**	
%correct w/ b/a correction		95%						100%									**90%**	
% correct w/ b/a/f correction		96%						100%									**93%**	
*** w/ = with *b/a = bermuda and alfalfa *b/a/f = bermuda, alfalfa, and fallow**																		

Ground Reference Fields

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Other Vegs.	Crucifers	Fallow	Dates	Safflower	**TOTALS**	
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**		
Alfalfa	**1**	**8329.09**		28.99		19.28		201.83			177.1			96.07			**0.00**	??
Cotton	**2**	39.90	**2399.42**				111.09				52.91			130.59		55.36	**2789.27**	86.02%
Small Grain	**4**	16.80		**3493.53**	13.08			19.45			79.28	52.42		9.13		22.79	**3706.48**	94.25%
Corn	**5**				**192.12**												**192.12**	100.00%
Lettuce	**6**																**0.00**	
Melons	**7**		162.37	12.3			**452.71**							37.27			**664.65**	68.11%
Bermuda Grass	**8**	37.31		18.29				**73.84**			36.87						**166.31**	44.40%
Citrus	**9**								**936.56**								**936.56**	100.00%
Tomatoes	**10**																**0.00**	
Sudan Grass	**11**	12.34	17.43	14.95	18.35		17.57	9.81			**322.22**			4.51			**417.18**	77.24%
Other Vegs.	**12**											**289.69**					**289.69**	100.00%
Crucifers	**13**													14.51			**14.51**	0.00%
Fallow	**14**	35.29	249.83	15.07	9.64		112.65			16.46	146.37			**514.66**		21.69	**1121.66**	45.88%
Dates	**15**														**391.96**		**391.96**	100.00%
Safflower	**16**										27.38					**9.85**	**37.23**	26.46%
TOTALS		**8470.73**	**2829.05**	**3583.13**	**233.19**	**19.28**	**694.02**	**304.93**	**936.56**	**16.46**	**842.13**	**342.11**	**0.00**	**806.74**	**391.96**	**109.69**	**19579.98**	Total Samples
%correct by crop		98%	85%	97%	82%	0%	65%	24%	100%	0%	38%	85%		64%	100%	9%	**17405.65**	Total Correct
																	89%	**% correct**
Total w/ fallow correction		8435.44	2579.22	3568.06	223.55	19.28	581.37	304.93	936.56	0	695.76	342.11	0	1413.74	391.96	88	19579.98	
%correct w/ fallow correction		99%	93%	98%	86%	0%	78%	24%	100%		46%	85%		83%	100%	11%	**92%**	
Total berm. OR alf. correct		8,366.40						275.67									**8642.07**	
%correct w/ b/a correction		99%						90%									**90%**	
% correct w/ b/a/f correction		99%						90%									**93%**	

* w/ = with; *b/a = bermuda and alfalfa; *b/a/f = bermuda, alfalfa, and fallow

Table Att-4.G — July 1998 Accuracy Assessment Error Matrix (Units: Acres)

Ground Reference Fields

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Other Vegs.	Crucifers	Fallow	Dates	Safflower	**TOTALS**	
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**		
Alfalfa	**1**	**7108.36**	479.26					128.58			273.61			121.47			**0.00**	??
Cotton	**2**	35.86	**2243.43**									21.99		91.49			**2392.77**	93.76%
Small Grain	**4**																**0.00**	
Corn	**5**				**37.28**			18.99						73.67			**129.94**	28.69%
Lettuce	**6**																**0.00**	
Melons	**7**																**0.00**	
Bermuda Grass	**8**	153.07						**121.4**						38.12			**312.59**	38.84%
Citrus	**9**								**1408.94**								**1408.94**	100.00%
Tomatoes	**10**																**0.00**	
Sudan Grass	**11**	12.55	5.73								**165.89**			69.12			**253.29**	65.49%
Other Vegs.	**12**																**0.00**	
Crucifers	**13**																**0.00**	
Fallow	**14**	163.39	313.16					123.64			179.87			**4241.39**			**5021.45**	84.47%
Dates	**15**														**362.42**		**362.42**	100.00%
Safflower	**16**																**0.00**	
TOTALS		**7473.23**	**3041.58**	**0.00**	**37.28**	**0.00**	**0.00**	**392.61**	**1408.94**	**0.00**	**619.37**	**21.99**	**0.00**	**4635.26**	**362.42**	**0.00**	**17992.68**	Total Samples
%correct by crop		95%	74%		100%			31%	100%		27%	0%		92%	100%		**15689.11**	Total Correct
																	87%	**% correct**
Total w/ fallow		7309.84	2728.42	0	37.28	0	0	268.97	1408.94	0	439.5	21.99	0	5415.32	362.42	0	17992.68	
%correct w/ fallow		97%	82%		100%			45%	100%		38%	0%		93%	100%		**92%**	
Total berm OR alf		7,261.43						249.98									**7511.41**	
%correct w/ b/a		97%						64%									**89%**	
% correct w/ b/a/f		99%						93%									**93%**	

* w/ = with ; *b/a = bermuda and alfalfa; *b/a/f = bermuda, alfalfa, and fallow

Table Att-4.H — November 1998 Accuracy Assessment Error Matrix (Units: Acres)

Ground Reference Fields

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Other Vegs.	Crucifers	Fallow	Dates	Safflower	**TOTALS**	
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**		
Alfalfa	**1**	**7049.80**	238.31			73.49		141.02			110.95	37.33		272.09			**7922.99**	88.98%
Cotton	**2**		**2493.11**											30.84			**2523.95**	98.78%
Small Grain	**4**			**120.62**													**120.62**	100.00%
Corn	**5**																**0.00**	
Lettuce	**6**					**1039.74**	14.07					14.4	15.13	83.57			**1166.91**	
Melons	**7**					124.5	**138**						22.47				**284.97**	48.43%
Bermuda Grass	**8**	32.02						**45.69**									**77.71**	58.80%
Citrus	**9**								**600**								**600.00**	100.00%
Tomatoes	**10**																**0.00**	
Sudan Grass	**11**	13.21												70.83			**84.04**	0.00%
Other Vegs.	**12**	35.22	34.82			17.89						**200.94**	18.57	63.43			**370.87**	54.18%
Crucifers	**13**					155.4						17.01	**489**	10.17			**671.58**	72.81%
Fallow	**14**	134.77	74.43			155.8						111.46	37.89	**4600.4**			**5114.75**	89.94%
Dates	**15**														**113.39**		**113.39**	100.00%
Safflower	**16**																**0.00**	
TOTALS		**7265.02**	**2840.67**	**120.62**	**0.00**	**1566.82**	**152.07**	**186.71**	**600.00**	**0.00**	**110.95**	**381.14**	**583.06**	**5131.33**	**113.39**	**0.00**	**19051.78**	Total Samples
%correct by crop		97%	88%	100%		66%	91%	24%	100%		0%	53%		90%	100%		**16890.69**	Total Correct
																	89%	**% correct**
Total w/ fallow correction		7130.25	2766.24	120.62	0	1411.02	152.07	186.71	600	0	110.95	269.68	545.17	5645.68	113.39	0	19051.78	
%correct w/ fallow correction		99%	90%	100%		74%	91%	24%	100%		0%	75%		91%	100%		**91%**	
Total berm OR alf correct		7,081.82						186.71									**7268.53**	
%correct w/ b/a correction		97%						100%									**90%**	
% correct w/ b/a/f correction		99%						100%									**92%**	

* w/ = with; *b/a = bermuda and alfalfa; *b/a/f = bermuda, alfalfa, and fallow

Results

Accuracy assessment tables indicate that overall accuracies are over 90 percent after accounting for expected confusion at particular growth stages as discussed above. It is important to note that those individual crop classes (at a particular classification time) that represent the majority of acreage in the study area tend to have the highest classification accuracies. Lower accuracies associated with individual crop classes are generally crops that do not represent a significant amount of acreage, or are statistically undersampled for that particular time because of crop planting practices (very little or none of that crop planted during a particular classification period). Multiple classifications per year ensure that these crops will be classed correctly when they are at a mature state.

There is some error in individual crop classes that warrants further study. Understanding error in the classification process should help in improving classification procedures and reducing error. The "Other Vegetable" class consists of a number of individual crops that may be better grouped as a function of water consumption. Crop classes within the "Other Vegetable" category have been analyzed and have been regrouped for calendar year 1999.

It is very important to understand error in the classification as a function of the intended use of the data. Error must be considered with respect to water consumption calculations. Error between particular crop classes may represent negligible error with respect to water consumption calculations when taking into account both acreage and evapotranspiration coefficients for each crop type. It is important to note that after the annual crop summary takes into account all four classification times, error between the fallow class and any other crop class is negligible. Further studies will present the effects of known error on water consumption calculations.

Annual Crop Summary

Annual acreage figures for each crop type 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 types 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 classes for each field at each classification time.

A computer program for crop 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 combinations (over 1,000 unique combinations in the 1998 database) and assigns acreage of crop type(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 as alfalfa has an annual ET coefficient, and accuracy assessment data indicate that Alfalfa and Sudan are sometimes confused in the August classification date. Because all classification dates except August were classified as Alfalfa, the August Sudan label is assumed to be classification error. 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. Fallow acreage is also reported. Results of the annual summary program are extensively reviewed for error and edited where necessary.

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 (modified to include all phreatophyte communities) from Wilson and Owen-Joyce (1994).

Annual phreatophyte updates are accomplished using change detection methodologies. This procedure identifies spectral difference between image dates (i.e. May 1997 and May 1998) and focuses remapping efforts in areas of spectral change.

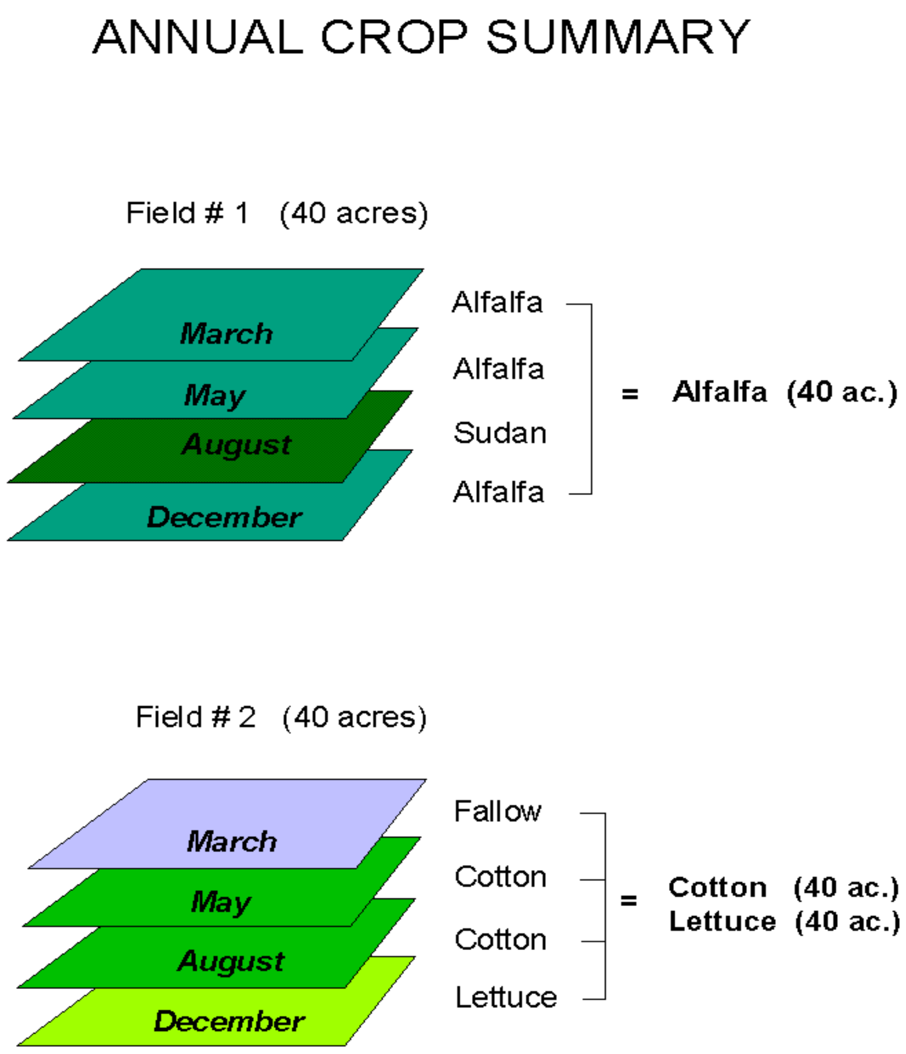
Ground Reference Data Collection

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 phreatophyte classes 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, vegetation types, percent crown closure by vegetation type, 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 natural vegetation communities often requires a different approach than that used for crops because image pixels often consist of a mixture of vegetation types rather than one type (i.e. irrigated field with one crop type). Unsupervised classifications consisting of unlabeled spectral classes are often generated before field work and plots of these are also taken into the field to help in establishing correlation between particular vegetation communities and spectral classes. Additionally, because natural vegetation communities 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.

Figure Att-4.6 — Annual Crop Summary.



Classification Strategies

A number of image band combinations were explored to determine the optimum combination for 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 vegetation classes when compared to the classification generated from the TM 6-band image. A May 1994 TM 6-band image was used for the phreatophyte classification. However, 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 classes (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 vegetation type in the landscape), signatures that are spectrally similar but represent different vegetation classes in the landscape (spectrally confused classes), 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 classed 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 community. 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 classes within each polygon is generated. Labeling rules specific to the classification system are then applied based on the relative percentages of phreatophyte pixel classes 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 vegetation communities, as well as unresolvable spectral confusion between some vegetation classes. 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 using band 7 has been chosen based on these results.

The image difference layer from the band 7 subtraction is then categorized into five classes based on all available ancillary data. This five-class map of change focuses on changes in vegetation and includes

1. No Change
2. Slight Increase in Vegetation
3. Significant Increase in Vegetation
4. Slight Decrease in Vegetation
5. Significant Decrease in Vegetation

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 classes are remapped. Remapping is accomplished by using classification processes as described above for phreatophytes. New polygons are spectrally generated in areas of change and again labeled based on the pixel classification. Remapped areas are then incorporated into the existing phreatophyte layer as an update.

Accuracy Assessment

Accuracy assessment work is still being completed for phreatophytes in conjuntion with Reclamation’s Environmental Group which is also mapping phreatophyte communities. Accuracy assessment for phreatophytes will include fuzzy set logic to address adequately complexities associated with natural vegetation communities (Gopal, et. al., 1994).

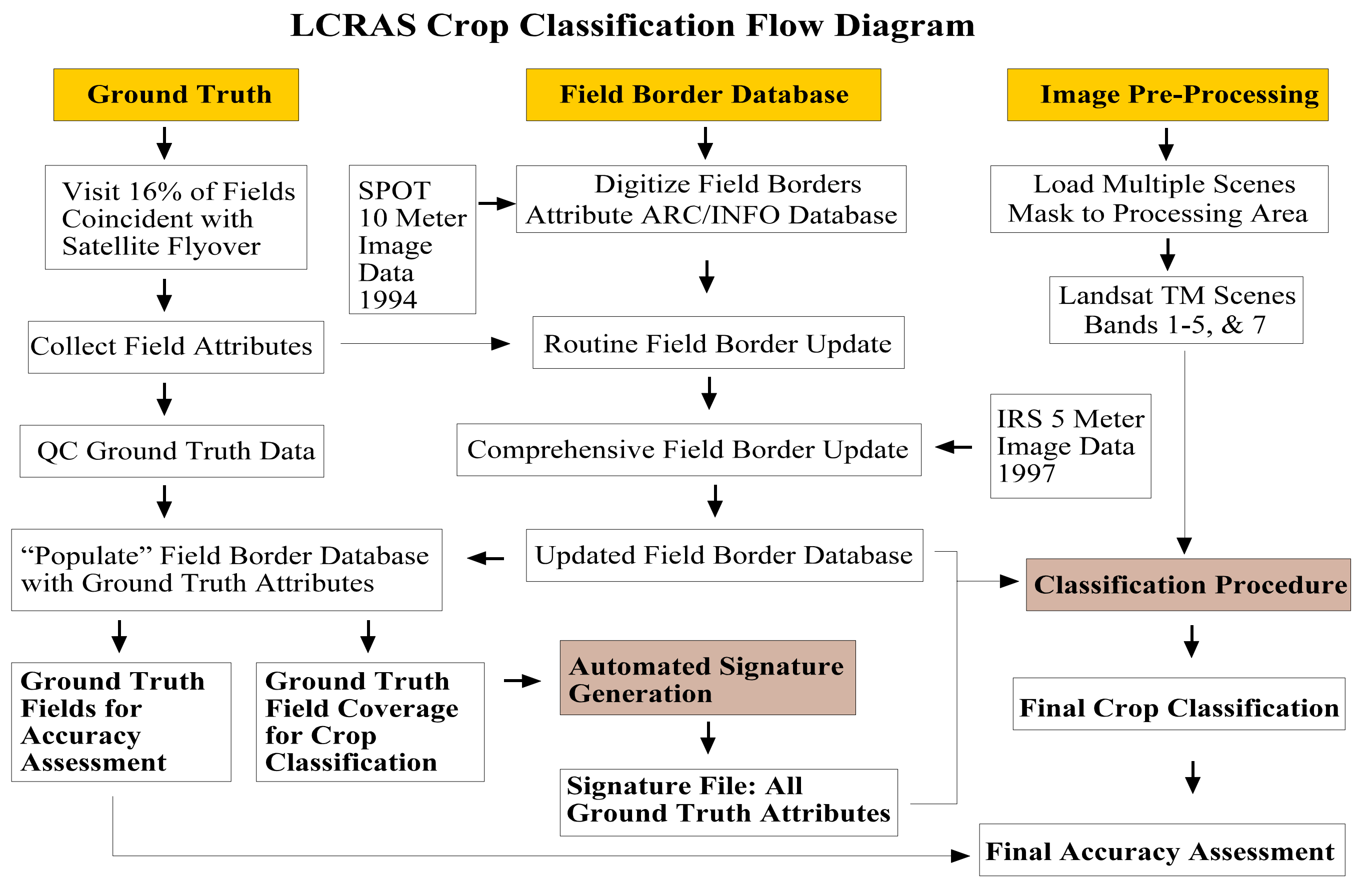


Figure Att-4.2 — LCRAS Crop Classification Flow Diagram.

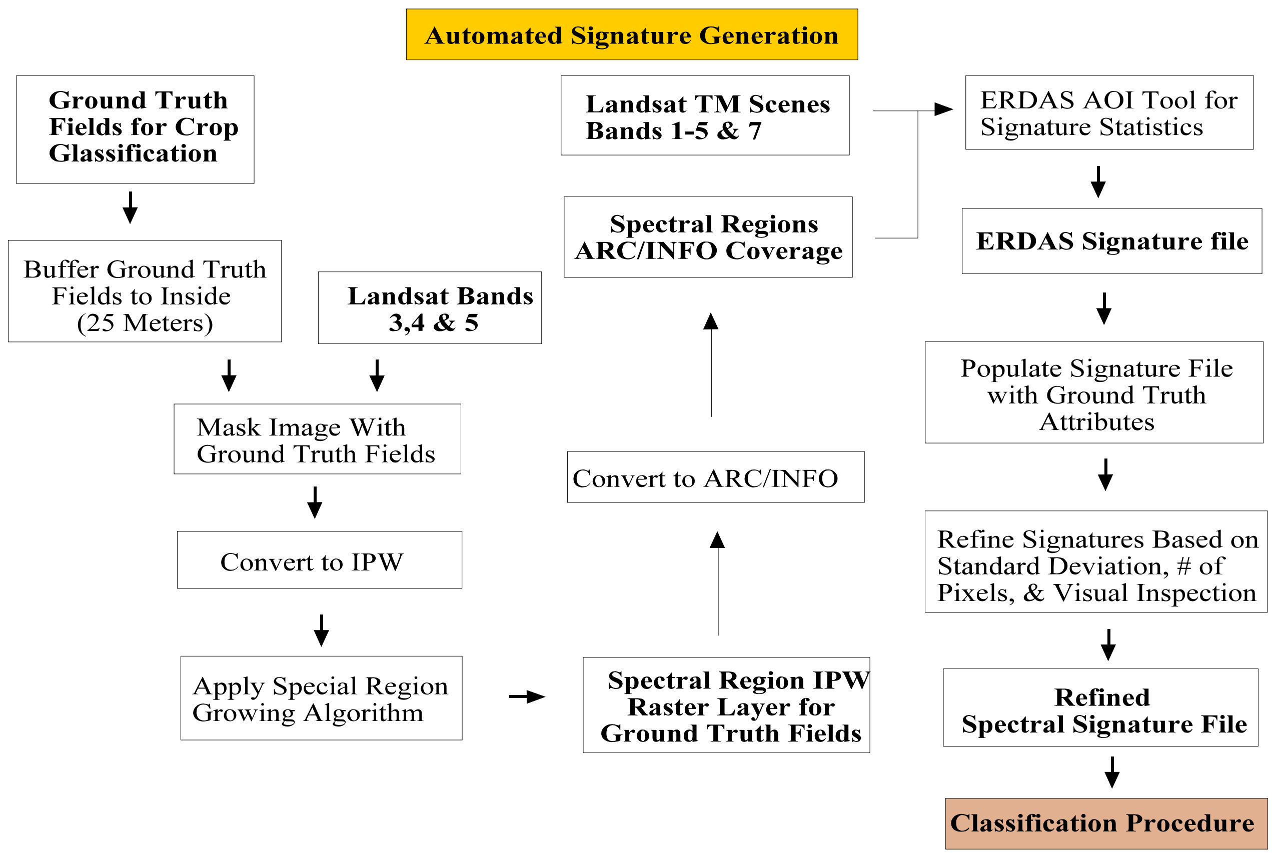


Figure Att-4.3 — Automated Signature Generation.

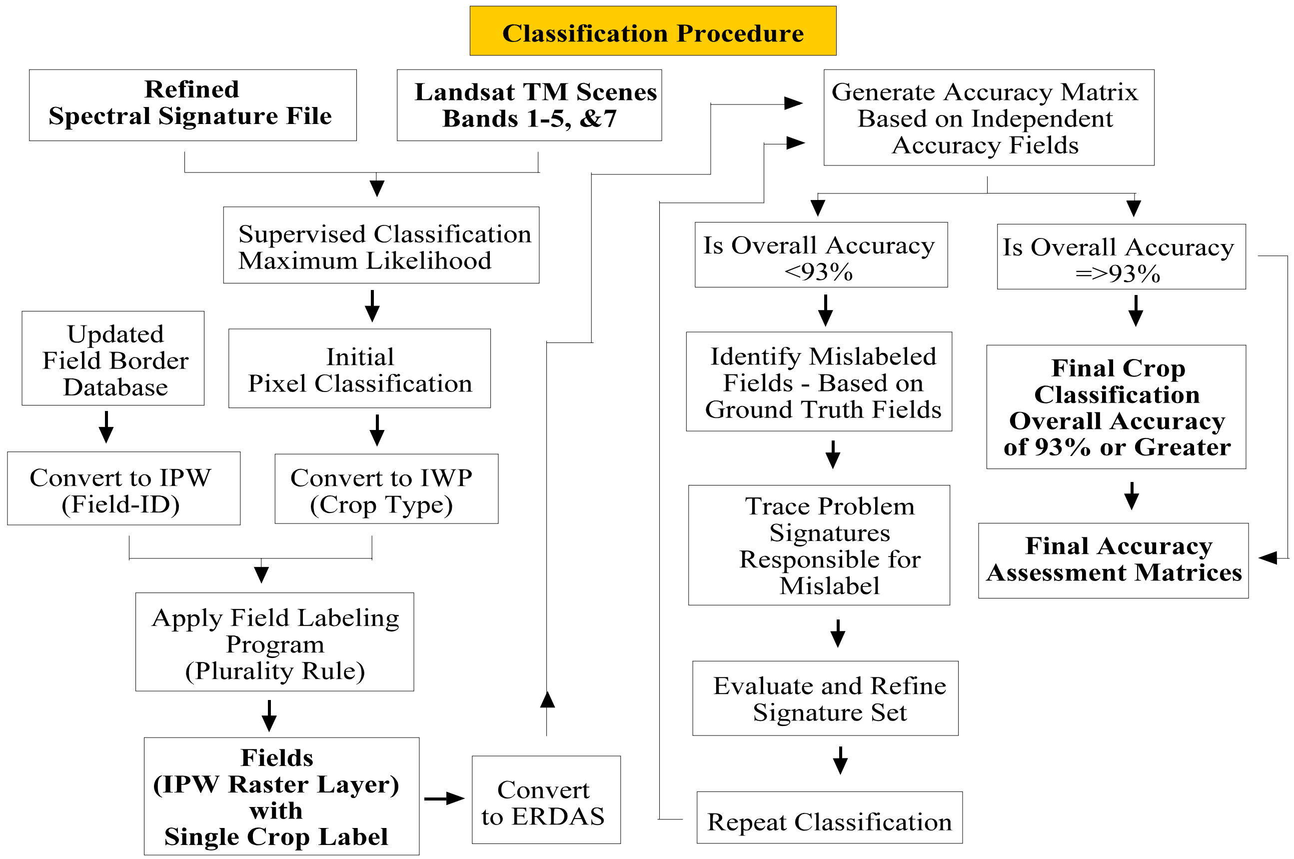


Figure Att-4.4 — Classification Procedure.

BIBLIOGRAPHY

Campbell, J. 1987. Introduction to Remote Sensing, The Guilford Press, NY, 551p.

ERDAS, Inc. 1995. ERDAS Field Guide, Third Ed., ERDAS Inc., Atlanta, GA.

ESRI, Inc. 1994. Understanding GIS: The ARC/INFO Method, Environmental Systems Research Institute, Redlands, CA.

Frew, J.E. Jr. 1990. Image Processing Workbench. Ph.D. Dissertation, University of California, Santa Barbara, Geography Dept. 305 pp.

Gopal, S. and C.E. Woodcock, 1994. Theory and Methods for Accuracy Assessment of Thematic Maps using Fuzzy Sets. Photogrammetric Engineering and Remote Sensing, Vol. 60, No. 2, pp. 181-188.

Ryherd, S.L., and C.E. Woodcock, 1990. The Use of Texture in Image Segmentation for the Definition of Forest Stand Boundaries. Proceedings: 23rd International Symposium on Remote Sensing of Environment. Bangkok, Thailand. April 1990. pp. 18-25.

Schott, J.B., C. Salvaggio, and W.J. Volchok, 1988. Radiometric Scene Normalization using Pseudo invariant Features, Remote Sensing of Environment, 26: 1-16.

Story, M. and R. Congalton, 1986. Accuracy Assessment: A User's Perspective. Photogrammetric Engineering and Remote Sensing. Vol. 52, No.3, pp.397-399.

Woodcock, C.E., and J. Harward, 1992. Nested-Hierarchical Scene Model and Image Segmentation. International Journal of Remote Sensing. 13(16):3167-3187.