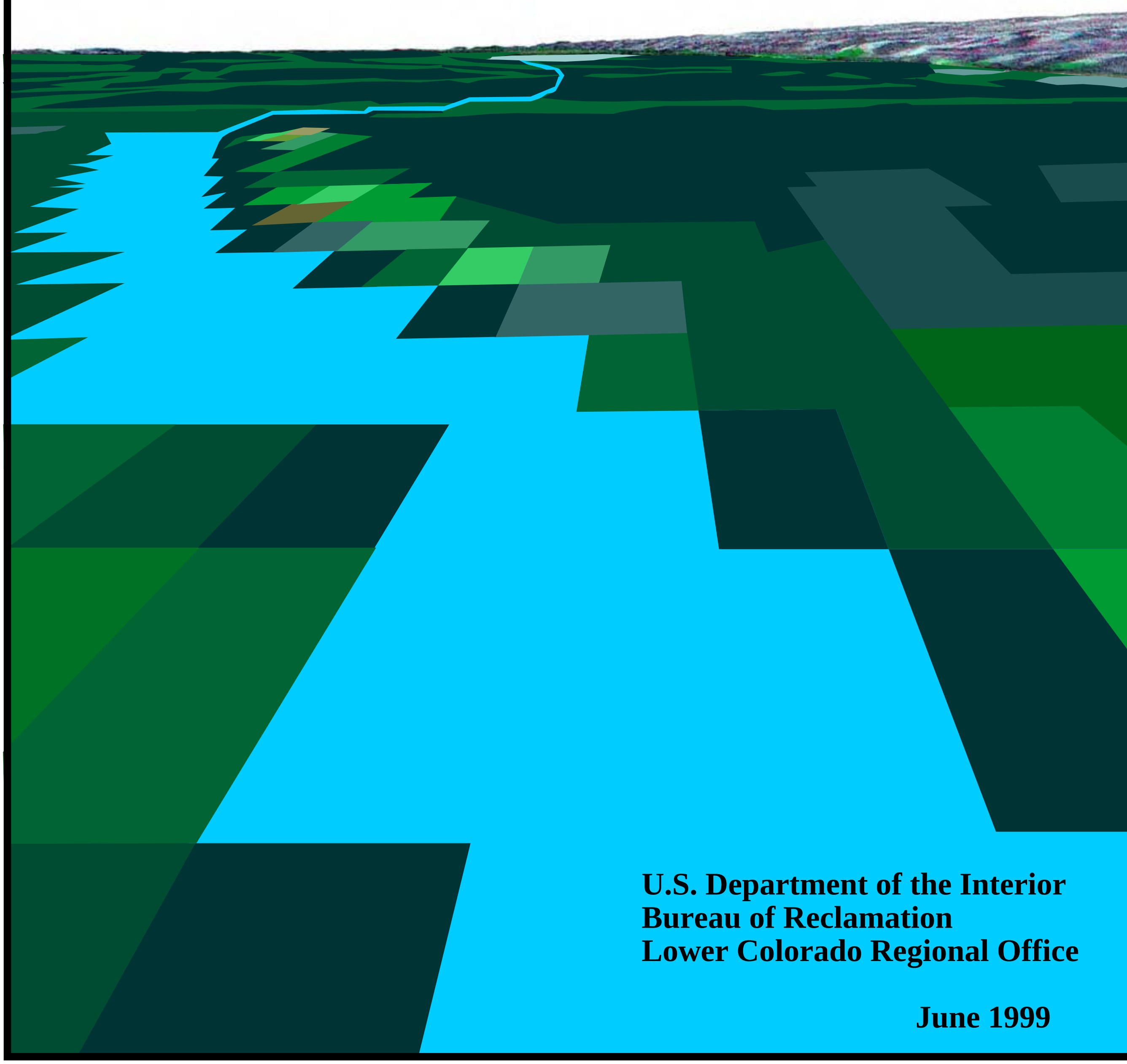
Lower Colorado River Accounting System *Demonstration of Technology*

Calendar Year 1997



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

June 1999

June 29, 1999

Lower Colorado River Accounting System Demonstration of Technology Calendar Year 1997

ERRATA

Table ES-2, Page v, references to 1996 Decree Accounting Report should reference 1997 Decree Accounting Report.

Exhibit 1, “A. Hover Dam to Davis Dam Reach” should read, “Hoover Dam to Davis Dam Reach”; “G. Imperial Dam to Morelos Dam Reach” should read, “Imperial Dam to Mexico Reach.”

Exhibit 2, Title, “LOWER COLORADO RIVER ACCOUNTING SYSTEM HOVER DAM TO DAVIS DAM REACH”, should read, “LOWER COLORADO RIVER ACCOUNTING SYSTEM HOOVER DAM TO DAVIS DAM REACH.”

Exhibit 8, Title, “LOWER COLORADO RIVER ACCOUNTING SYSTEM IMPERIAL DAM TO MORELOS DAM REACH”, should read, “LOWER COLORADO RIVER ACCOUNTING SYSTEM IMPERIAL DAM TO MEXICO REACH.”

Attachment 4, Results in Tabular Form, Page Att-26, footnote reference number 46 for the Wellton-Mohawk Irrigation and Drainage District should be footnote reference number 45.

For further information contact

Jeffrey Addiego
Code BCOO-4631
Us Bureau of Reclamation
Lower Colorado Region
Boulder Canyon Operations Office
PO Box 61470,
Boulder City, NV 89006-1470
TEL (702) 293-8525
jaddiego@lc.usbr.gov

Lower Colorado River Accounting System Demonstration of Technology Calendar Year 1997

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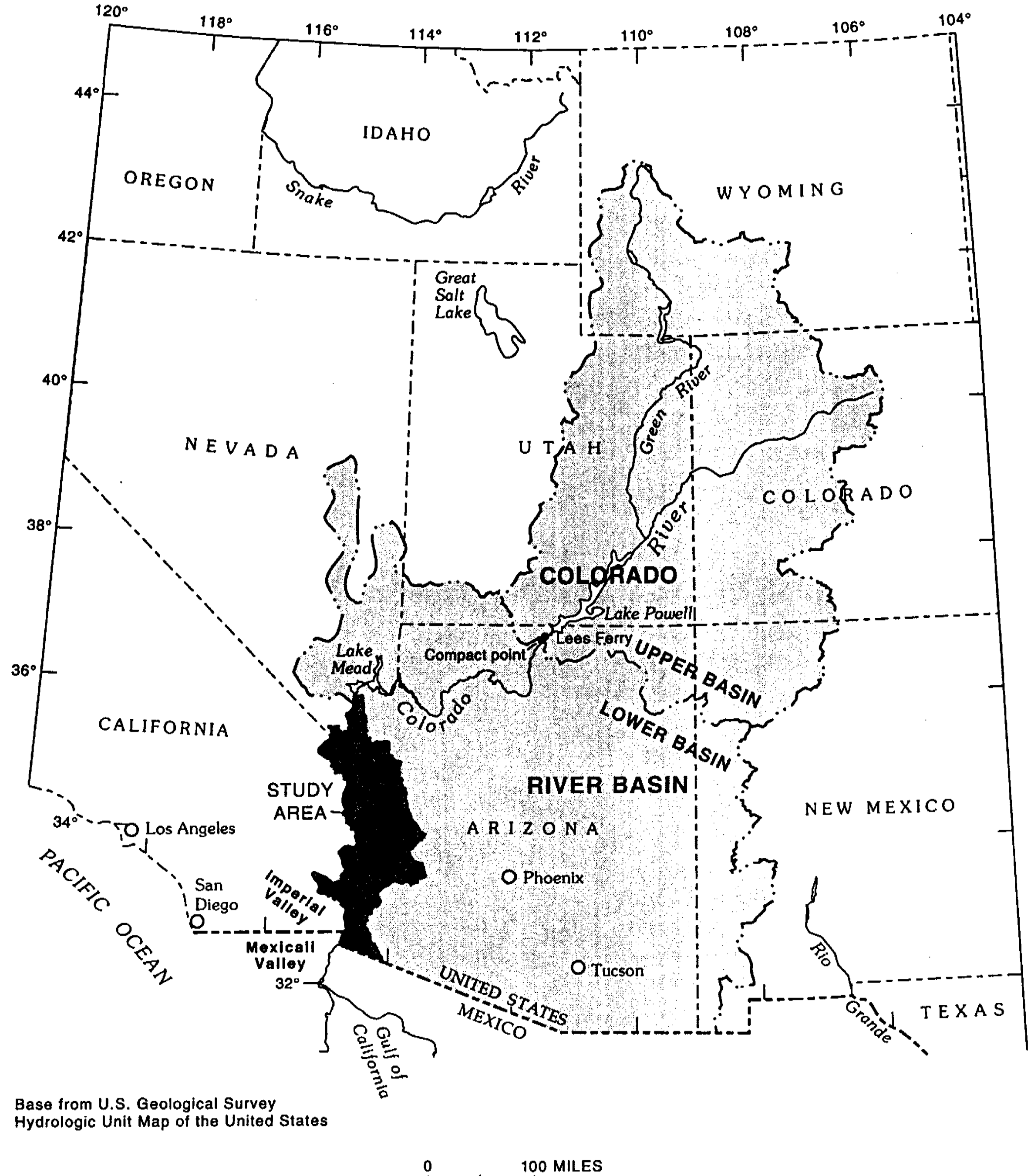

Base from U.S. Geological Survey
Hydrologic Unit Map of the United States

COLORADO RIVER BASIN AND STUDY AREA

Executive Summary

The Colorado River is the principal source of water for agricultural, domestic, municipal, industrial, recreational, and hydroelectric purposes 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) provides 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 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.

The Bureau of Reclamation (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 Bureau of Indian Affairs to develop a method for estimating and distributing agricultural consumptive use to agricultural[1] water diverters between Hoover Dam and Mexico. This effort was in response to the Lower Basin States' request 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 finished its development of LCRAS in the late 1980s, but a final report was not published until 1995. In 1990, Reclamation assumed responsibility for continuing development of LCRAS. Reclamation has modified LCRAS and issued reports in 1997 and 1998 entitled "Lower Colorado River Accounting System Demonstration of Technology " for calendar years 1995 and 1996 (1995 or 1996 LCRAS Report), which document Reclamation's previous applications of LCRAS. This report documents the application of LCRAS to calendar year 1997 and the changes made to the LCRAS method made since the 1996 LCRAS Report was issued.

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[1] Agricultural consumptive use includes consumptive use by irrigation districts, wildlife refuges, and other reservations of land (5 acres or more). All other consumptive uses are domestic consumptive uses.

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 equation in which all the inflows, outflows, and water uses are calculated or estimated. The residual of this water balance (residual) reflects errors of estimate in all inflows, outflows, and water uses. The residual is distributed to all 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 1998).

Consumptive use by vegetation is equal to the evapotranspiration (ET) plus a proportion of the residual. The residual can be either a positive or a negative number, therefore the consumptive use by vegetation can be either slightly larger or smaller than the ET, and the consumptive use of domestic users can be slightly larger or smaller than initially estimated for the water budget.

ET is estimated using (1) reference values for short grass (ET_0) provided by the California Irrigation Management Information System and Arizona Meteorological Network stations located in agricultural 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).

Domestic uses are initially estimated by subtracting a measured return flow from a measured diversion, or if a measured return flow is unavailable by applying a consumptive use factor to a measured diversion (usually 0.6), or if a measured diversion and a measured return flow are unavailable by applying a per-capita consumptive use factor to a population (usually 0.14 acre-feet per year per capita if turf irrigation is not significant). In a few cases, domestic uses are initially estimated by a method submitted by a domestic user. The derivation of the domestic use coefficients mentioned above can be found in attachment 3 of the 1996 LCRAS report.

Results

LCRAS calculates both agricultural and phreatophyte consumptive use for each agricultural diverter and wildlife refuge, and domestic consumptive use for each domestic diverter along the mainstream of the lower Colorado River. The amount, if any, of the phreatophyte consumptive 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 show excellent results using Landsat V image data to discriminate crop classes. Reliable results were 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 per year) in 1997.

Discrimination between phreatophytes, while not as well defined as crops, was successful. Phreatophytes were grouped into several classes. The phreatophyte communities database was updated in 1997 using remote-sensing-based change detection methodologies and the 1996 phreatophyte database. Post-classification accuracy assessment is not yet complete for this data set.

Image classification processes were also used to quantify open water surface areas. Open water surface areas for reservoirs derived from image classification processes were compared with the equivalent values derived from published elevation/capacity/area tables in 1995. This comparison showed the open water surface areas derived from the two methods to be within 3 percent of each other. This comparison was not repeated for 1997.

Water Balance Results

The water balance closure was evaluated for each reach by comparing the value of the residual to the presumed measurement error of the upstream inflow to the reach. A second measure of water balance closure used in 1997 is the magnitude of the final adjustments to the flows at the major dams and the flow to Mexico which define the upstream and downstream flows for 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 upstream inflow to the reach. The residual was distributed in all reaches for 1997 to present the effect of the distribution, even though the residual was less than the presumed measurement error of the upstream gauge in all of the reaches.

The presumed standard errors of estimate for the upstream inflows to each reach is 1.4 percent for Hoover Dam, 2.2 percent for Davis and Parker Dams, and 1.5 percent for 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)
(Unit: acre-feet per year unless otherwise noted)

Water balance inflows, outflows, and water uses	Reach				
	Hoover Dam to Davis Dam	Davis Dam to Parker Dam	Parker Dam to Imperial Dam	Imperial Dam to Mexico	Hoover Dam to Mexico
Flow at the upstream boundary (Q_{us})	11,669,100	11,527,400	8,471,000	7,389,156	11,669,100
Flow at the downstream boundary (Q_{ds})	11,527,400	8,471,000	7,389,156	2,954,455	2,954,455
Residual	-94,144	-6,429	-43,780	98,706	-45,647
Residual as a percentage of the flow entering the reach (Q_{us})	-0.81%	-0.06%	-0.52%	1.34%	-0.39%
Difference between upstream and downstream flow (Q_{dif})	141,700	3,056,400	1,081,844	4,434,701	8,714,645
Measured Tributary inflow (Trm)	0	9,156	0	16,830	25,986
Unmeasured Tributary inflow (Trum)	6,480	36,290	33,750	3,000	79,520
Exported flow (Q_{ex})	0	2,652,590	0	3,881,560	6,534,150
Evaporation (E)	126,101	120,004	53,313	4,718	304,136
Domestic consumptive use [2] (CU_d)	421	37,750	5,580	27,872	71,623
Crop evapotranspiration (ET_{crop})	0	71,928	752,782	373,208	1,197,918
Phreatophyte evapotranspiration (ET_{pht})	902	182,803	352,502	68,467	604,674
Change in reservoir storage ()S_r)	114,900	43,200	-4,803	0	153,297
Change in aquifer storage ()S_a)	0	0	0	0	0

[2] Domestic consumptive use includes all non-agricultural consumptive uses that are not exports.

Consumptive Use Results

Table ES-2 compares the crop, phreatophyte, and domestic consumptive use calculated by LCRAS to consumptive use as reported in the Decree Accounting Report as State totals.

Table ES-2.— Consumptive use
(unit: acre-feet per year)

LCRAS			**Decree Accounting**	
Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
Nevada				
Uses above Hoover Dam (from 1997 Decree Accounting Report)		224,458	224,458	Uses above Hoover Dam
Uses below Hoover Dam	21,526	17,192	18,321	Uses below Hoover Dam
			732	Unmeasured return flow credit
Nevada Total	21,526	241,650	242,047	Nevada Total
California				
			5,250,122	Sum of individual diverters
			88,227	Unmeasured return flow credit
California Total	196,301	5,233,027	5,161,895	California Total
Arizona				
Subtotal (below Hoover Dam, less Wellton-Mohawk IDD)	386,615	2,272,326	2,608,883	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (1997 Decree Accounting Report)		183	183	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (1997 Decree Accounting Report)		312,514	312,514	Wellton-Mohawk IDD
			67,679	Pumped from South Gila wells (drainage pump outlet channels [DPOCs]): returns
			156,912	Unmeasured return flow credit
Arizona Total	386,615	2,585,023	2,696,989	Arizona Total
Lower Basin Total				
Total Lower Basin Use	604,442	8,059,700	8,100,931	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, which form the upstream and downstream boundaries of the reaches, have been adjusted as described in Lane 1998.

Table ES-3.— Final distributed and adjusted water balance values
(units: acre-feet per year)

Water balance inflows, outflows, and water uses	Reach				
	Hoover Dam to Davis Dam	Davis Dam to Parker Dam	Parker Dam to Imperial Dam	Imperial Dam to Mexico	Hoover Dam to Mexico
Flow at the upstream boundary (Q_{us})	11,751,401	11,515,606	8,452,969	7,328,991	11,751,401
Flow at the downstream boundary (Q_{ds})	11,515,606	8,452,969	7,328,991	2,962,138	2,962,138
Residual	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	235,795	3,062,637	1,123,978	4,366,853	8,789,263
Measured Tributary inflow (Trm)	0	9,156	0	16,823	25,979
Unmeasured Tributary inflow (Trum)	6,484	36,297	33,842	2,996	79,619
Exported flow (Q_{ex})	0	2,652,413	0	3,910,666	6,563,079
Evaporation (E)	126,060	120,002	53,307	4,718	304,087
Domestic consumptive use (CU_d)	421	37,750	5,580	27,874	71,625
Crop consumptive use (CU_{crop})	0	71,927	751,512	374,890	1,198,329
Phreatophyte consumptive use (CU_{pht})	902	182,798	352,224	68,524	604,448
Change in reservoir storage (ΔS_r)	114,896	43,200	-4,803	0	153,293
Change in aquifer storage (ΔS_a)	0	0	0	0	0

Continued Development of LCRAS

LCRAS used the best and most complete data sources and analytic techniques available to produce the results presented in this report; however, improvements are possible, and some questions remain outstanding.

Specific areas identified for continued development include remote sensing, image processing, and geographic information system analysis tools; open water surface evaporation and precipitation estimates; and the appropriate assessment of phreatophyte use, if any, to diverters.

Conclusions

Reclamation is directed to manage the limited resources of the lower Colorado River in a manner that is fair for all diverters. To achieve this goal, Reclamation has taken the lead in the development of LCRAS, a water accounting method that meets the following criteria:

- Uses the best technology available
- Fulfills the Supreme Court Decree mandate to account for the consumptive use of water
- Provides consistent methods of determining consumptive use for all diverters in the lower Colorado River basin

The goal of the LCRAS program is to improve consumptive use calculations for Decree Accounting using state-of-the-art technologies. Reclamation will continue the process of refining each element of LCRAS as technology develops and our understanding of the hydrologic system improves.

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 year 1998 and the next several years and 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 to agricultural and 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. 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 would be created at least annually (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. The Lower Basin States asked the Bureau of Reclamation (Reclamation), in 1969, 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 the 1995 LCRAS report.

This report 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 1997.

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 equation in which all the inflows, outflows, and water uses are calculated or estimated. The residual of this water balance reflects errors of estimate in all inflows, outflows, and water uses. The residual, which can be either a positive or negative number, is distributed to all inflows, outflows, and water uses in the water balance in proportion to the product of their magnitude and an estimate of their error.

Consumptive use by vegetation is equal to the evapotranspiration (ET) plus a proportion of the residual. The consumptive use by vegetation can be slightly larger or smaller than the ET, and the consumptive use of domestic users can be slightly larger or smaller than initially estimated for the water balance.

Evapotranspiration is estimated using (1) reference values for short grass (ET_0) provided by the California Irrigation Management Information System (CIMIS) and the Arizona Meteorological Network (AZMET) stations located in agricultural areas along the Colorado River, (2) vegetation-class-specific ET coefficients, and (3) the acreage of each crop and phreatophyte class that appeared along the lower Colorado River developed from the classification of remotely sensed data (image classification).

Domestic uses are initially estimated by subtracting a measured return flow from a measured diversion, or if a measured return flow is unavailable by applying a consumptive use factor to a measured diversion (usually 0.6), or if a measured diversion and a measured return flow are unavailable by applying a per-capita consumptive use factor to a population (usually 0.14 acre-feet per year per capita if turf irrigation is not significant). In a few cases, domestic uses are initially estimated by a method submitted by a domestic user[3].

[3] A more detailed explanation of consumptive use coefficients for domestic users can be found in Attachment 3 of the report, “Lower Colorado River Accounting System Demonstration of Technology Calendar Year 1996.”

Water Balance

The water balance used by LCRAS performs a summation of all identified inflows, outflows, and water uses of the four specified reaches of the lower Colorado River. The result of this summation is called a residual, and it represents the impreciseness of measurement or estimation in some or all of the inflow, outflow, and water use values. In an ideal world, when all inflows, outflows, and water uses of a stream have been summed, the residual is zero. In the real world, the residual of a water balance is seldom, if ever, zero.

To determine a final value of crop, phreatophyte, and domestic consumptive use, the residual of the water balance is distributed (added or subtracted) to the original estimates for all inflows, outflows, and water uses in proportion to the product of their magnitude and variance (the square of the standard error of the estimate, or SEE).

Comparison of LCRAS with Decree Accounting Reports

The table in attachment 4, 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 previous LCRAS reports.

Chapter 2

LCRAS in Calendar Year 1997

Reclamation's activities for the 1997 LCRAS Demonstration of Technology began at the first of the year with scheduled ground reference data collection to record crop and field conditions. Reclamation processed satellite imagery using standard image classification procedures (incorporating recent improvements) developed in previous years. Reclamation also finalized the district boundaries that would be used in 1997, after consultation with several irrigation districts to confirm and update the district boundaries that were used in 1996.

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 1997. For 1997, 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 (the averaging technique used to develop the average ET_0 values will be discussed in more detail later in this report). Reclamation compiled domestic uses and change in reservoir storage values during 1997 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.

As calendar year 1997 came to a close, analysis of all the data for the year began. From image classification and GIS processes, the acreage of each crop class grown, acreage in the flood plain of each phreatophyte class, and the number of acres of open water exposed to evaporation by reservoirs and the river channel between Hoover Dam and Mexico were produced. This information, combined with the final diverter boundaries for 1997, allowed Reclamation to calculate the number of acres occupied by each crop and phreatophyte class for each agricultural diverter, 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 agricultural diverter, wildlife refuge, or other reservation of land, and calculated the evaporation from open water areas required for water balance calculations.

Reclamation finalized the form of the water balance that would be used in 1997, then calculated and proportionally distributed the residual to each water balance inflow, outflow, and water use producing values of crop, phreatophyte, and domestic consumptive use.

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 1997.

Remote Sensing and Geographic Information Systems

Remote sensing and GIS processes were used to identify and map the vegetation class (crop and phreatophyte) and open water areas along the lower Colorado River. All satellite data and GIS coverages are projected into UTM Zone 11, datum NAD 27.

The flood plain boundary (shown in exhibits 2 through 8) used in 1997 is the same as the flood plain boundary used in 1996. The flood plain boundary was 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 were 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 the type and aerial extent of crop classes, a fallow class, phreatophyte communities, and open water surfaces along the lower Colorado River.

GIS data base management tools were 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 data base management tools were used to calculate, summarize, and generate reports defining the aerial extent of each crop class and phreatophyte community for each diverter and the open water areas along the lower Colorado River.

Satellite Image Processing

Multispectral analysis was performed on image data to classify and map vegetation and open water areas along the mainstream of the lower Colorado River for calendar year 1997. Vegetation and open water classification processes have been developed for image data acquired by the Thematic Mapper (TM) sensor onboard the Landsat V satellite. This sensor detects and records reflected radiance (light) from the

Earth's surface in seven bands of 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 being used for image analysis is resampled to 25 meters. TM image data were acquired for analysis in the World Reference System[4] locations and on the dates shown below during calendar year 1997:

Path 38, rows 36 and 37	March 07, 1997	Path 39, row 35	February 28, 1997
Path 38, rows 36 and 37	May 12, 1997	Path 39, row 35	May 03, 1997
Path 38, rows 36 and 37	August 16, 1997	Path 39, row 35	August 23, 1997
Path 38, rows 36 and 37	January 07, 1998	Path 39, row 35	January 14, 1997

These image data were selected as they adequately covered the study area, were cloud free, and captured the variation in crop planting practices during the year.

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 agricultural practices of representative sites 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 were collected for approximately 1,900 of the 12,800 agricultural fields in the study area. This represents about 15 percent of the total agricultural area. From 65 to 70 percent of the ground reference data were used in image classification, and the remaining 30 to 35 percent were used to assess the accuracy of the identification and mapping of crop and phreatophyte classes. Selection of

[4] Landsat V 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.

ground reference sites was based on the vegetation distribution in each major agricultural area along the mainstream of the lower Colorado River. Agricultural fields were selected randomly from a data base of the agricultural fields and their borders. In 1997, ground reference data were collected and satellite imagery was purchased four times. Ground reference data is collected at times which coincide with the acquisition of the satellite imagery. Variability in planting and harvesting times for each crop is critical in the selection of data collection dates during the year.

Table 1 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 1 — Crop classes

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

The phreatophytes were divided into the classes shown in table 2.

Table 2 — 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 and Phreatophyte Areas, and Open Water Surface

A detailed description of the image processing and GIS processes used for this report can be found in attachment 5.

Delineation of Crop Areas

A relational database (GIS coverage) has been developed that delineates the field borders in all agricultural 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 on-screen digitized 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 1997. Reclamation has initiated a comprehensive field border update using 5-meter Indian Remote Sensing satellite data. This data was acquired in October 1997. The updated field borders will be used to develop the 1998 LCRAS Demonstration of Technology Report. Field borders will continue to be routinely updated using information gathered during ground reference data collection over the course of the year. In addition, new imagery will be used for annual field border updates when necessary.

All areas along the mainstream of the lower Colorado River that are known by Reclamation to divert or pump water were included in this analysis and shown on exhibits 2 through 8. Exhibit 1 is an index for exhibits 2 through 8, exhibit 9 is an example of digitized field borders, and exhibit 10 shows an overview of the diverter boundaries.

Excellent results were obtained for crop classes listed in table 1, using a single-date image classification process. 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 were updated for 1997 by delineating areas of spectral change using image to image comparisons (change detection methods) from May 1996 and May 1997 Landsat TM imagery. Areas of spectral change were then field checked to confirm that the spectral change was actually due to land-cover change. Areas of land-cover change were re-mapped and used to update the 1997 phreatophyte database.

Delineation of Open Water Surface

A separate class for open water was developed, and image classification processes were used to quantify open water surface areas. A single-image classification process was performed on the Landsat V image acquired August 13, 1996, for this purpose. In 1995, open water surface areas for reservoirs derived from image classification processes were compared with the equivalent values derived from published elevation/capacity/area tables. This comparison showed the open water surface areas derived from the two methods to be within 3 percent of each other. This comparison was not repeated for 1997.

Water Balance Equation

The water balance equation used for 1997 is the same as that used for 1996. This 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 at the upstream boundary of the reach
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 surface evaporation
CU_d	=	Domestic, municipal, and industrial use

ET_{pht} = The total estimated phreatophyte ET
ET_{crop} = The total estimated crop ET
ΔS_r = The change in reservoir storage
ΔS_a = The change in storage in the alluvial aquifer

This equation was 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.[5]

The data used in this LCRAS Demonstration of Technology report are the most accurate and complete data that were available when the calculations were performed. Data were gathered from Reclamation records and reports, and reports provided to Reclamation by other sources. The following sections of this report discuss the sources of data, calculations made with the data, and significant 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 were provided by the Geological Survey, Reclamation, the International Boundary and Water Commission (IBWC), Metropolitan Water District of Southern California (MWD), and the Central Arizona Project (CAP).

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

The majority of mainstream flows used by LCRAS are reported by the Geological Survey[6]. Some mainstream flows are provided by the diverter and and some by the IBWC. A listing of the gages used by LCRAS and the reporting agency can be found in attachment 2.

[5] 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.

[6] 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 1997.*

Export Flow (Q_{ex})

Flows into the California Aqueduct and the CAP were reported by MWD and Central Arizona Water Conservation District, respectively, from their own measurements. The initial estimate of net export by MWD was 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 Report.

The initial estimate of export by the CAP was the measured diversion from Lake Havasu.

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

About 6,700 acre-feet of the water pumped by the Drainage Pump Outlet Channels near Yuma, Arizona, was discharged into the Main Outlet Drain or Main Outlet Drain Extension in 1997. This water was bypassed to the Santa Clara Slough and not returned to the Colorado River. This water was considered exported from the Colorado River system for water balance purposes.

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 3 below. The presumed standard error of estimate for export flows is 2 percent.

Table 3 — Changes in export values after residual distribution

Export	**Initial Estimate**	**Final Estimate**	**Change in Percent**
MWD	1,238,660	1,238,577	-0.01
CAP	1,413,930	1,413,836	-0.01
Wellton-Mohawk	382,909	385,780	0.75
IID & Coachella	3,492,000	3,518,185	0.75

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.

The flow measured below Alamo Dam does not reach 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[7] from the sum of the flow below Alamo Dam and estimates of unmeasured inflow to the Bill Williams River.

The boundary of Lake Havasu is defined by the extent of the accounting surface (Wilson and Owen-Joyce, 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 connected and 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 25,986 acre-feet in 1997, or about 0.22 percent of the flow below Hoover Dam. After the residual from the water balance was distributed, the final value of measured tributary inflow decreased to 25,979 acre-feet, a change of about 0.03 percent. Measured tributary inflow values can be found in attachment 2.

[7] 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.

Unmeasured Tributary Inflow Data (T_{rum})

Unmeasured tributary inflow values were taken directly from Owen-Joyce (1987). The flow values presented in that Geological Survey report are primarily a compilation of existing studies based upon mean annual precipitation that were available at the time of publication.

The sum of the unmeasured tributary inflows reported in Owen-Joyce (1987) is 88,320 acre-feet,[8] or less than 1 percent of the flow below Hoover Dam.

The Arizona Department of Water Resources (ADWR) provided Reclamation with the results and background of their recent investigation into the unmeasured groundwater inflow from Sacramento Wash into the lower Colorado River valley. ADWR's conclusion is that the unmeasured groundwater inflow from Sacramento Wash is about 1,200 acre-feet annually, far less than the 10,000 acre-feet reported in Owen-Joyce (1987). Reclamation has accepted ADWR's results and incorporated them into LCRAS for 1997.

The sum of the unmeasured tributary flows, using ADWR's estimate of the inflow from Sacramento Wash, is 79,520 acre-feet.

After the residual from the water balance was distributed, the final value of unmeasured tributary inflow increased to 79,619 acre-feet, a change of about 0.12 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 the consumptive use of water for each agricultural diverter. Evapotranspiration calculations require the following:

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[8] Includes only unmeasured tributary inflows to the Colorado River. Not included are unmeasured tributary inflow estimates for the Bill Williams River between Alamo Dam and Lake Havasu presented in Owen-Joyce and Raymond (1996).

- Daily ET_0
- Daily crop and phreatophyte class ET coefficients
- Number of acres covered by each crop and phreatophyte class

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. LCRAS used a weighted average of the daily ET_0 values for 1997. 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 1997 for each vegetation class are the same as those used in 1996[9]. Reclamation developed the acreage covered in 1997 by each vegetation class by applying the analysis described in "Delineation of Crop and Phreatophyte Areas, and Open Water Surface," above.

Weighted Average ET_0 Values

In March 1998 Reclamation staff noted that the annual summation of daily ET_0 values reported by the AZMET stations differed by as much as 17 inches from that of the two CIMIS stations during a 3-year period (1995 - 1997). The variation in the annual summation of daily ET_0 values reported by the AZMET stations themselves is as much as 12 inches during this same period.

Table 4 lists the annual summation of daily ET_0 values (inches) for the stations along the lower Colorado River.

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

Table 4 — Annual Summation of Daily ET_0 Values

Year	Fort Mohave	Parker	Blythe NE	PVID	North Gila	Yuma Valley	Yuma Mesa
1997	85.07	91.15	69.76	67.00	82.31	88.78	83.19
1996	86.84	93.40	NA	72.10	87.31	92.11	83.28
1995	76.72	89.10	NA	71.63	82.99	89.57	78.98

Consultation with Dr. Paul Brown of the University of Arizona (AZMET), Dr. Simon Eching of the California Department of Water Resources (CIMIS), and Dr. Marvin Jensen 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 are acknowledged to 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. The variation in the ET_0 values shown in table 4 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, to identify the effect siting has on the variation of reported ET_0 values. This study is targeted for completion in August of 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 effect on the reported ET_0 values from the different methods used to calculate net solar radiation used by the AZMET and CIMIS networks. 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[10]. The equations used by the CIMIS and AZMET networks to calculate net radiation have been

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

found to differ in the methods 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 for AZMET stations when compared to the CIMIS stations.

LCRAS uses a single set of vegetation ET coefficients along the lower Colorado River, which leads to the conclusion that consistent ET_0 values are required from the CIMIS and AZMET networks. Until the planned use of equivalent methods of calculating the net solar radiation component of ET_0 are implemented, or identical ET_0 equations are adopted, the use of an average ET_0 value was suggested by representatives of the CIMIS and AZMET networks and Reclamation's consultant for evapotranspiration calculations at the LCRAS public meeting in Henderson, Nevada, in October 1998.

Reclamation applied a weighted average method to daily ET_0 values reported by the CIMIS and AZMET networks for 1997. Average daily ET_0 values were 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 resulted in a single set of average daily ET_0 values that were applied over the entire study area. The ET_0 values reported by each automated weather station and accompanying precipitation values, and the average ET_0 used in this report are shown on figure 1.

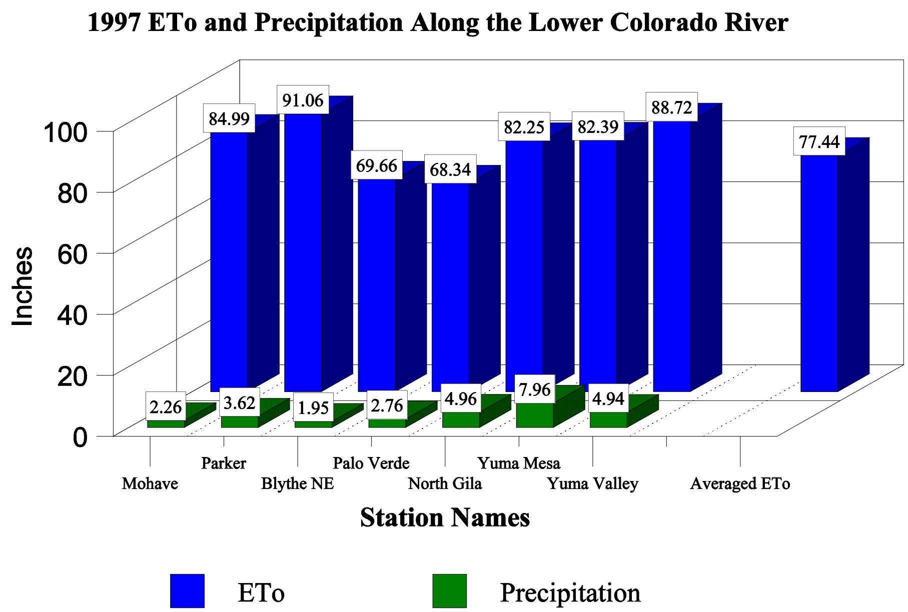


Figure 1. — ET_0 and Precipitation Values from AZMET and CIMIS Stations and the Average ET_0 used in this report.

Crops (ET_{crop})

The first step in calculating the water use by crops within a diverter's boundary was to calculate an ET rate for each crop class. Average daily ET_0 values (inches) were multiplied by daily crop coefficients (dimensionless), unique to each crop class, to arrive at the daily ET rate for each crop class. The impact of rainfall on crop water use was considered by subtracting effective precipitation (inches) from the ET rate for each crop class.

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 LCRAS Demonstration of Technology are documented in

Jensen (1993).

The equation used to calculate effective precipitation is:

Effective Precipitation = Precipitation × Effective Precipitation Coefficient

The depth of precipitation that fell over the lower Colorado River Valley in 1997 ranged from 7.96 inches, measured at the Yuma Mesa AZMET station, to 1.95 inches measured at the Blythe NE CIMIS station. The unweighted precipitation average recorded across the lower Colorado River valley for 1997 was 4.15 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 was done using remotely sensed data. Satellite images were used to separately identify each crop class. GIS coverages were used to identify the diverter boundaries within which the crops fall and to quantify the area covered by each crop class within a diverter's boundary. There are 15 crop classes, some with numerous subclasses, for which this calculation was performed. These crop classes were listed in table 1 in the "Ground-Reference Data Collection" section.

Monthly ET for each diverter, in acre-feet, was calculated by summing the daily ET rate (corrected for effective precipitation and converted to feet) for each month and multiplying by the area (acres) covered by each crop class within each diverter boundary.

Monthly ET for each diverter was summed for the year to yield the annual ET for each diverter.

An example equation using cotton is shown below:

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

Where:

ET_{cotton} = The total monthly or annual ET by cotton for the diverter in question

Σ_n = Summation for $_n$ time, either monthly or annually

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

K_{cotton} = Daily crop coefficient (Jensen, 1997) specific to cotton

AC_{cotton} = Acreage of cotton for the diverter in question

Effective PPT = Effective precipitation, the amount of rainfall “effective” in reducing crop demand for Colorado River water

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

The sum of the ET_{crop} compiled for calendar year 1997 was 1,197,918 acre-feet. After the residual from the water balance was distributed, the final calculation of crop consumptive use increased to 1,198,329 acre-feet, a change of about 0.03 percent. Crop consumptive use accounts for about 15 percent of the total lower Colorado River basin consumptive use (crop, domestic, and export).

Phreatophytes (ET_{pht})

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

Using the same process applied to crop evapotranspiration, the summation of ET from all phreatophyte classes within a diverter’s boundaries yields the total phreatophyte ET for a diverter.

The total phreatophyte ET for all diverters within a reach were summed to give the phreatophyte outflow ET_{pht} for the water balance equation.

Phreatophytes were grouped into the 14 classes listed in table 2 in the section "Ground Reference Data Collection." Remote sensing processes, including analysis of aerial photography, were used to develop acreage figures for each phreatophyte class used to calculate ET_{pht}.

The sum of the ET_{pht} calculated for calendar year 1997 was 604,674 acre-feet. After the residual from the water balance was distributed, the final calculation of phreatophyte use decreased to 604,448 acre-feet, a change of 0.04 percent. Phreatophyte 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 surfaces of Lakes Mohave and Havasu, Senator Wash, and the open water surfaces of the Colorado River and adjacent backwaters (such as Topock Marsh and Mittry Lake) from Hoover Dam to Mexico. These values were used in the water balance of each reach.

LCRAS calculated monthly open water surface evaporation rate in 1997 as the product of the monthly summation of the average daily AZMET and CIMIS ET_0 values times a monthly evaporation coefficient. Monthly precipitation measured at the appropriate AZMET or CIMIS station was subtracted from the evaporation rate to yield a corrected monthly evaporation rate. The corrected evaporation rate (converted from inches to feet) was multiplied by the open-water surface area (acres) to yield the monthly open-water surface evaporation (acre-feet).

The depth of precipitation that fell over the lower Colorado River valley in 1997 ranged from 7.96 inches, measured at the Yuma Mesa AZMET station, to 1.95 inches, measured at the Blythe NE CIMIS station. The unweighted precipitation average recorded across the valley for 1997 was 4.15 inches.

The open water surface area (acres) for Lakes Mohave and Havasu was derived from area estimates developed by analyzing the August 1997 satellite images (more details are available in the section on remote sensing). This value was used to represent the annual open water surface area for each lake. The same procedure was used to develop the open water surface areas for the river below Hoover Dam to the Southerly International Boundary, backwater areas, and Senator Wash Reservoir.

The sum of the initial estimate of evaporation (below Hoover Dam) calculated for calendar year 1997 was 304,136 acre-feet. After the residual from the water balance was distributed, the final calculation of evaporation decreased to 304,087 acre-feet, a change of 0.02 percent. Evaporation accounts for about 3.5 percent of the combined lower Colorado River basin water use and loss from crops, domestic uses, exports, phreatophytes, and evaporation.

Domestic Use (CU_d)

Domestic use, in this report, means any use of Colorado River water that was not consumptive use by vegetation or an export. Domestic use includes municipal use, industrial use, and individual household use.

Domestic uses are 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 (usually 0.14 acre-feet per year per capita if turf irrigation is not significant).

In a few cases, domestic uses are initially estimated by a method submitted by a domestic user. The derivation of the consumptive use and per-capita consumptive use factors mentioned above can be found in attachment 3 of the 1996 LCRAS report.

The list of domestic diverters was compiled from those listed in Owen-Joyce and Raymond (1997), the Decree Accounting Report (both the main body and the miscellaneous users section), and from those identified as nonagricultural diverters in the Reclamation Water Contracts Data Base, so long as each diverter's existence could be verified and a reliable value for water use was provided. The diversions by MWD and CAP were not included here. These diversions were considered to be exports rather than domestic diverters.

The sum of the initial estimates of domestic use compiled for calendar year 1997 was 71,623 acre-feet. After the residual from the water balance was distributed, the final estimate of total domestic use increased to 71,625 acre-feet, a change of much less than one-tenth of 1 percent. Domestic consumptive use accounts for about 1 percent of the total lower Colorado River basin consumptive use (crop, domestic, and export), and about one-tenth of 1 percent of the combined lower Colorado River basin use and loss from crops, domestic uses, exports, evaporation, and phreatophytes.

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 were no reservoir in a reach, the change in reservoir storage value was zero.

Storage calculations are performed daily by Reclamation on Lakes Mohave and Havasu, and Senator Wash Reservoir using stage versus capacity tables. Reservoir storage values are reported monthly in Reclamation Reservoir Elevations and Contents tables, provided by the Lower Colorado Dams Facilities Office. The annual change in reservoir storage, used for LCRAS, was a summation of the difference between storage calculated on the first day of each month and the first day of the succeeding month.

A table showing the reservoir contents at the beginning and end of each month of the year is included in attachment 3.

Change in Aquifer Storage ())S_a)

A value of zero was used for all reaches of the river for calendar year 1997 (as was done in the 1995 and 1996 LCRAS reports). Currently, no network of wells exists that would give consistent current water-level data throughout the study area. A method for measuring changes in groundwater elevation in the lower Colorado River valley and the infrastructure for performing such measurements will be studied in the future.

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 the perfect mathematical modeling of a system, where all factors were accounted for and all measurements were absolutely accurate, the residual would be zero. In the real world conditions within which LCRAS operates, the residual 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 5.

Table 5 — Water balance summary (unadjusted for residual)
(unit: acre-feet per year)

Water balance inflows, outflows, and water uses	Reach				
	Hoover Dam to Davis Dam	Davis Dam to Parker Dam	Parker Dam to Imperial Dam	Imperial Dam to Mexico	Hoover Dam to Mexico
Flow at the upstream boundary (Q_{us})	11,669,100	11,527,400	8,471,000	7,389,156	11,669,100
Flow at the downstream boundary (Q_{ds})	11,527,400	8,471,000	7,389,156	2,954,455	2,954,455
Residual	-94,144	-6,429	-43,780	98,706	-45,647
Residual as a percentage of the flow entering the reach (Q_{us})	-0.81%	-0.06%	-0.52%	1.34%	-0.39%
Difference between upstream and downstream flow (Q_{dif})	141,700	3,056,400	1,081,844	4,434,701	8,714,645
Measured Tributary inflow (Trm)	0	9,156	0	16,830	25,986
Unmeasured Tributary inflow (Trum)	6,480	36,290	33,750	3,000	79,520
Exported flow (Q_{ex})	0	2,652,590	0	3,881,560	6,534,150
Evaporation (E)	126,101	120,004	53,313	4,718	304,136
Domestic consumptive[1] use (CU_d)	421	37,750	5,580	27,872	71,623
Crop evapotranspiration (ET_{crop})	0	71,928	752,782	373,208	1,197,918
Phreatophyte evapotranspiration (ET_{pht})	902	182,803	352,502	68,467	604,674
Change in reservoir storage (**)** S_r)	114,900	43,200	-4,803	0	153,297
Change in aquifer storage (**)** S_a)	0	0	0	0	0

[1] Domestic consumptive use includes all non-agricultural consumptive uses.

The residuals in 1997 were 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 LCRAS water balance is considered to be the summation of the errors of measurement and approximation associated with each inflow, outflow, and water use. The final value of crop, phreatophyte, domestic consumptive use, and all other water uses is realized when the residual is distributed to each of these terms.

The annual summations of the initial estimates of all water uses are termed undistributed annual values (UAV); once the residual has been distributed, the revised values are termed distributed annual values (DAV). Distributed annual values of ET for vegetation and water use for domestic diverters are the values of consumptive use. The distributed annual values of the initial estimate for exports and other water uses is the final estimate for exports and other uses.

Numerous proposals have been tendered for distributing the residual. The distribution method that appears to have the best statistical validity overall when applied to a wide variety of conditions distributes a portion of the residual based on the magnitude and accuracy of each inflow, outflow, and water use. For 1997, the residual was distributed based upon the presumed variance (in acre-feet squared) of each inflow, outflow, and water use as described in Lane 1998. The residual was 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 water balance closure were evaluated for each reach by comparing the value of the residual to the estimated measurement error of the upstream inflow to the reach. Distributing the residual is considered optional if it was about equal to or less than the estimated measurement error of the flow entering the reach. The residual was distributed in all reaches for this LCRAS Demonstration of Technology to present the effect of the distribution, even though the residual was within the assumed measurement error of the upstream gauge in all of the reaches.

The standard error of estimate and variance values used in this report are based upon values recommended in Lane 1998. Minor adjustments were made to some of the recommended values based upon judgement.

The standard error of estimate and variance values used for 1997 can be found in the water balance tables in Appendix I.

Interaction between Reaches

Lane 1998 introduces two methods to treat the problem of interaction between reaches. This problem appears where the same variable is used in two different reaches; for example, the flow below Davis Dam which is used as outflow to the Hoover Dam to Davis Dam reach and as inflow to the Davis Dam to Parker Dam reach. If each reach is treated independently when the residual is distributed, two different adjusted values for the same variable result; for example, the distributed value for the flow below Davis Dam would be different in the Hoover Dam to Davis Dam reach than it was in the Davis Dam to Parker Dam reach. When the interaction between reaches is considered, the result is a single adjustment to the flows below Hoover, Davis, and Parker Dams, at Imperial Dam, and the flow to Mexico.

The method used in 1997 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 1998). This was accomplished by using a three-step process:

1. The flow below Hoover Dam was temporarily fixed at the gaged value,

2. Temporary values were 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}[11] from the reaches above each dam and the flow to Mexico,

[11] 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}).

3. The average of the temporary changes made to the gaged flows was subtracted from the temporary flows calculated in 1 and 2 above to yield the final adjusted flow at each dam and to Mexico.

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

Table 6 — Adjustments to flow at or below the major dams and the flow to Mexico
(units: acre-feet unless otherwise noted)

Description	Hoover Dam	Davis Dam	Parker Dam	Imperial Dam	Flow to Mexico [12]	Average
Measured flow	11,669,100	11,527,400	8,471,000	7,389,156	2,954,455	
Amount of residual apportioned to Q_{dif} of the reach below each dam from the water balance	-94,095	-6,236	-42,134	67,849	N/A	
Initial adjustment value (start with zero at most upstream dam and add cumulative to most downstream flow)	0	-94,095	-100,331	-142,465	-74,616	-82,301
Initial adjusted flow (measured flow + initial adjustment)	11,669,100	11,433,305	8,370,669	7,246,691	2,879,839	
Final adjusted flows below each dam and to Mexico (initial adjusted flow - average of initial adjustment values)	11,751,401	11,515,606	8,452,969	7,328,991	2,962,138	
Final adjustments to measured flows (final adjusted value - measured value)	82,301	-11,794	-18,031	-60,165	7,683	
Final adjustments to measured flows in percent	0.71%	-0.10%	-0.21%	-0.81%	0.26%	

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 magnitude of adjustment

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

required to the flow at these dams and the flow to Mexico can be used as an additional index of the quality of the water balance closure. Small adjustments to the flows at these dams and the flow to Mexico tend to support a conclusion that the water balance was successful.

As can be seen from examining table 6, the final adjustments to the measured flows below the Hoover, Davis, and Parker Dams, at Imperial Dam, and the flow to Mexico were small, supporting our conclusion that the water balance was successful. The final results of the water balance are shown on table 7.

Table 7 — Final distributed and adjusted water balance values

Water balance inflows, outflows, and water uses	Reach				
	Hoover Dam to Davis Dam	Davis Dam to Parker Dam	Parker Dam to Imperial Dam	Imperial Dam to Mexico	Hoover Dam to Mexico
Flow at the upstream boundary (Q_{us})	11,751,401	11,515,606	8,452,969	7,328,991	11,751,401
Flow at the downstream boundary (Q_{ds})	11,515,606	8,452,969	7,328,991	2,962,138	2,962,138
Residual	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	235,795	3,062,637	1,123,978	4,366,853	8,789,263
Measured Tributary inflow (Trm)	0	9,156	0	16,823	25,979
Unmeasured Tributary inflow (Trum)	6,484	36,297	33,842	2,996	79,619
Exported flow (Q_{ex})	0	2,652,413	0	3,910,666	6,563,079
Evaporation (E)	126,060	120,002	53,307	4,718	304,087
Domestic Consumptive Use	421	37,750	5,580	27,874	71,625
Crop Consumptive Use	0	71,927	751,512	374,890	1,198,329
Phreatophyte Consumptive Use	902	182,798	352,224	68,524	604,448
Change in reservoir storage (ΔS_r)	114,896	43,200	-4,803	0	153,293
Change in aquifer storage (ΔS_a)	0	0	0	0	0

Sample Calculation

This sample calculation used data for the Colorado River Indian Reservation in Arizona (CRIR, AZ) as an example for calculating consumptive use by crops and phreatophytes. From this point on in the example, CRIR, AZ will be referred to simply as CRIR. The process shown in this example is the same as was done for all diverters along the river. The calculation is a five-step process.

First, the acreage of each crop and phreatophyte class within the CRIR diverter boundary was calculated using remotely sensed data and a GIS database.

Second, the ET for each crop and phreatophyte class was calculated using ET_0, vegetation coefficients, and crop and phreatophyte acreages. The ET for all crop and phreatophyte classes was summed to provide the total crop and phreatophyte ET for CRIR.

Third, all inflows, outflows, and water uses for the Parker Dam to Imperial Dam reach were assembled and entered into the water balance equation, and the residual was calculated.

Fourth, the residual was distributed 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.

Fifth, the distributed values of crop and phreatophyte consumptive use were apportioned to CRIR and all other agricultural diverters within the Parker Dam to Imperial Dam reach.

The process used to calculate the consumptive use of crops is presented below.

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 finding 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. The values displayed on the tables in Appendix I have been rounded.[13]

[13] The crop acreage data used for this example and the LCRAS Run were calculated using Reclamation's remote sensing process; they were not provided by the districts in crop reports.

This sample calculation begins with the calculation of an ET rate and leads the reader through the calculation of the water balance and distribution of the residual.

This year, as noted in the section titled "Evapotranspiration" in Chapter 2, Reclamation used an average ET_0 calculated from the CIMIS and AZMET stations along the lower Colorado River for all diverters. The ET_0 values from individual CIMIS and AZMET stations along with the average ET_0 values used in this report can be found in Appendix I.

The remainder of the process is the same as the previous year. All calculations are performed on the daily average ET_0 values in the same way as in previous years with ET_0 values from individual CIMIS and AZMET stations.

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 was 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 on sheet D that the average ET_0 value for January 1 is 0.04837 inch, and the total average ET_0 value for the month of January is 2.95 inches. The K_c for alfalfa on January 1 is 1.020 inches (listed on page 2 of 2, sheet E). Since there was no rain that day, the product of the average ET_0 and K_c values (0.05) is the ET rate, in inches, for alfalfa on January 1, as shown on sheet E, page 1 of 2.

Let us look at January 12 for an example of an ET rate calculation when there was precipitation. 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 12, the effective precipitation coefficient of 0.4 (the value for the month of January from sheet C), was multiplied by the measured precipitation (0.906 inch from sheet B), to yield an effective precipitation of 0.36 inch (0.4 × 0.906 inch), as shown on sheet C.

Then we calculated the ET rate[14] for alfalfa for January 12 as $(ET_0 \times K_c)$! effective precipitation. With ET_0 equal to 0.0158 (from sheet D), K_c for alfalfa equal to 1.020 (from sheet E, page 2 of 2), and effective precipitation equal to 0.36 (from sheet C), the ET rate for January 12th was -0.35 inch (shown on sheet E) indicating a net gain in soil moisture.

Let us continue our example with the month of January. The ET rate for alfalfa was calculated for each day of January and summed to derive the cumulative alfalfa ET rate for January (1.6 inches). This process was repeated for each month of the year. The daily values for each month and the monthly summations are displayed on sheet E of the Parker Crops Table.

The monthly alfalfa ET for CRIR was obtained by multiplying the monthly ET rate for alfalfa by the number of acres in alfalfa within the CRIR diverter boundary for each month. The crop acreage for CRIR is listed on sheet O, page 2 of 3, of Appendix I, Part 2, Parker Dam to Imperial Dam Water Balance Table. To calculate the January ET for alfalfa, find the cumulative January ET rate for alfalfa (1.6 inches, from the Parker Crops Table, sheet E, page 1 of 2) and the acreage of alfalfa on CRIR in 1997 (44,971 acres, from the Parker Dam to Imperial Dam Water Balance Table, sheet O, page 2 of 3), multiply these values together and divide the product by 12 (inch to foot conversion) to produce the alfalfa ET (5,996 acre-feet, as shown on the Parker Dam to Imperial Dam Water Balance Table, sheet O, page 1 of 3). The equation for this calculation is shown in the previous section entitled “Crops (ET_{crop})” using cotton as a sample crop.

The process was repeated for all other crop and phreatophyte classes (except that effective precipitation was not subtracted from phreatophyte ET). The annual crop and phreatophyte ET for CRIR was 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 was repeated for each diverter within the Parker Dam to Imperial Dam reach to obtain their crop and phreatophyte ET.

The water balance was calculated for the Parker Dam to Imperial Dam reach to produce the residual, a

[14] 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.

portion of which was distributed to the diverter's crop and phreatophyte ET, to yield the diverter's crop and phreatophyte consumptive use.

The water balance was performed on annual values in the Parker Dam to Imperial Dam Water Balance Table, sheet A, using the water balance equation described previously. Annual, monthly, and daily values for each term were shown in the Parker Dam to Imperial Dam Water Balance Table. For simplicity, this sample calculation will discuss the annual totals only.

The major inflow to the Parker Dam to Imperial Dam reach was provided by the mainstream of the Colorado River, measured as it entered the reach through Parker Dam. This value, 8,471,000 acre-feet, termed "Flow at the Upstream Boundary (Q_{us})", is shown on sheet A, page 1 of 2, of the Parker Dam to Imperial Dam Water Balance Table.

The unmeasured tributary inflow values were provided by the Geological Survey on page 46 of Owen-Joyce and Raymond (1996). There were no measured tributary inflows in the Parker Dam to Imperial Dam reach. The values are shown and summed on sheet C of the Parker Dam to Imperial Dam Water Balance Table. The total tributary inflow was 33,750 acre-feet.

Flow at the downstream boundary of this reach was the sum of four flows measured at and below Imperial Dam, shown on sheet H of the Parker Dam to Imperial Dam Water Balance Table. They were Station 60 on the All-American Canal, Station 30 on the Gila Gravity Main Canal, the inflow to Mittry Lake, and the Imperial Dam sluiceway. The annual flows were 6,168,500 acre-feet, 837,628 acre-feet, 10,378 acre-feet, and 372,650 acre-feet, respectively. The sum of these outflows resulted in the downstream outflow (flow at Imperial Dam) of 7,389,156 acre-feet as shown on sheet A of the Parker Dam to Imperial Dam Water Balance Table. The individual outflows from this reach are tabulated monthly on sheet H. There were no exports from the system in this reach. Therefore, the value used for export in the water balance was zero. Where exports are present they are reported on sheet D.

Evaporation was calculated by multiplying the average open water surface area, in acres, by the monthly evaporation rate minus precipitation. The evaporation rate (in feet) was calculated as the monthly sum of daily ET_0, in inches, times a monthly evaporation coefficient less precipitation in inches, divided by 12.

The Parker Dam to Imperial Dam reach is divided into five subsections for the purpose of calculating evaporation. This accounts for differing water temperatures within the reach, a backwater area, and Senator Wash Reservoir. For the purpose of demonstration, the evaporation calculation for January in River Section 1 in the Parker Dam to Imperial Dam reach is described below.

The January evaporation rate was derived by multiplying the monthly average ET_0 (2.95 inches, from sheet D of the Parker Crops Table) times the evaporation coefficient (0.52, from sheet H of the Parker Dam to Imperial Dam Water Balance Table) less precipitation in January (1.02 inches, from sheet B of the Parker Crops Table), divided by 12, times the area of open water in river section 1 (3,551 acres from sheet H of the Parker Dam to Imperial Dam Water Balance Table). The result of this calculation was 151 acre-feet of evaporation in January, as shown on sheet H of the Parker Dam to Imperial Dam Water Balance Table.

This calculation is performed for all five subsections, and totaled for the Parker Dam to Imperial Dam reach. The total evaporation in the Parker Dam to Imperial Dam reach for the month of January was 821 acre-feet, as shown on sheet H of the Parker Dam to Imperial Dam Water Balance Table.

Domestic uses without measured diversions were estimated using the population given in the most recent census and a per capita use rate of 0.14 acre feet per capita year. For example, Poston has a population of approximately 480. The annual per capita use rate for that area was given as 0.14 acre-foot per person. The product of these values was 67 acre-feet of use for Poston. The domestic uses were calculated on sheet E of the Parker Dam to Imperial Dam Water Balance Table. Domestic uses are described more fully in the section entitled "Domestic Use (CU_d)."

Senator Wash is the only reservoir in the Parker Dam to Imperial Dam reach. The annual change in reservoir storage was calculated on sheet D of the Parker Dam to Imperial Dam Water Balance Table as the sum of the difference in water held in Senator Wash between the beginning and end of each month. The beginning-of-month value was the storage measured on the last day of the previous month. In

January, the beginning-of-month storage (as measured midnight December 31, 1996) was 7,740 acre-feet, the end-of-month storage (as measured midnight January 31, 1997) was 9,125 acre-feet. The difference was a gain of 1,385 acre-feet. The monthly reservoir changes were summed to confirm the total change in reservoir storage of -4,803 acre-feet.

To this point, this sample calculation has described how the totals for each inflow, outflow, and water use in the water balance were calculated. Once the water balance equation has been used to calculate the residual and it has been distributed, each resulting inflow, outflow, and water use value was termed a distributed annual value (DAV). Consumptive use and the final estimate of all other water uses is the DAV.

The water balance was calculated on sheet A, page 1 of 2, of the Parker Dam to Imperial Dam Water Balance Table, yielding a residual of -43,780 acre-feet for the Parker Dam to Imperial Dam reach. 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 was calculated as shown on the following page:[15]

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

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

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

The UAV of crop ET in the Parker Dam to Imperial Dam reach was 752,782 acre-feet, and the SEE was 5 percent, yielding a variance of 1,416,701,849 acre-feet squared. The TVAR was 48,852,691,475 acre-feet squared, and the residual was -43,780 acre-feet.

Substituting these values into the equation results in

$$DAV_{ETcrop} = 752{,}782 + [(1{,}416{,}701{,}849 \div 48{,}852{,}691{,}475) \times (-43{,}780)]$$

$$DAV_{ETcrop} = 751{,}512 \text{ acre-feet}$$

The residual was distributed to the crop ET of each diverter based on that diverter's proportion of the total UAV of crop ET. Continuing the sample calculation for CRIR, the equation for distribution is as follows:

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

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_{crop} above

Substituting values into the above equation yields the proportion of residual distributed to crop ET in CRIR:

$$DDET_{crop\ CRIR} = 324{,}249 \text{ acre-feet} \div (752{,}782 \text{ acre-feet} \div 751{,}512 \text{ acre-feet})$$

$DDET_{crop\ CRIR}$ = 323,702 acre-feet [16] = Consumptive Use

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

The distributed value for phreatophytes for each diverter was calculated in the same fashion using the UAV and DAV for phreatophytes. The phreatophyte consumptive use for CRIR was 136,086 acre-feet. These values were considered to be the consumptive use by crops and phreatophytes[17] at CRIR. The distributed values of domestic consumptive use were calculated in a similar manner.

An explanation of how the water balance calculations were 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 the LCRAS Demonstration of Technology for Calendar Year 1997 are presented in the numerous tables and charts found below and in the attachments. Table 8 presents a summary of consumptive use prepared by LCRAS and by the current decree accounting method.

Some of the differences evident in the table 8 can be attributed to consumptive uses by individual diverters, which were reported by LCRAS but not in the Decree Accounting Report. There were also several places where the consumptive use by some fields was reported by LCRAS as being charged to the State in which they are located and not to the adjacent irrigation district because these fields are not within known irrigation district boundaries.

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

Table 8 — Consumptive use by State
(Unit: flows in acre-feet per year)

LCRAS			**Decree Accounting**	
Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
		Nevada		
Uses above Hoover Dam (from 1997 Decree Accounting Report)		224,458	224,458	Uses above Hoover Dam
Uses below Hoover Dam	21,526	17,192	18,321	Uses below Hoover Dam
			732	Unmeasured return flow credit
Nevada Total	21,526	241,650	242,047	Nevada Total
		California		
			5,250,122	Sum of individual diverters
			88,227	Unmeasured return flow credit
California Total	196,301	5,233,027	5,161,895	California Total
		Arizona		
Subtotal (Below Hoover Dam, less Wellton-Mohawk IDD)	386,615	2,272,326	2,608,883	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (from the 1997 Decree Accounting Report)		183	183	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (from 1997 Decree Accounting Report)		312,514	312,514	Wellton-Mohawk IDD
			67,679	Pumped from South Gila wells (DPOCs): returns
			156,912	Unmeasured return flow credit
Arizona Total	386,615	2,585,023	2,696,989	Arizona Total
		Lower Colorado River Basin Total		
Total Use	604,442	8,059,700	8,100,931	Total Use

Figure 2 presents data for the states of California and Arizona. These differences are also displayed and discussed in attachment 4.

The table and bar charts found in attachment 4 present the results of the LCRAS Demonstration of Technology for Calendar Year 1997 and also present a comparison between the LCRAS results and the values published in the Decree Accounting Report. There are several footnotes and the bar charts that assist in interpreting the results displayed on the table in attachment 4.

The differences in attachment 4 between consumptive uses reported by the Decree Accounting Report and those developed by LCRAS on a district-by-district basis have given rise to three questions:

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

2. What portion, if any, of the consumptive use from phreatophytes 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.

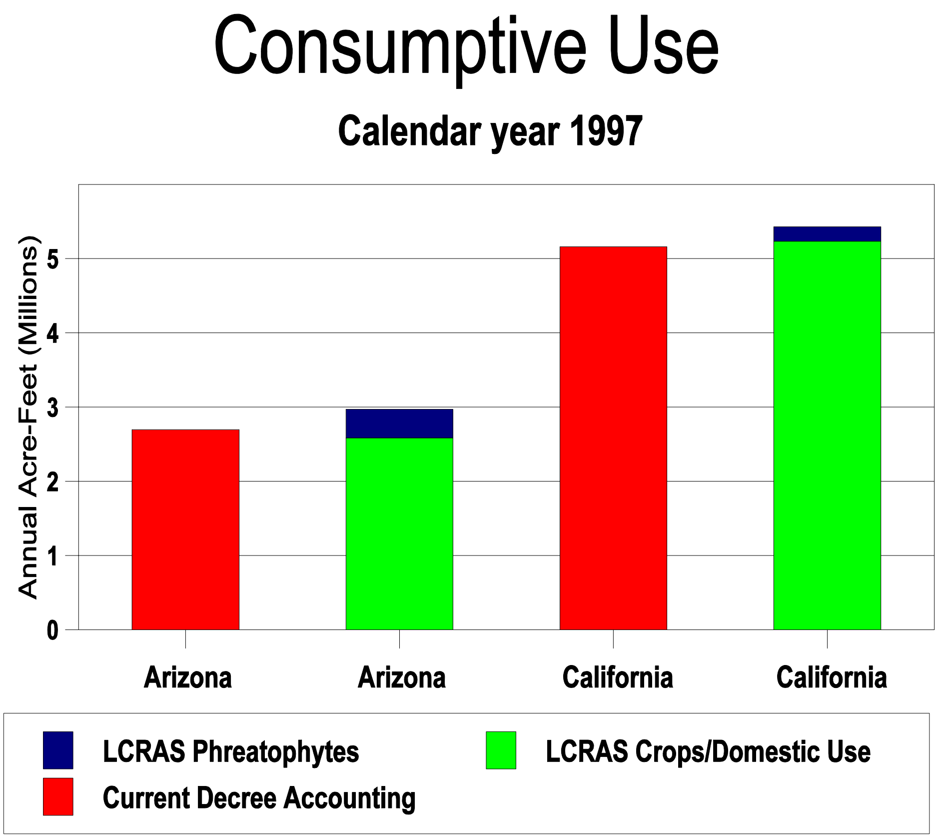


Figure 2. — State totals, Arizona and California (consumptive use for calendar year 1997).

LOWER COLORADO RIVER ACCOUNTING SYSTEM MAP INDEX

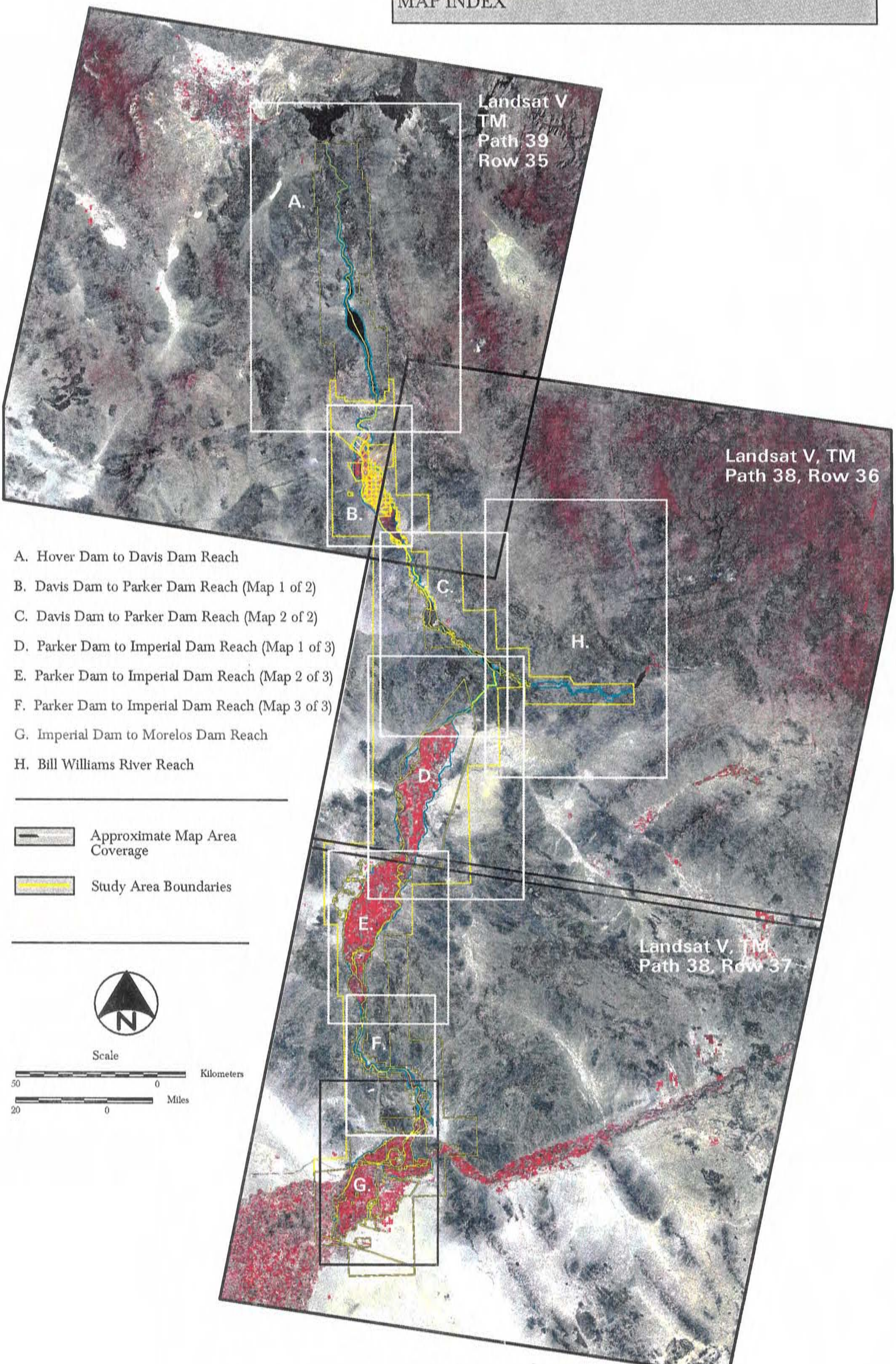


Exhibit 1

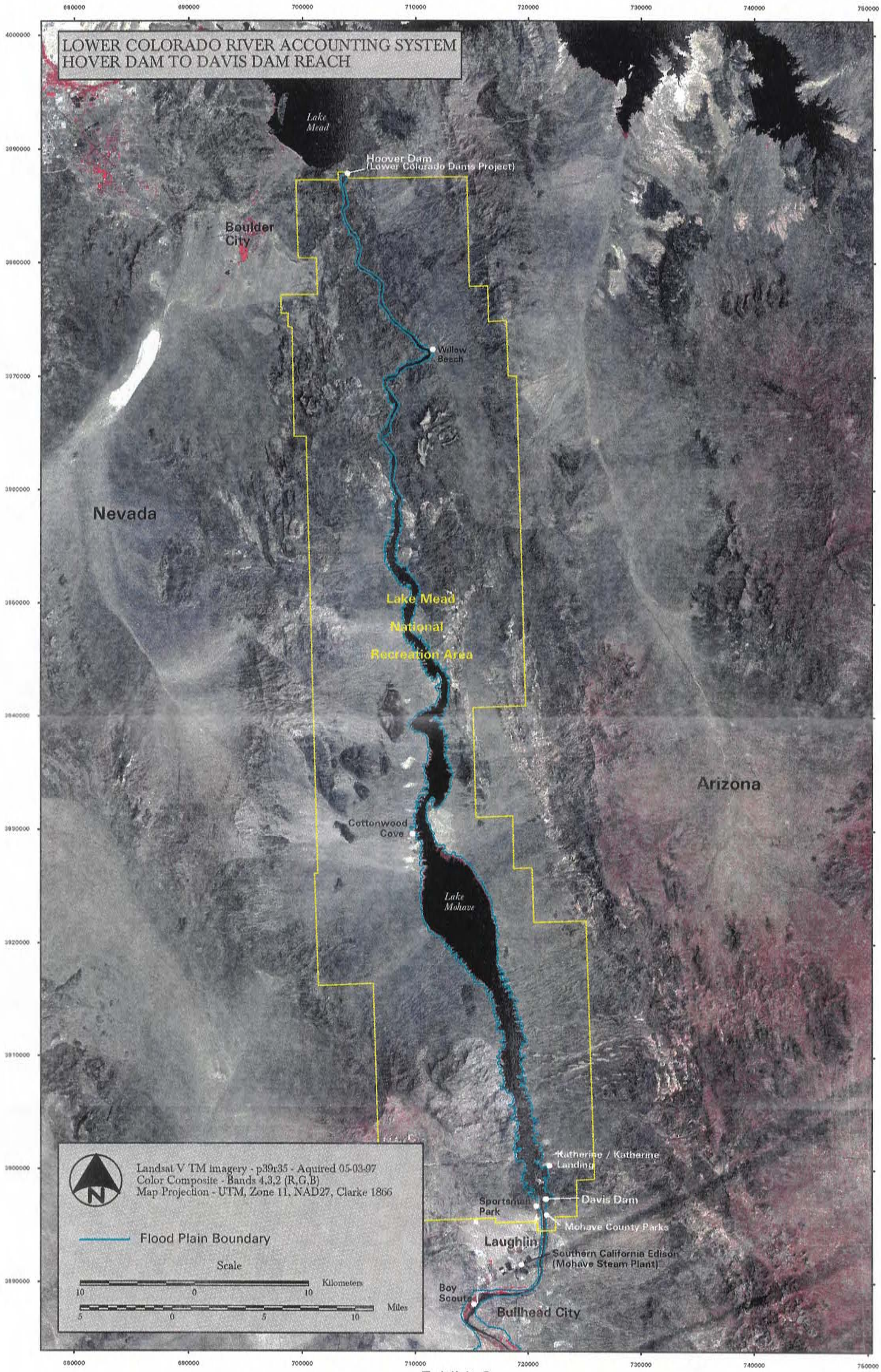

LOWER COLORADO RIVER ACCOUNTING SYSTEM
HOVER DAM TO DAVIS DAM REACH
Lake Mead
Hoover Dam
(Lower Colorado Dams Project)
Boulder City
Willow Beach
Nevada
Lake Mead
National
Recreation Area
Arizona
Cottonwood Cove
Lake Mohave
Katherine / Katherine Landing
Davis Dam
Sportsman Park
Mohave County Parks
Laughlin
Southern California Edison
(Mohave Steam Plant)
Boy Scouts
Bullhead City
Landsat V TM imagery - p39r35 - Aquired 05-03-97
Color Composite - Bands 4,3,2 (R,G,B)
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
Flood Plain Boundary
Scale
Kilometers
Miles

Exhibit 2

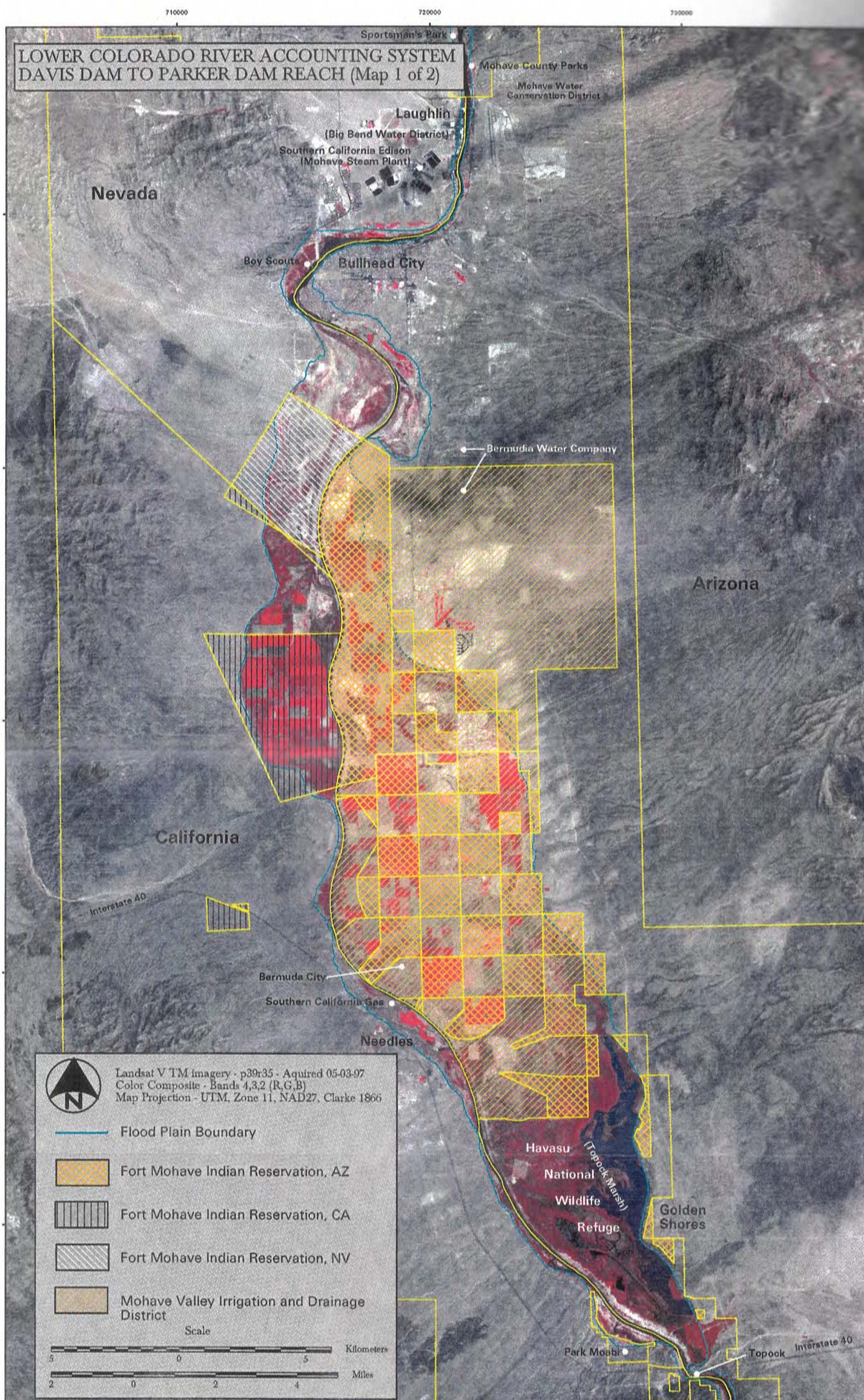

LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 1 of 2)
Sportsman's Park
Mohave County Parks
Mohave Water Conservation District
Laughlin
(Big Bend Water District)
Southern California Edison (Mohave Steam Plant)
Nevada
Boy Scouts
Bullhead City
Bermudia Water Company
Arizona
California
Interstate 40
Bermuda City
Southern California Gas
Needles
Havasu
National
Wildlife
Refuge
(Topock Marsh)
Golden Shores
Park Moabi
Topock
Interstate 40
Landsat V TM imagery - p39r35 - Aquired 05-03-97
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
710000
720000
730000

Exhibit 3

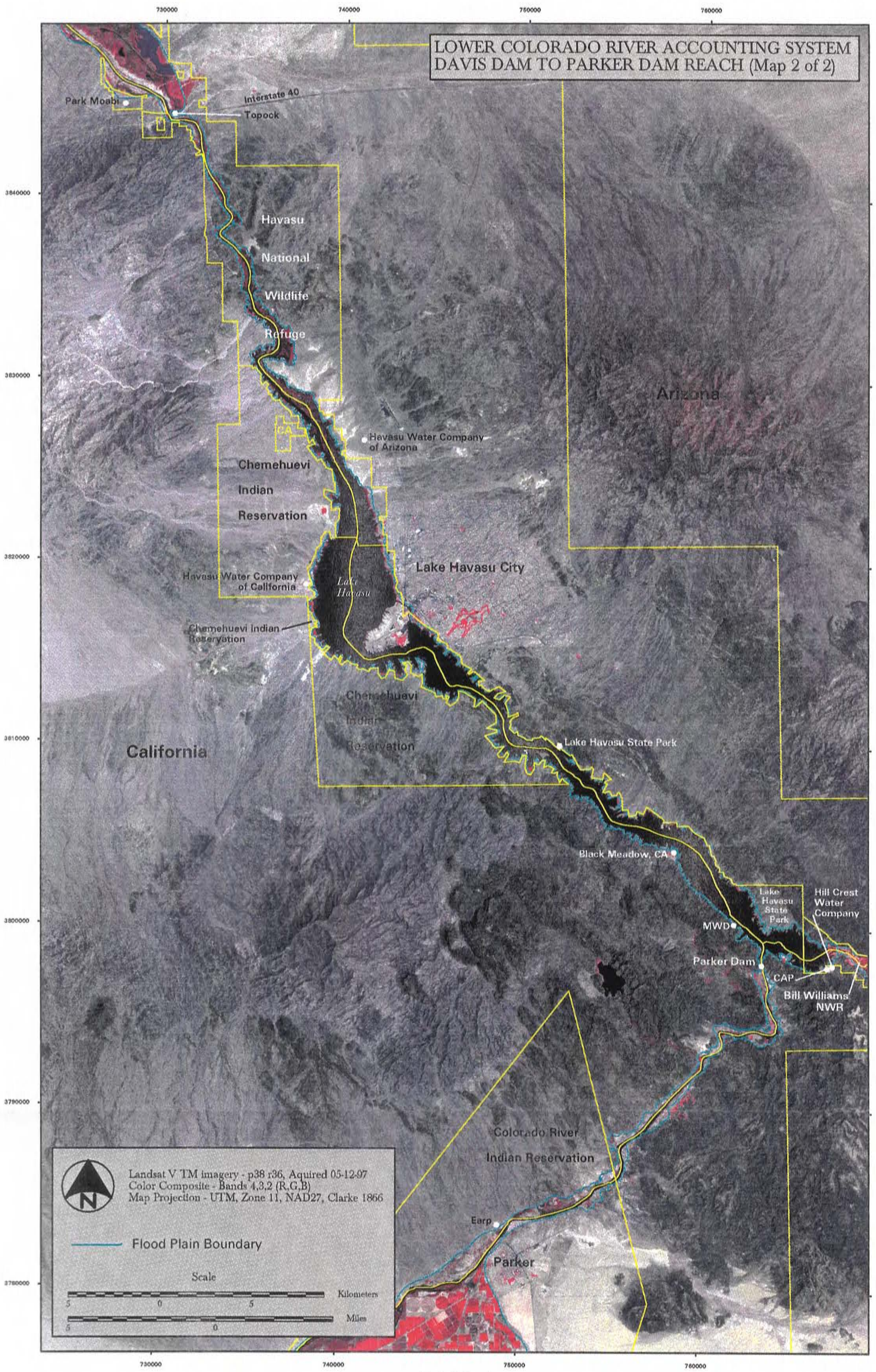

LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 2 of 2)
Park Moabi
Interstate 40
Topock
Havasu
National
Wildlife
Refuge
Arizona
Havasu Water Company of Arizona
Chemehuevi
Indian
Reservation
Lake Havasu City
Havasu Water Company of California
Lake Havasu
Chemehuevi Indian Reservation
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 V TM imagery - p38 r36, Aquired 05-12-97
Color Composite - Bands 4,3,2 (R,G,B)
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
Flood Plain Boundary
Scale
Kilometers
Miles
730000
740000
750000
760000
3840000
3830000
3820000
3810000
3800000
3790000
3780000

Exhibit 4

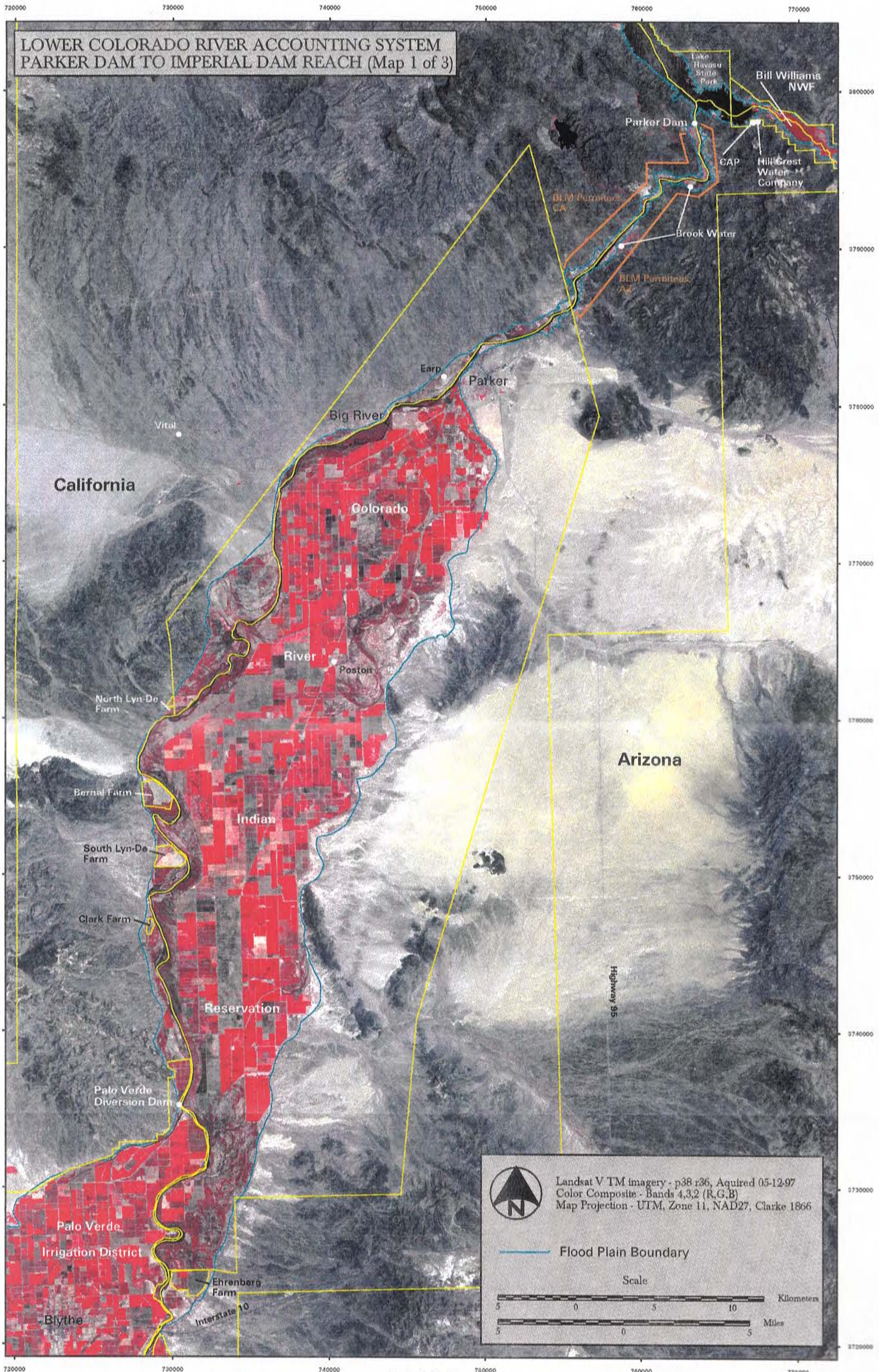

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 1 of 3)
Lake Havasu State Park
Bill Williams NWF
Parker Dam
CAP
Hill Crest Water Company
BLM Permittees CA
Brook Water
BLM Permittees AZ
Earp
Parker
Big River
Vidal
California
Colorado
River
Poston
North Lyn-De Farm
Arizona
Bernal Farm
Indian
South Lyn-De Farm
Clark Farm
Highway 95
Reservation
Palo Verde Diversion Dam
Palo Verde
Irrigation District
Ehrenberg Farm
Interstate 10
Blythe
Landsat V TM imagery - p38 r36, Aquired 05-12-97
Color Composite - Bands 4,3,2 (R,G,B)
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
Flood Plain Boundary
Scale
Kilometers
Miles

Exhibit 5

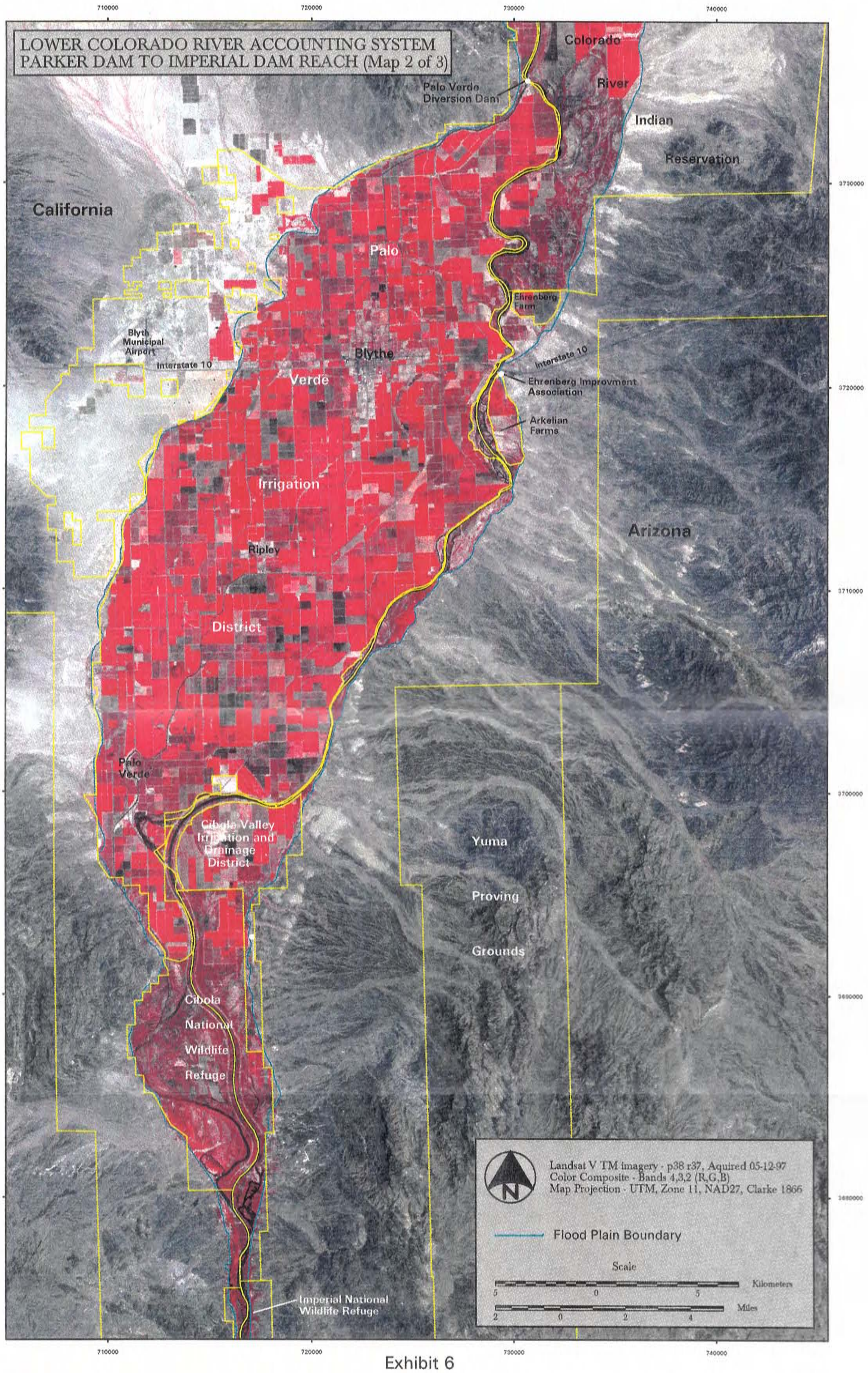

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 2 of 3)
710000
720000
730000
740000
3730000
3720000
3710000
3700000
3690000
3680000
Colorado
River
Indian
Reservation
Palo Verde
Diversion Dam
California
Palo
Verde
Irrigation
District
Blythe
Ripley
Blyth
Municipal
Airport
Interstate 10
Ehrenberg
Farm
Ehrenberg Improvment
Association
Arkelian
Farms
Arizona
Palo
Verde
Cibola Valley
Irrigation and
Drainage
District
Yuma
Proving
Grounds
Cibola
National
Wildlife
Refuge
Imperial National
Wildlife Refuge
Landsat V TM imagery - p38 r37, Aquired 05-12-97
Color Composite - Bands 4,3,2 (R,G,B)
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
N
Flood Plain Boundary
Scale
Kilometers
5
0
5
Miles
2
0
2
4

Exhibit 6

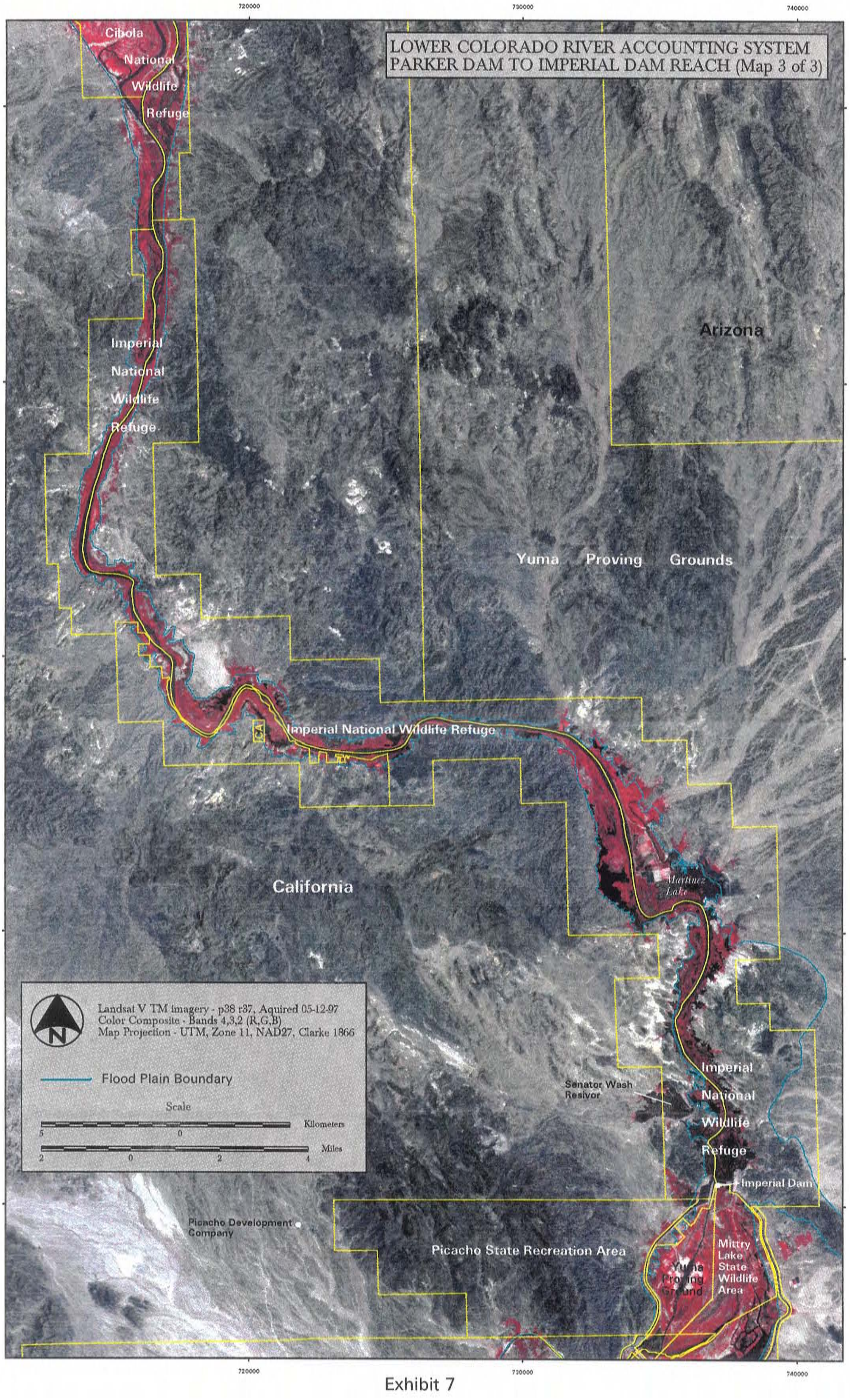
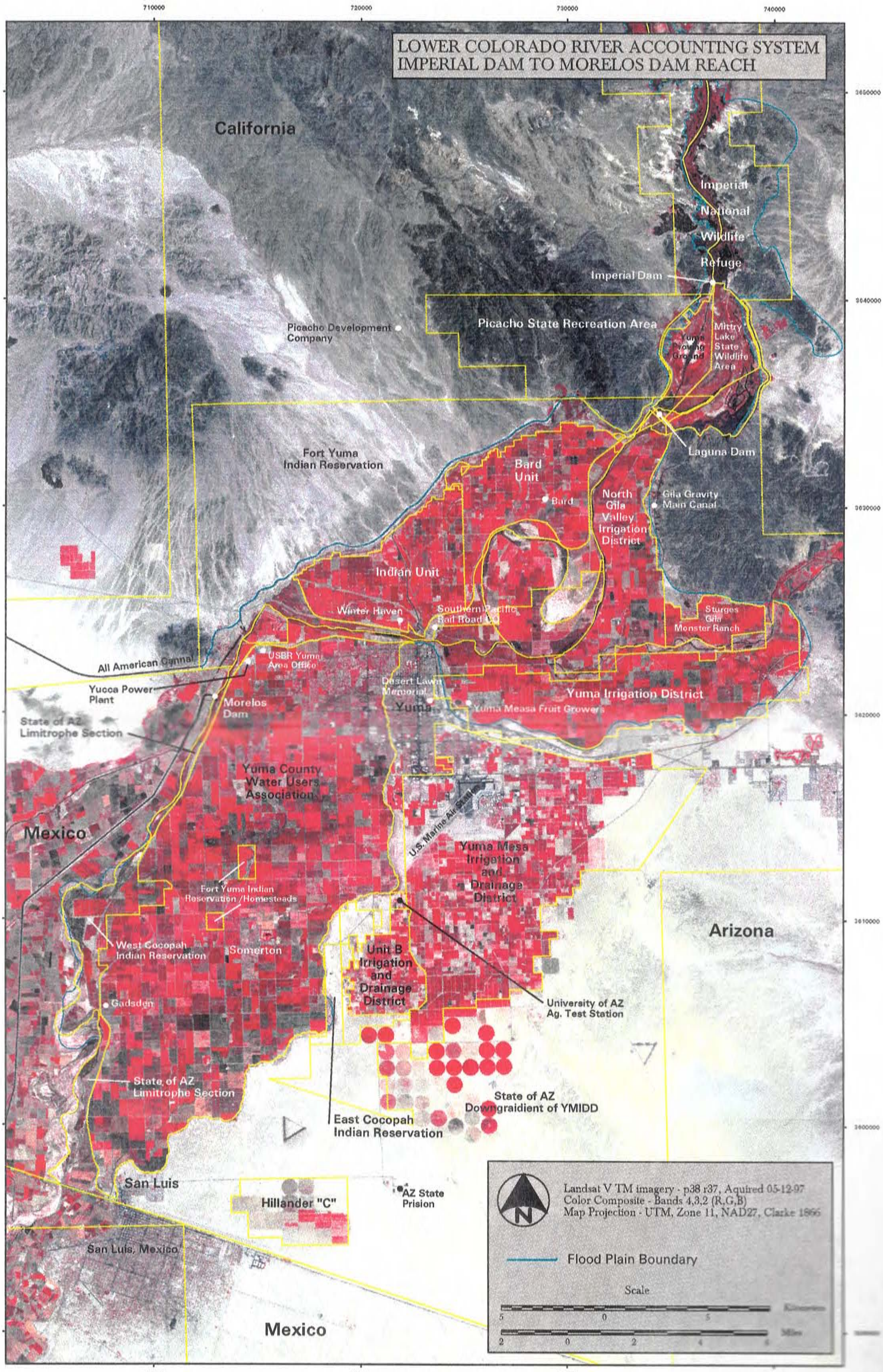

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 3 of 3)
Cibola National Wildlife Refuge
Imperial National Wildlife Refuge
Arizona
Yuma Proving Grounds
Imperial National Wildlife Refuge
California
Martinez Lake
Senator Wash Resivor
Imperial National Wildlife Refuge
Imperial Dam
Picacho Development Company
Picacho State Recreation Area
Yuma Proving Ground
Mittry Lake State Wildlife Area
Landsat V TM imagery - p38 r37, Aquired 05-12-97
Color Composite - Bands 4,3,2 (R,G,B)
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
Flood Plain Boundary
Scale
Kilometers
Miles
720000
730000
740000
3680000
3670000
3660000
3650000
3640000

Exhibit 7



LOWER COLORADO RIVER ACCOUNTING SYSTEM
IMPERIAL DAM TO MORELOS DAM REACH
California
Imperial National Wildlife Refuge
Imperial Dam
Picacho Development Company
Picacho State Recreation Area
Yuma Proving Ground
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
Winter Haven
Southern Pacific Rail Road Co.
Sturges Gila Monster Ranch
All American Canal
USBR Yuma Area Office
Yucca Power Plant
Morelos Dam
Desert Lawn Memorial
Yuma
Yuma Irrigation District
Yuma Measa Fruit Growers
State of AZ Limitrophe Section
Yuma County Water Users Association
Mexico
U.S. Marine Air Station
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 V TM imagery - p38 r37, Aquired 05-12-97
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 8

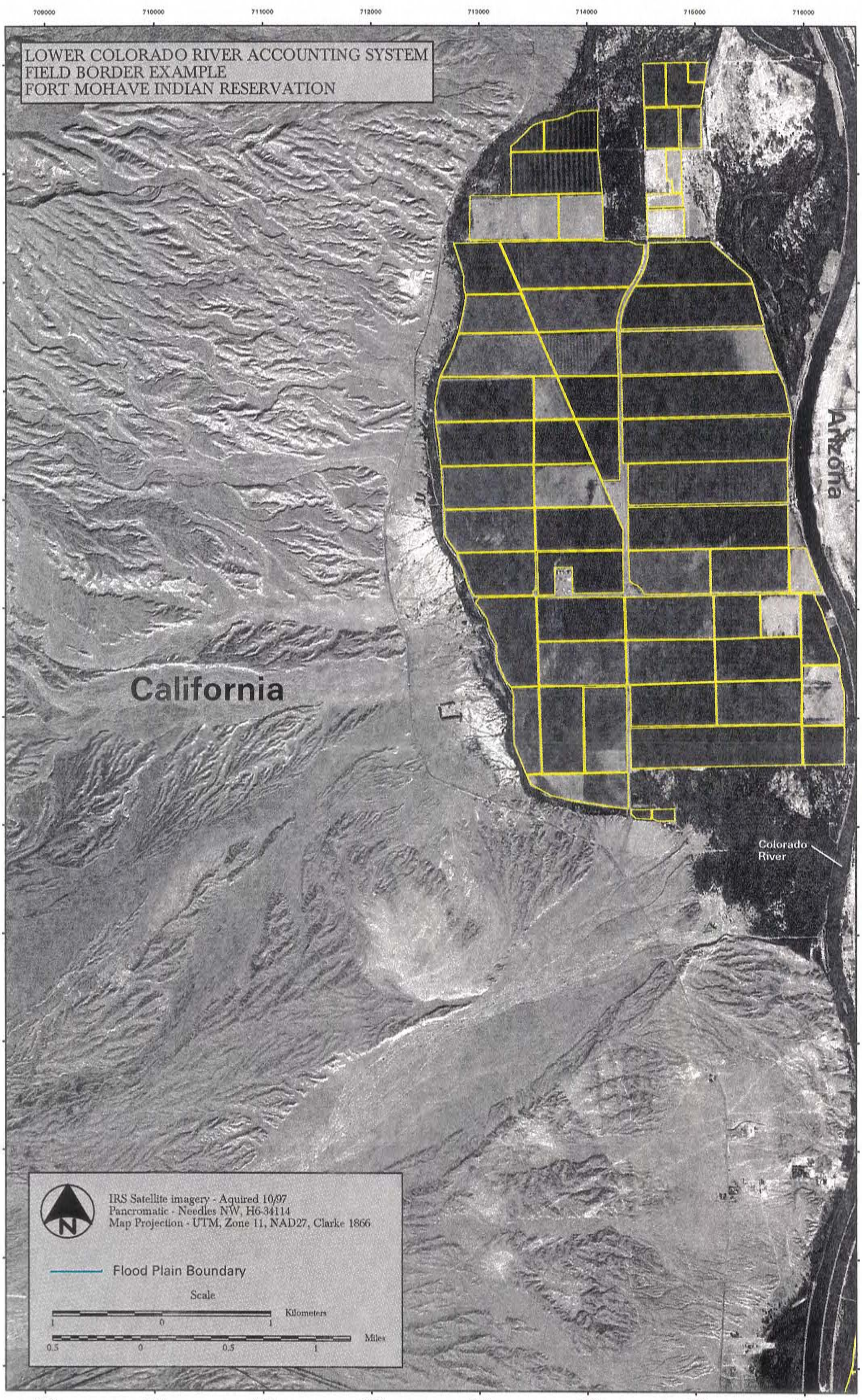
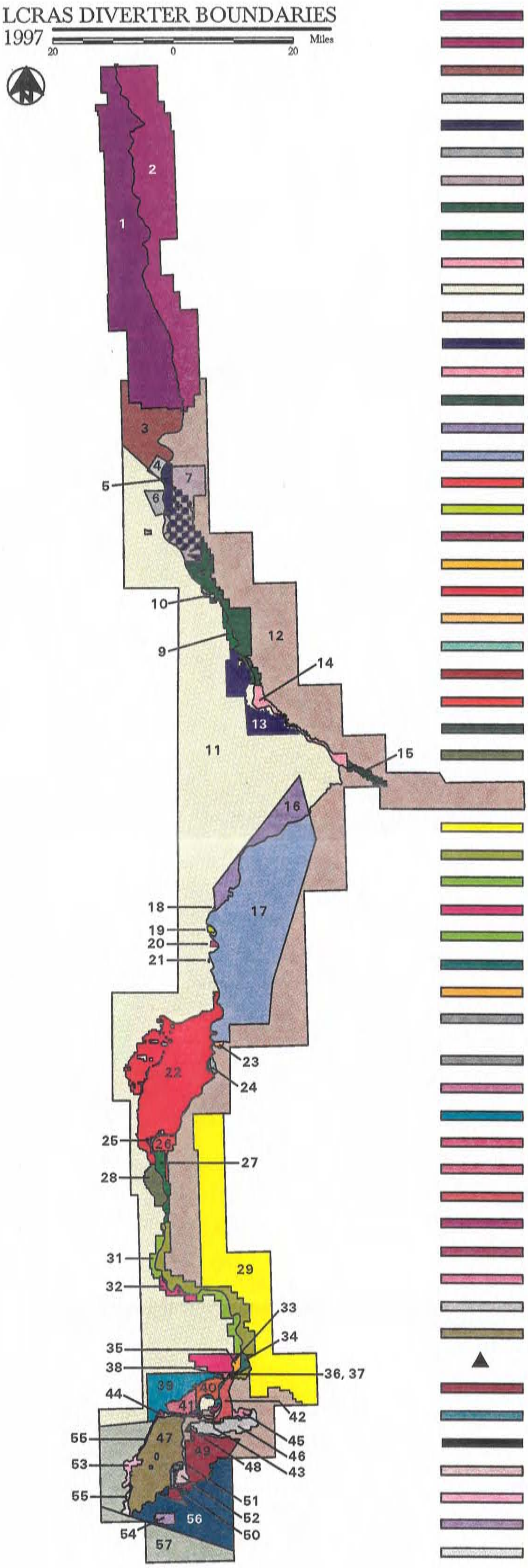

LOWER COLORADO RIVER ACCOUNTING SYSTEM
FIELD BORDER EXAMPLE
FORT MOHAVE INDIAN RESERVATION
California
Arizona
Colorado River
IRS Satellite imagery - Aquired 10/97
Pancromatic - Needles NW, H6-34114
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
Flood Plain Boundary
Scale
Kilometers
Miles

Exhibit 9



- (1) Lake Mead National Recreation Area, NV
- (2) Lake Mead National Recreation Area, AZ
- (3) State of Nevada
- (4) Fort Mohave Indian Reservation, NV
- (5) Fort Mohave Indian Reservation, AZ
- (6) Fort Mohave Indian Reservation, CA
- (7) Mohave Valley Irrigation and Drainage District, AZ
- (8) Havasu National Wildlife Refuge, AZ
- (9) Havasu National Wildlife Refuge, CA
- (10) Park Moabi, CA
- (11) State of California
- (12) State of Arizona
- (13) Chemehuevi Indian Reservation, CA
- (14) Lake Havasu State Park, AZ
- (15) Bill Williams National Wildlife Refuge, AZ
- (16) Colorado River Indian Reservation, CA
- (17) Colorado River Indian Reservation, AZ
- (18) North Lyn-De Farm, CA
- (19) Bernal Farm, CA
- (20) South Lyn-De Farm, CA
- (21) Clark Farm, CA
- (22) Palo Verde Irrigation District, CA
- (23) Ehrenberg Farm, AZ
- (24) Arkelian Farm, AZ
- (25) Palo Verde Irrigation District, AZ
- (26) Cibola Valley Irrigation and Drainage District, CA
- (27) Cibola National 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

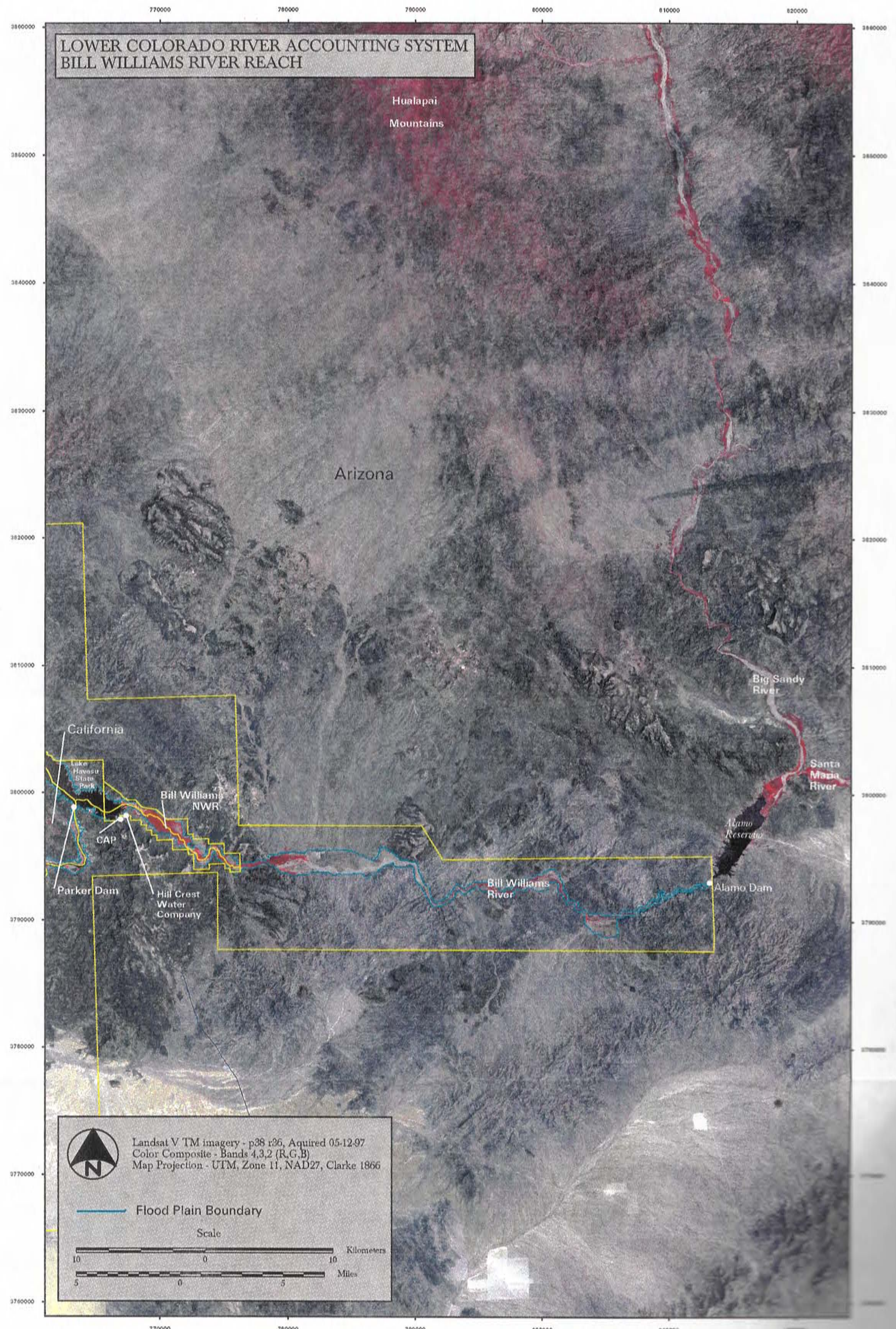

LOWER COLORADO RIVER ACCOUNTING SYSTEM
BILL WILLIAMS RIVER REACH
Hualapai
Mountains
Arizona
Big Sandy
River
Santa
Maria
River
California
Lake
Havasu
State
Park
Bill Williams
NWR
CAP
Parker Dam
Hill Crest
Water
Company
Bill Williams
River
Alamo
Reservoir
Alamo Dam
Landsat V TM imagery - p38 r36, Aquired 05-12-97
Color Composite - Bands 4,3,2 (R,G,B)
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
N
Flood Plain Boundary
Scale
Kilometers
10
0
10
Miles
5
0
5

Exhibit 11

Chapter 3

LCRAS Improvements

Improvements continue to be made to LCRAS, and that effort will continue into the future. Below, in italics, are the potential areas for improvement as they were written in the 1996 LCRAS report. Below each of these items are the descriptions of the changes made in this 1997 report. Additional improvements made to the LCRAS method identified while reviewing the 1996 LCRAS Report are also shown below. Improvements or studies identified in the 1995 LCRAS Report that have been completed, or assigned a low priority by the 1996 LCRAS 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 1996 LCRAS report and the districts' service areas. Information gained through these meetings has been used to update the diverter boundaries used by LCRAS in 1997. Such information sharing and gathering will be an ongoing effort.

The following diverter boundaries were deleted for 1997 (these areas were included in other diverter boundaries or moved into the domestic use section):

Imperial Dam to Mexico reach:

East Cocopah Indian Reservation, AZ (moved to domestic use section)

The following diverter boundaries were added for 1997:

Imperial Dam to Mexico reach:

Desert Lawn Memorial, AZ (moved from the domestic use section)

University of AZ-Ag Test Station, AZ (previously included in State of Arizona)

Crop Consumptive Use

Some minor modifications were made to the growth window of some crop classes in the Parker and Blythe areas for 1996 based upon information acquired during ground-reference data collection. The crop coefficient values used for 1997 remain the same as used for 1996. The crop coefficient values and growth windows used in 1997 can be found in Appendix I, Part 1, Evapotranspiration Rate Calculations.

Phreatophyte Consumptive Use

What portion, if any, of the consumptive use from phreatophytes within the boundary of an agricultural diverter, 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 proposes the following outline for a solution to this question:

1. Water use from phreatophytes not located within any diverter boundary should be considered system loss,

2. Water use from phreatophytes growing within a diverter boundary, that are drawing water from a water table elevation that is equal to or less than the elevation of the Colorado River adjacent to the phreatophytes, should be considered system loss,

3. Water use from phreatophytes growing within a diverter boundary should be considered part of the consumptive use of the diverter if they are

    a. Drawing water from a water table elevation that is above the elevation of the Colorado River adjacent to the phreatophytes, and

    b. Downgradient from the location of the diverter's primary use of the diverted water.

Reclamation will seek input from State water agencies and others knowledgeable in the Law of the River to derive a final solution to this question.

Reclamation continues toward a resolution of this question. This issue remains unresolved and is left open in this report.

Incidental Use Factor

The ET figures used for calendar year 1995 did not apply an incidental use factor to account for consumptive uses of water by an irrigation district in addition to the use of water by the crops themselves. Such uses include evaporation from the canals and laterals, phreatophytes growing along the canals and fields, and other uses of the water outside the border of the field. An incidental use factor is currently envisioned as a fixed percentage added to the ET calculated for the crops alone. Reclamation will develop a process to calculate a fair, accurate, and equitable incidental use factor for each agricultural diverter along the mainstream of the lower Colorado River.

Incidental use factors have not been developed to date, nor has the LCRAS consultation process identified this question to be of interest. Reclamation has therefore assigned this question a low priority.

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.

This loss distribution is not included in this 1997 report. The evaporation and phreatophyte use associated with the operation of the Gila Gravity Main Canal was 1,397 acre-feet and 2,154 acre-feet respectively, for a total of 3,551 acre-feet. The equivalent sum for the All-American Canal was about 5,482 acre-feet in 1997. These losses are currently included in the residual of the water balance, and thus 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 Surface Evaporation and Precipitation

Evaporation calculations could be improved by the collection of more directly applicable meteorological information along the river. LCRAS currently uses meteorological data collected from the six AZMET and CIMIS stations noted in the section titled "Evapotranspiration" to calculate evaporation. Not all of the micrometeorology stations are close enough to the river to provide weather data fully representative of open water conditions. Ideally, reference ET should be calculated over open water.

To provide the best possible evaporation estimates, Reclamation will investigate locating additional stations over water.

In the desert Southwest, precipitation generally occurs as rainfall events of high intensity, short duration, and local extent. As noted in the "Precipitation (P)" section above, rainfall occurring within the basin, yet outside of diverter boundaries, is currently accounted for in the water balance as unmeasured tributary inflow, which was estimated in Owen-Joyce (1987), using long-term average rainfall data.

Also, rainfall occurring over farmland and open water is currently measured only by the six CIMIS and AZMET stations. Increasing the density of precipitation gauges could potentially yield a more representative rainfall estimate. There are numerous other agencies, such as the National Park Service and National Weather Service, that record precipitation. Incorporating their data into LCRAS could potentially improve ET calculations. Reclamation will assess the appropriateness of incorporating these data into the LCRAS program.

Reclamation is planning an evaporation study along the lower Colorado River. Plans currently include placing meteorological stations over water. These stations will calculate ET_0 over water and compare the values with ET_0 values currently being used to calculate evaporation. 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 9, below, displays the residuals for the reaches of the water balance for this and previous applications of LCRAS.

Table 9 — Residuals By Reach And By Year

Year	Hoover Dam to Davis Dam		Davis Dam to Parker Dam		Parker Dam to Imperial Dam		Imperial Dam to Mexico	
	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%
1996	-62,469	-0.63%	-198,208	-2.00%	14,051	0.19%	142,625	2.34%
1997	-94,144	-0.81%	-6,429	-0.06%	-43,780	-0.52%	98,706	1.34%

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 LCRAS 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. 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 current decree accounting method for calendar years 1998 through 2000 to compare the results of the two methods. The purpose of this exercise is to acquaint the users of the Decree Accounting Reports with LCRAS, as well as to examine any trends that may appear in the differences of the results provided by the two methods.

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ATTACHMENTS

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 over the past 60 years, primarily to meet agricultural and domestic needs and to generate electric power. Urban dwellers in Las Vegas, Phoenix, Los Angeles, and San Diego also receive water from the lower Colorado River.

Today, the waters of the lower Colorado River are needed more than ever to meet the increasing needs of cities and suburbs, Native Americans, fish and wildlife, recreationists, and other interests. At the same time, the water needs of existing diverters must continue to be met.

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," comprised of five major 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 Basin States—where most of the river's water supply originates—and the Lower Basin States, where most of the water demands were developing. At that time, the Upper Basin 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 and a lower half and gave each basin the right to develop and use 7.5 million acre-feet of river water annually. 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 Compact
- Authorized the construction of Hoover Dam and related irrigation facilities in the Lower Basin
- Approved the development of an agreement among the Lower Basin States apportioning the Lower Basin's 7.5 million acre-feet among the states of Arizona (2.8 million acre-feet), California (4.4 million acre-feet), and Nevada (0.3 million acre-feet)
- Authorized and directed the Secretary of the Interior (Secretary) to function as the sole contracting authority for Colorado River water use in the Lower Basin

Mexican Water Treaty of 1944

This treaty committed 1.5 million acre-feet of the Colorado River's annual flow to Mexico.

Arizona v. *California* Supreme Court Decision and Decree

In 1963, the Supreme Court issued a decision settling a 25-year-old dispute between Arizona and California that stemmed from California’s claim that Arizona's use of water from the Gila River, a Colorado River tributary, constituted use of its Colorado River apportionment and that it had developed a historical use of some of Arizona's apportionment. The Supreme Court rejected California's arguments, ruling that Lower Basin States have a right to appropriate and use tributary flows before the tributary commingles with the Colorado River without such use being charged against the Lower Basin apportionments.

In 1964, the Supreme Court issued its decree. This decree enjoined the Secretary from delivering water outside the framework of apportionments defined by the law and mandated the preparation of annual reports documenting the uses of water in all three Lower Basin 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 Watermaster. In the Lower Basin, the Secretary performs a role similar to that of a State engineer in administering water rights. Through the Bureau of Reclamation, the Secretary contracts for all water used in the Lower Basin, 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

Hoover Dam to Davis Dam Reach	Flow in acre-feet	Station number
Colorado River below Hoover Dam	11,669,100	09421500
Change in storage Lake Mohave !	114,900	09422500
Davis Dam to Parker Dam Reach		
Colorado River below Davis Dam	11,527,400	09423000
Colorado River Aqueduct $	1,238,660	09424150
Bill Williams River below Alamo Dam	10,948	09426000
Central Arizona Project Canal $	1,413,930	09426650
Change in storage Lake Havasu !	43,200	09427500
Parker Dam to Imperial Dam Reach		
Colorado River below Parker Dam	8,471,000	09427520
Change in storage Senator Wash !	-4,803	
Colorado River above Imperial Dam	7,389,156	09429490
Imperial Dam to Mexico Reach		
Diversion to Mittry Lake	10,378	09522400
All-American Canal	6,168,500	09523000
All-American Canal below Pilot Knob	3,492,000	09527500
Gila Gravity Main Canal **	837,628	09522500
Wellton-Mohawk Canal **	382,909	09522700
Colorado River below Imperial Dam	372,650	09429500
Gila River near Dome	16,830	09520500
Colorado River at NIB #	2,755,819	09522000
Eleven Mile wasteway #	1,756	09525000
Cooper wasteway #	1,505	09531850
Twenty-one Mile wasteway #	968	09533000
Main drain + 242 wells #	98,845	09534000
West Main Canal wasteway #	5,959	09534300
East Main Canal wasteway #	7,603	09534500

$ Provided by the user and published by the Geological Survey

! Geological Survey - December 1996 minus December 1997

** Bureau of Reclamation open-channel acoustic velocity meter data

Provided by International Boundary and Water Commission on a monthly basis

* Added to Colorado River above Imperial Dam table in the annual report. Remaining data is provided monthly and at end of year

Unmeasured Tributary Inflow Estimates

Hoover Dam to Davis Dam reach	Flow in acre-feet
Springs	3,080
Unmeasured runoff	2,100
Groundwater discharge	200
Eldorado Valley	1,100
Davis Dam to Parker Dam reach	
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[18]	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[18]	4,000
Parker Dam to Imperial Dam reach	
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

[18] 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.

Imperial Dam to Mexico reach	
Groundwater Discharge	
Gila River	1,000
Unmeasured runoff, Yuma area	2,000
Total Unmeasured Inflow to the lower Colorado River below Hoover Dam	79,520

Attachment 3

Monthly Storage Values for Lakes Mohave and Havasu, and Senator Wash Reservoir

Reservoir		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Lake	EOM	1,672,200	1,683,400	1,726,800	1,713,800	1,743,100	1,703,100	1,693,000	1,636,100	1,674,100	1,491,200	1,473,900	1,692,700	
Mohave	BOM	1,577,800	1,672,200	1,683,400	1,726,800	1,713,800	1,743,100	1,703,100	1,693,000	1,636,100	1,674,100	1,491,200	1,473,900	
(acre-feet)	Change	94,400	11,200	43,400	-13,000	29,300	-40,000	-10,100	-56,900	38,000	-182,900	-17,300	218,800	114,900
Lake	EOM	563,900	586,400	549,700	580,200	608,800	593,000	588,900	577,900	579,800	551,900	562,800	598,400	
Havasu	BOM	555,200	563,900	586,400	549,700	580,200	608,800	593,000	588,900	577,900	579,800	551,900	562,800	
(acre-feet)	Change	8,700	22,500	-36,700	30,500	28,600	-15,800	-4,100	-11,000	1,900	-27,900	10,900	35,600	43,200
Senator	EOM	9,125	6,719	4,270	2,886	3,953	7,273	2,784	6,667	8,651	6,985	8,680	2,937	
Wash	BOM	7,740	9,125	6,719	4,270	2,886	3,953	7,273	2,784	6,667	8,651	6,985	8,680	
(acre-feet)	Change	1,385	-2,406	-2,449	-1,384	1,067	3,320	-4,489	3,883	1,984	-1,666	1,695	-5,743	-4,803

Attachment 4

Results in Tabular Form

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Nevada				
Lake Mead National Recreation Area, NV.	303		345	Lake Mead National Recreation Area, diversion from Lake Mohave (Cottonwood). Reported as a diversion.
Cottonwood Cove (domestic consumptive use).		207		
Southern California Edison (domestic consumptive use).		13,127	13,126	Southern Nevada Water Authority (Southern California Edison), pumped from Sec 24 T32S R66E. Diversion = consumptive use.
Big Bend Water District (domestic consumptive use).		2,633	2,632	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).		5	8	Boy Scouts of America. Reported as a diversion.
Fort Mojave Indian Reservation, NV.	9,604		2,200	Fort Mohave Indian Reservation (Avi), 2 wells, sections 27 & 5. Domestic Use reported as a diversion.
Fort Mojave Indian Reservation, NV (Avi) (Domestic consumptive use).		1,210		
State of Nevada[19].	11,619			Not reported.
Subtotal: Uses below Hoover Dam.	21,526	17,192	18,321	Subtotal: Uses below Hoover Dam.
Uses above Hoover Dam [20].		224,458	224,458	Uses above Hoover Dam.
			732	Unmeasured return flow credit to Nevada.
Nevada Total.	21,526	241,650	242,047	Nevada Total.

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

[20] From 1997 Decree Accounting.

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
California				
Fort Mojave Indian Reservation, CA.	5,166	14,888	27,241	Fort Mohave Indian Reservation, pumped from river and wells. Reported as a diversion.
Needles (domestic consumptive use).		1,453	1,396	City of Needles, 4 wells NW SW Sec 29 T9N R23E SBM. Reported as a consumptive use.
Havasu Water Company.		42	71	Havasu Water Company. 1 well, T5N/R25E Sec31.
Colorado River Aqueduct (export).		1,238,577	1,238,660	Metropolitan Water District, diversion from Lake Havasu. Reported as a consumptive use.
Parker Dam/Gov't. Camp (domestic consumptive use).		111	189	Parker Dam and Government Camp, diversion at Parker Dam. Reported as a diversion.
Total Colorado River Indian Reservation, CA[21].	36,603	2,986	4,496	Colorado River Indian Reservation, pumped from 11 pumps and wells, 4 pumps from river. Reported as a diversion[22].
Colorado River Indian Reservation, CA.	35,432	664		
North Lyn-De Farm, CA[23].	1	161		
South Lyn-De Farm, CA.	2	1,554		
Bernal Farm, CA.	1,168	0		
Clark Farm, CA.	0	607		

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

[22] 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.

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

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name	
LCRAS			**Decree Accounting**		
Total Chemehuevi Indian Reservation, CA.	47	235	252	Chemehuevi Indian Reservation, Diversions from Pumps.	
Chemehuevi Indian Reservation, CA.	47	235			
Chemehuevi Indian Reservation, CA. (domestic use not reported or 1997).		0			
BLM-Black Meadow (Domestic consumptive use).		0		BLM Permittees.	
Havasu National Wildlife Refuge, CA.	5,983	0		Not reported.	
Park Moabi, CA.	267			Not reported.	
BLM Permittees, CA.		338	564	BLM Permittees.	
Total Palo Verde Irrigation District, CA.	9,167	401,133	421,851	Palo Verde Irrigation District, diversion from Palo Verde Dam.. Reported as a consumptive use.	
Palo Verde Irrigation District, CA.	9,167	397,365			
Palo Verde Irrigation District, AZ.	0	764			
Blythe (city, domestic consumptive use).		2,905			
Ripley (domestic consumptive use).		53			
Palo Verde (domestic consumptive use).		46			
Cibola National Wildlife Refuge, CA.	41,933	0		Not reported.	
Imperial National Wildlife Refuge, CA.	19,167	0		Not reported.	
Winterhaven (Domestic consumptive use).		77	130	130	City of Winterhaven, 1 well, SE SE NE Sec 27 T16S R22E SBM.
				0	Town of Winterhaven, 1 well, 6S-22E 27DAA (No Report).
				Reported as diversions.	

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name	
LCRAS			**Decree Accounting**		
Fort Yuma Indian Reservation and Picacho State Recreation Area, CA.	1	0		Not reported.	
Picacho State Recreation Area, CA.	4,546	0		Not reported.	
Picacho Development Corp., CA (Domestic consumptive use).		58	96	Picacho Development Corp. Reported as a diversion.	
All-American Canal below Pilot Knob[24].		3,518,185	3,496,514	3,158,486	Imperial Irrigation District, diversion at Imperial Dam.
				338,028	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).		35	78	Southern Cal Gas. Reported as a diversion.	
Imperial National Wildlife Refuge and Yuma Proving Ground, CA.	47	0		Not reported.	
Yuma Proving Ground, CA.	8,269	0		Not reported.	
Fort Yuma Indian Reservation and Yuma Proving Ground, CA .	836	62		Not reported.	

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

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use			Diverter name
LCRAS			**Decree Accounting**			
Total Fort Yuma Indian Reservation, CA.	14,030	45,774	44,035		30,575	Yuma Projects, Reservation Division Indian Unit, diversion at Imperial Dam (consumptive use).
Fort Yuma Indian Reservation, Indian Unit, CA.	503	17,098			52,744	Yuma Projects, Reservation Division Bard Unit, diversion at Imperial Dam (Consumptive use).
Fort Yuma Indian Reservation, Bard Unit, CA.	826	24,470			41,728	Returns from Yuma Project, Reservation Division returns.
Bard (domestic consumptive use).		214		41,591		Sum Yuma Projects, Reservation Division (consumptive use).
Fort Yuma Indian Reservation, CA.	12,701	3,992		0		Ralph Land, Sec 35 T15S R23E DDC.
				153		Living Earth Farm, Sec 02 T16S R23E BBC.
				0		Berrymen, (C-16S-23E) 9 CCA.
				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 consumptive use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
State Of California[25].	50,239	8,836	14,549	589	Ida Cal, 11N/22W -31BAB.
				753	Ida Cal, 11N/21E -36ADD.
				717	Ida Cal, 11N/21E -36CDA.
				The above Ida Cal wells irrigate lands north of Fort Mohave Irrigation District in CA.	
				30	Lye, C.L., 1S/24E -16Gb.
				600	Harp, P. (R. Harp), (C-8-23) 13AAD.
				2,305	Horizon Farms, (08S/R22W) 6CDA.
				500	Horizon Farms, (10S/R22W) 7ADB.
				577	Horizon Farms, (08S/R22W) 7BAB.
				500	Horizon Farms, (10S/R22W) 6DCB.
				600	Horizon Farms, (08S/R22W) 6BBD.
				24	Horizon Farms, (08S/R22W) 6BCD.
				0	Horizon Farms, (10S/R22W) 6CBB.
				871	Horizon Farms, (C-8-23) 1DCC.
				295	Horizon Farms, (C-8-23) 12CDB.
				984	Horizon Farms, (08S/R22W) 6CBA.
				0	Living Earth Farm, (C-8-23) 2ADC.
				0	Ed Weavers Farms, (C-8-22) 6BCD (No Report).

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

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name	
LCRAS			**Decree Accounting**		
				0	Ed Weavers Farms, (C-8-22) 1BBA.
				0	Ed Weavers Farms, (C-8-23) 1BAD.
				0	Ed Weavers Farms, (C-8-22) 6CBA (No Report).
				593	Valdez, Mike, Sec T16S R23E 30 ACC.
				1,071	Valdez, Mike, Sec T16S R23E 30 ADD.
				1,198	Power, O.L., (C-8-23) 11 DCA.
				180	Harp, Robert, (C-8-23) 12 DAC.
				2,131	Dees, Alex, (C-8-23) 1 DAC.
				22	Wilson Farms, (C-8-23) 12 BBA.
				0	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).
			88,227	Unmeasured return flow credit to California.	
California Total.	196,301	5,233,027	5,161,895	California Total.	

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Arizona				
Total Lake Mead National Recreation Area, AZ.	1,069	213	355	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).	703			
Lake Mead National Recreation Area, AZ (Davis Dam to Parker Dam).	366			
Katherine Landing and Willow Beach (Domestic consumptive use).		213		
Lower Colorado Region Dams Project (Domestic consumptive use).		0	0	Lower Colorado Region Dams Project (Davis Dam), Diversion at Davis Dam. Reported as a consumptive use.
Bullhead City (Domestic consumptive use).		4,569	7,616	Bullhead City, Pumped from wells. Reported as a diversion.
Mohave County Parks (Domestic consumptive use).		56	94	Diversion at Davis Dam, Mohave Co. Parks. Reported as a diversion.
Total Mohave Valley Irrigation and Drainage District	35,441	26,729	42,600	Mohave Valley Irrigation and Drainage District, Pumped from wells. Reported as a diversion[26].
MVIDD (Domestic consumptive use)[27].		4,474		
Mohave Valley Irrigation and Drainage District, AZ (includes no domestic use).	35,441	22,255		
Fort Mojave Indian Reservation, AZ.	36,776	33,853	69,967	Fort Mohave Indian Reservation, 6 pumps and wells in flood plain. Reported as diversions.

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

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

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Golden Shores (Domestic consumptive use).		319	532	Golden Shores Water Conservation District, pumped from wells. Reported as a diversion.
Topock (Domestic consumptive use).		126		Not reported.
Crystal Beach Water Conservation District		5	8	Crystal Beach Water Conservation District Reported as a diversion
Havasu Water Company, AZ (Domestic consumptive use).		233	389	Havasu Water Co. of AZ (Citizens Utilities). Reported as a diversion.
Mohave Water Conservation District (Domestic consumptive use).		415	692	Mohave Water Conservation District; pumped from wells. Reported as a diversion.
Brook Water (Domestic consumptive use).		242	403	Brook Water, (was Consolidated Water Utilities), pumped from river. Reported as a consumptive use.
Havasu National Wildlife Refuge, AZ[28].	50,001		30,811	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).		9,007	15,012	Lake Havasu City, pumped from wells. Reported as diversions.
Bill Williams National Wildlife Refuge (Lake Havasu).	612			Not reported.
Central Arizona Project Canal (export).		1,413,836	1,413,930	Central Arizona Project; pumped from Lake Havasu. Reported as a diversion.
Town of Parker (Domestic consumptive use).		638	1,031	Town of Parker; pumped from river, 1 well-NW NW NW Sec 7 T9N R19W G&SRM. Reported as a consumptive use.

[28] Topock Marsh evaporation is estimated to be about 12,000 acre-feet. This evaporation was not assigned to any diverter for this 1997 demonstration.

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Lake Havasu State Park, AZ[29].	3,717	0		Not reported.	
Poston (Domestic consumptive use).		67		Not reported.	
Colorado River Indian Reservation, AZ.	136,086	323,702	392,723	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).		299	499	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	2,320	3,945	3,864	Jack Rayner (B-04-22) 34 DCC (CDD).
				81	Jack Rayner (B-04-22)34 DCC (DCD).
				Reported as diversions.	
Arkelian Farms, AZ.	2,207	2,008	2,208	0	George Arkelian (B-03-22)16 DBD (DAD).
				2,208	George Arkelian (B-03-22)16 DBD (DAD).
				Reported as diversions.	

[29] May have missed a golf course.

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Total Bureau of Land Management permittees (Domestic consumptive use).	0	545	913		Bureau of Land Management permittees. Reported as a diversion.
Bureau of Land Management permittees (Davis Dam to Parker Dam).		0			
Bureau of Land Management permittees (Parker Dam to Imperial Dam).		545			
Hillcrest Water Company (Domestic consumptive use).		13	22		Hillcrest Water Co. Reported as a diversion.
Total Yuma Proving Ground.	370	623	1,039		Yuma Proving Ground, diversion at Imperial Dam, wells X,Y,M. Reported as a consumptive use.
Yuma Proving Ground.	370	0			
Yuma Proving Ground (Domestic consumptive use).		623			
Fort Yuma Indian Reservation, Mittry Lake State Wildlife Area and Yuma Proving Ground, AZ.	869	0			Not reported.
Fort Yuma Indian Reservation and Homesteads, AZ.	3,925	1,661	2,914	998	Dulin, A (C-8-22) 9 CCC.
				206	Dulin, A (C-8-22) 7 DAC.
				0	Glen Curtis Cit (C-8-22) 18 CAD.
				200	Glen Curtis Cit (C-8-22) 18 DDD.
				550	Glen Curtis Cit, (C-8-22) 7 CCD.
				960	Yowelman, R., Sec 17 T08S/ R22W CBC.
					Reported as a diversions.
Martinez Lake (Domestic consumptive use).		1			Not reported.

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Cibola Valley Irrigation and Drainage District, AZ.[30]	6,410	14,153	30,883	Cibola Valley Irrigation District, 5 pumps Sections 20, 21, and 26T1N R23W. Reported as a diversion.
Cibola National Wildlife Refuge, AZ.	21,967	6,557	15,075	Cibola National Wildlife Refuge, 4 pumps, Secrion 2 T1S R24W, Section 31 T1S, R23W. Reported as a diversion.
Imperial National Wildlife Refuge, AZ.	31,649	0	8,000	Imperial National Wildlife Refuge, 2 wells, Sec 13 T5S R22W G&SRM. Reported as a diversion.
Mittry Lake State Wildlife Area, AZ.	9,967	0	360	Pumper L. Pratt Sec 14 T7S R22W ABC.
Sturges Gila Monster Ranch, AZ.	47	7,255	7,961	Sturges, diversions at Imperial Dam (Warren Act). Reported as a consumptive use.
City of Yuma (Domestic consumptive use).		16,970	16,969	City of Yuma, diversion at Imperial Dam (All-American Canal), diversion at Imperial Dam (Gila). Reported as a consumptive use.
Marine Corps Air Station [31](Domestic consumptive use).		1,274	2,123	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	355	1,200	University of Arizona, diversion at Imperial Dam (Warren Act). Reported as a diversion.
Yuma Union High School (Domestic consumptive use).		120	200	Yuma Union High School, diversion at Imperial Dam. Reported as a diversion.

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

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

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name	
LCRAS			**Decree Accounting**		
Unidentified in LCRAS[32].			29	Camille, Alec, Jr., diversion at Imperial Dam (Warren Act). Reported as a diversion.	
Desert Lawn Memorial.		271	2	Desert Lawn Memorial, diversion at Imperial Dam. Reported as a diversion.	
North Gila Valley Irrigation District, AZ.	831	18,806	20,599	North Gila Valley Irrigation District, diversion at Imperial Dam. Reported as a consumptive use.	
Yuma Irrigation District, AZ.	319	30,134	51,549	50,875	Yuma Irrigation District, diversion at Imperial Dam and pumped from private wells. Reported as a consumptive use.
				241	Cameron Bros Sec 24 T08S R22W CCB.
				308	Cameron Bros Sec 24 T08S R22W CAD.
				125	Judd T. Ott Sec 30 T08S R22W BAB.
				Individual wells are reported as diversions.	

[32] Apparently an Ag user included in another user's total. Need actual location and user boundary.

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Total	0	142,806	188,356	Yuma Mesa Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use[33].
Yuma Mesa Irrigation and Drainage District, AZ.	0	69,041		
Underflow to Mexico[34].		52,700		
Consumptive use by down gradient users[35].	0	14,287		
Hillander "C" Irrigation District, AZ .	0	6,766		
The Prison (Domestic consumptive use).		12		

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

[34] The portion of the underflow to Mexico that is presumed to be from the application of water on the Yuma Mesa (85 percent of 62,000 acre-feet).

[35] 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 consumptive use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
Total Yuma County Water Users Association, AZ.	1,974	170,204	230,423	222,706	Yuma County Water Users Association, diversion at Imperial Dam and pumped from wells[36].
Yuma County Water Users Association, AZ.	29	145,890		300	Burrell, Sec 33 T08S R24W BAB.
Underflow to Mexico[37].		19,600		168	Farmland Management Sec 19 T09S R24W BAD.
State of Arizona - Limitrophe Section.	1,945	2,470		456	Farmland Management, Sec19 T09S/ R24W BDD.
City of Somerton (Domestic use).		720		271	Farmland Management, Sec19 T09S/ R24W BDA
City of Gadsden (Domestic use).		24		1,129	Waymon Farms, Sec 31 T09S/R24W AAA.
City of San Luis (Domestic use).		1,500		1,714	Waymon Farms (C-9-24) 31 BBB.
				907	J.W. Cumings, (C-10-25) 1BBA.
				State of Arizona Limitrophe Section:	
				412	J.W. Cumings (C-10-25), 14ADB.
				480	C & J Cummings, (C-10-25) 26BAB.
				480	J. Barkley, (C-10-25) 35CBA.
				726	Brown, Rodger S., (C-11-25) 2BBA.

[36] 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.

[37] The underflow to Mexico across the Limitrophe section that is presumed to be from the application of water within the Yuma County Water Users Association's boundaries (about 98 percent of 20,000 acre-feet, or about 19,600 acre-feet).

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
				674	Earl Huges, (C-11-25) 3DAC.
Total Unit B Irrigation and Drainage District, AZ.	0	18,797	21,282		Unit "B" Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use[38].
Unit B Irrigation and Drainage District, AZ.	0	9,497			
Underflow to Mexico[39].		9,300			
Total West Cocopah Indian Reservation, AZ.	6,139	6,885	11,434	8,854	Cocopah Indian Reservation, diversion at Imperial Dam. Pumped from wells (includes return flows). Reported as a consumptive use[40].
West Cocopah Indian Reservation, AZ.	6,139	6,485		630	W. Brand, D. Donnely (C-9-25) 35 ABA.
Underflow to Mexico[41].		400		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.

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

[39] The portion of the underflow to Mexico that is presumed to be from the application of water on Unit B (15 percent of 62,000 acre-feet).

[40] 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).

[41] 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 (20,000 acre-feet), or about 400 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, and the total underflow to Mexico across the Limitrophe Section is currently estimated to be about 20,000 acre-feet.

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name	
LCRAS			**Decree Accounting**		
Yucca Power Plant [42](Domestic consumptive use).		323	680	Yucca Power Plant. Sec 36 T16S R21E CBA. Reported as a diversion.	
Total North Cocopah Indian Reservation, AZ.	713	1,281	2,442	1,426	Huerta Packing 16S/22E-30CDA.
North Cocopah Indian Reservation, AZ.	713	1,077		676	Huerta Packing 16S/21E-25ADD.
Cocopah Bend RV (Domestic consumptive use)[43].		204		340	Cocopah Bend RV. 1 well, Sec 30 T16S R22E BDB.
				Reported as diversions.	
East Cocopah Indian Reservation, AZ. (Domestic Consumptive use)		14		Not reported.	
Yuma County (Domestic consumptive use).		4,794		Not reported.	

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

[43] Located within North Cocopah Indian Reservation.

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use		Diverter name
LCRAS			**Decree Accounting**		
State of Arizona[44].	35,526	8,817	10,585	432	Hall, Ansil (Sec 36 T16S R21E BCB
				123	Texas Hill Farm (Sec 28 T16S R22E CDA
				153	Curry Family LTD (Sec 29 T16S R22E DAC
				2,850	R.E. & P. Power (Sec 30 T16S R22E ACC
				419	Ogram, George, Sec 24 T08S R23W DCC
				538	Ogram, George, Sec23 T08S R23W CDA (Indeterminate location)
				161	Peach, Sec 22 T08S R23W DCC
				0	AZ prod, Sec 23 T08S R23W CDA (No Report)
				568	Ott, Judd T., (C-8-22) 19CCA
				1,980	Glen Curtis Cit (C-8-22) 24BDD
				3,361	Glen Curtis Cit (C-8-22) 24BDD
				0	Murphy Broadcasting, Inc (No Report).
				Reported as diversions.	
Arizona Subtotal (Below Hoover Dam, less Wellton-Mohawk Irrigation and Drainage District).	386,615	2,272,326	2,608,883	Arizona Subtotal (Below Hoover Dam, less Wellton-Mohawk Irrigation and Drainage District).	

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

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS				**Decree Accounting**
			67,679	Pumped from South Gila Wells (drainage pump outlet channels): Returns.
Arizona uses above Hoover Dam[45].		183	183	Arizona uses above Hoover Dam.
			166	Lake Mead Nat'l Recreation, AZ. Diversions from Lake Mead (Temple Bar).
			17	Marble Canyon Company.
Wellton-Mohawk Irrigation and Drainage District [46].		312,514	312,514	Wellton-Mohawk Irrigation and Drainage District.
			156,912	Unmeasured return flow credit to Arizona.
Arizona Total.	386,615	2,585,023	2,696,989	Arizona Total.
Total Lower Basin Use.	604,442	8,059,700	8,100,931	Total Lower Basin Use[46].

[45] From 1997 Decree Accounting Report.

[46] Includes some unquantified amount of phreatophyte consumptive 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:

Consumptive Use, State of Nevada

Consumptive Use (State Totals, AZ and CA)

Palo Verde Irrigation and Drainage District (CA)

Colorado River Indian Reservation (AZ)

Yuma County Water Users Association (AZ)

Cibola National Wildlife Refuge (AZ)

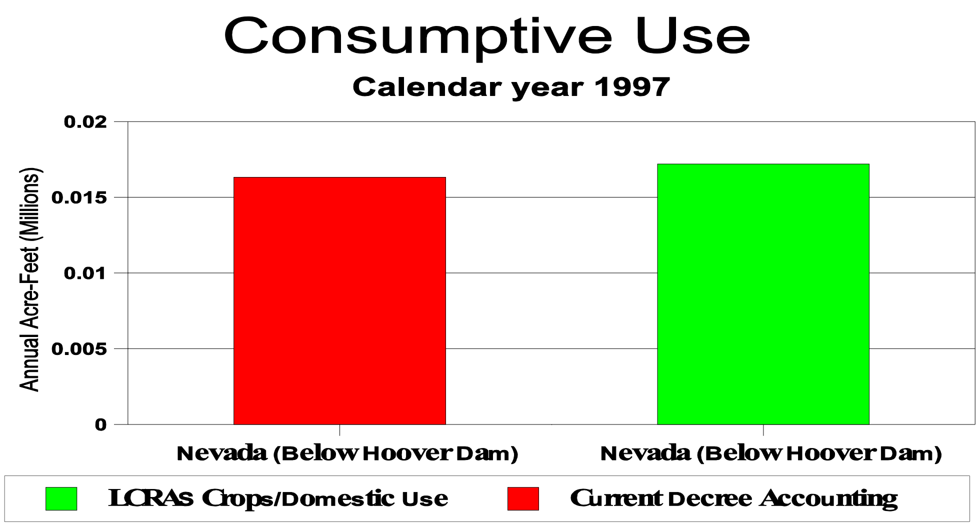
Cibola Valley Irrigation and Drainage District (AZ)

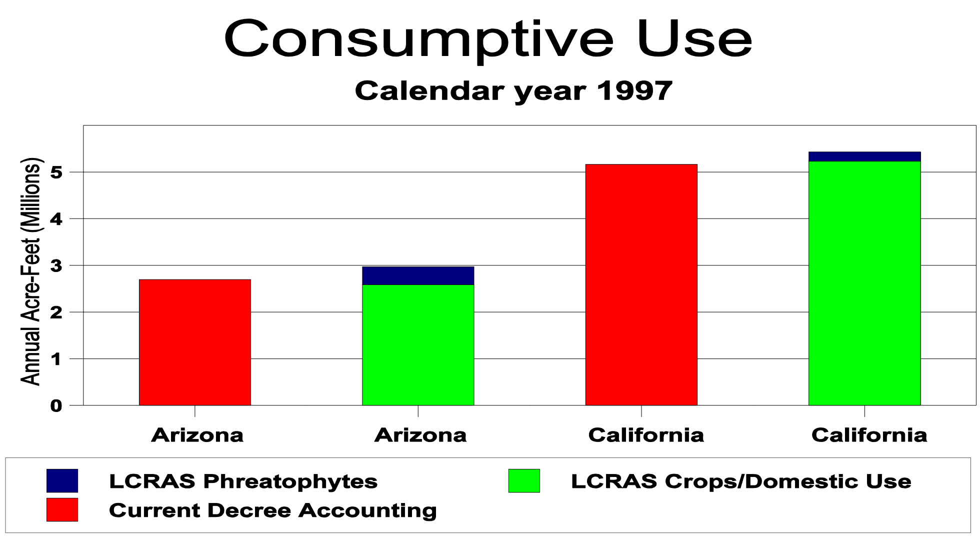
The following bar charts show the consumptive use reported by the 1997 Decree Accounting Report and the consumptive use of crops, phreatophytes, and domestic uses produced by LCRAS for State totals, and selected irrigation districts and wildlife refuges. These bar charts highlight three major points:

- Importance of determining the amount of phreatophyte use that should be reported as part of a diverters' consumptive use.

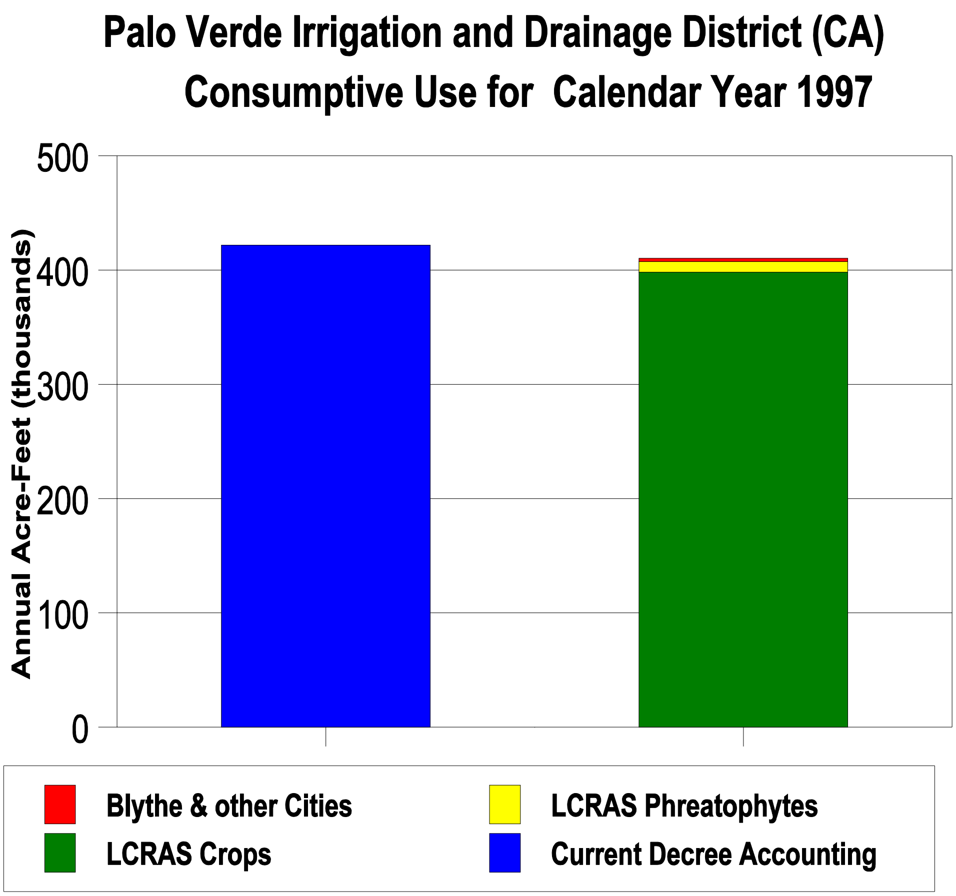
- Comparison between the consumptive use of crops produced by LCRAS and the consumptive use reported by the Decree Accounting Report.

- Consumptive use calculated by decree accounting can include more than the crop consumptive use within an irrigation district.

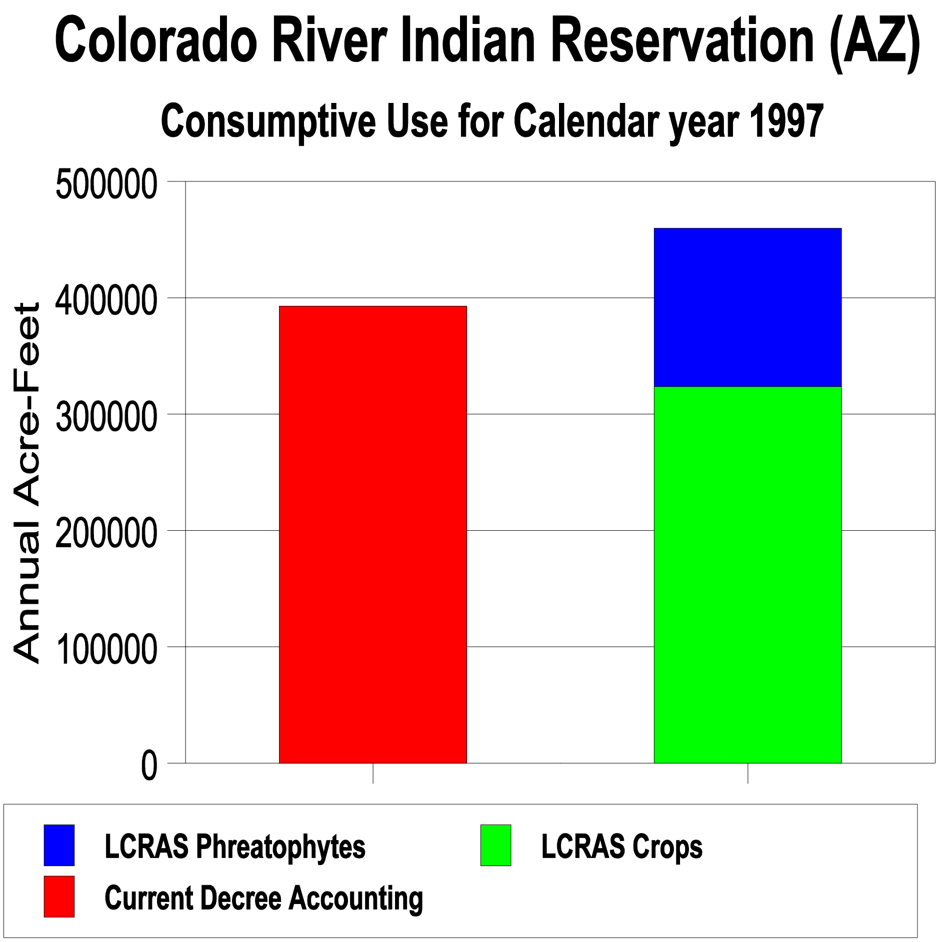




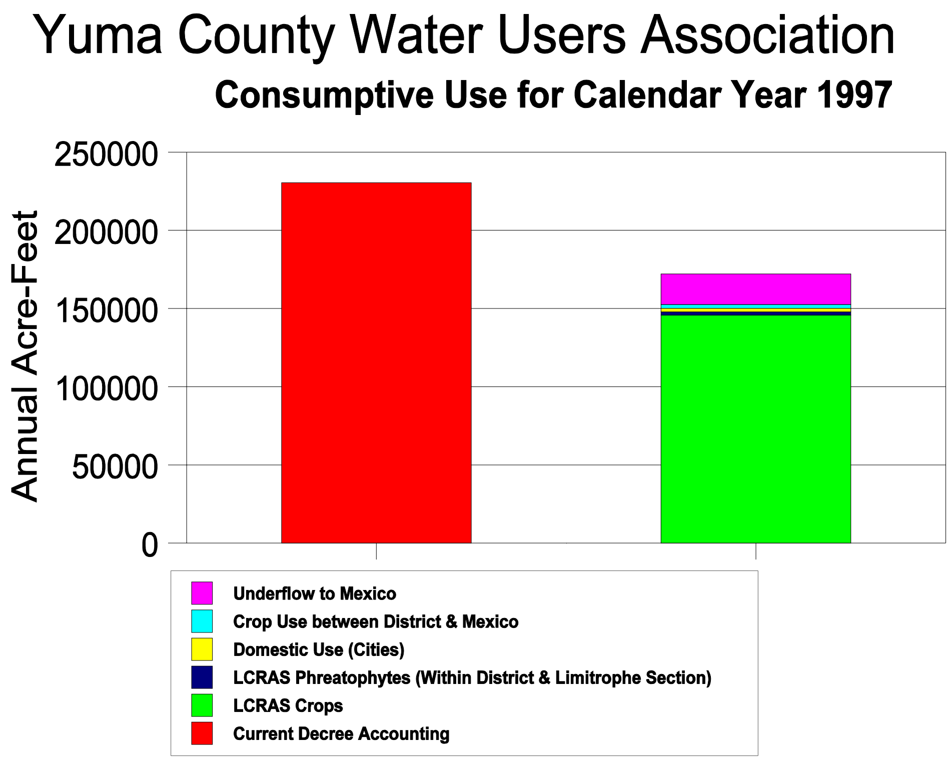
The bar chart for the State of Nevada shows the minor impact LCRAS has on consumptive use calculations in Nevada. LCRAS has a minor impact because there was no irrigation in Nevada in 1997. The bar chart for the States of California and Arizona shows a good comparison between the consumptive uses of crops produced by LCRAS, the total consumptive uses reported by the Decree Accounting Report (with Decree Accounting estimates of unmeasured return flows to the States included), and the minor amount of phreatophyte consumptive use on a statewide basis.



The bar chart for the Palo Verde Irrigation District shows the sum of consumptive uses from crops, phreatophytes, and domestic uses compared with the consumptive use value reported by Decree Accounting. The consumptive use value 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.

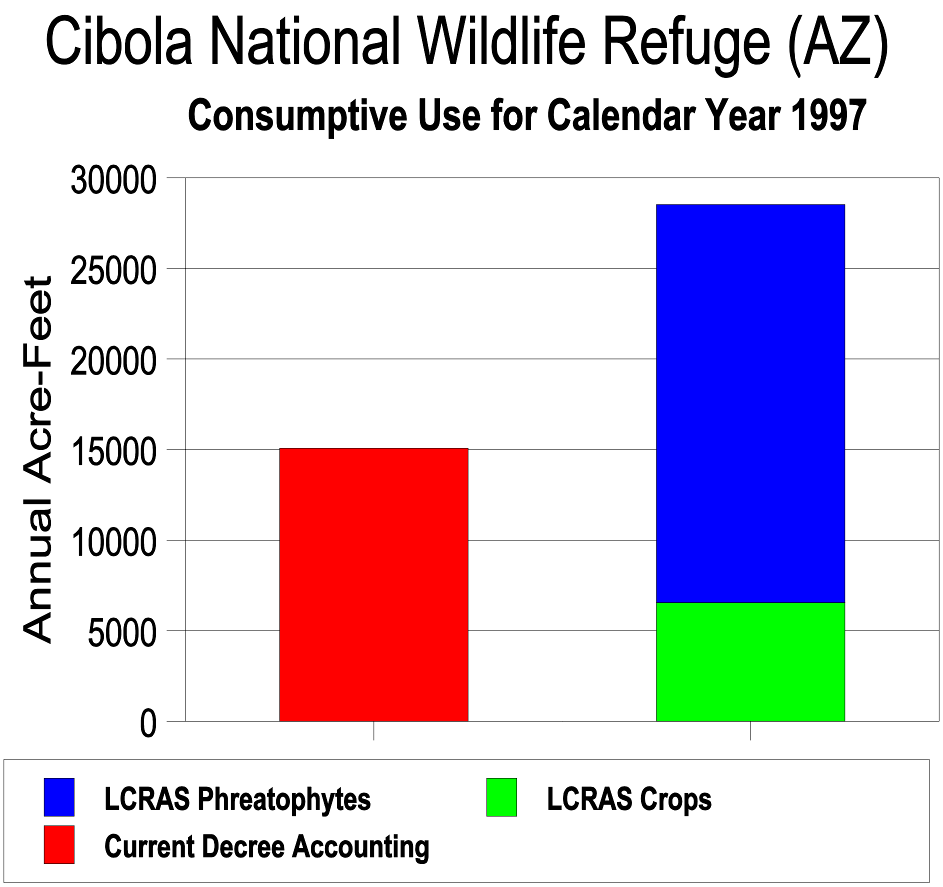


The bar chart for the Colorado River Indian Reservation (AZ) shows the sum of consumptive uses from crops and phreatophytes, and the consumptive use value reported by Decree Accounting. The consumptive use value reported for the Colorado River Indian Reservation by Decree Accounting does not include the estimate of unmeasured return flow from the Colorado River Indian Reservation that is applied to Arizona's apportionment.

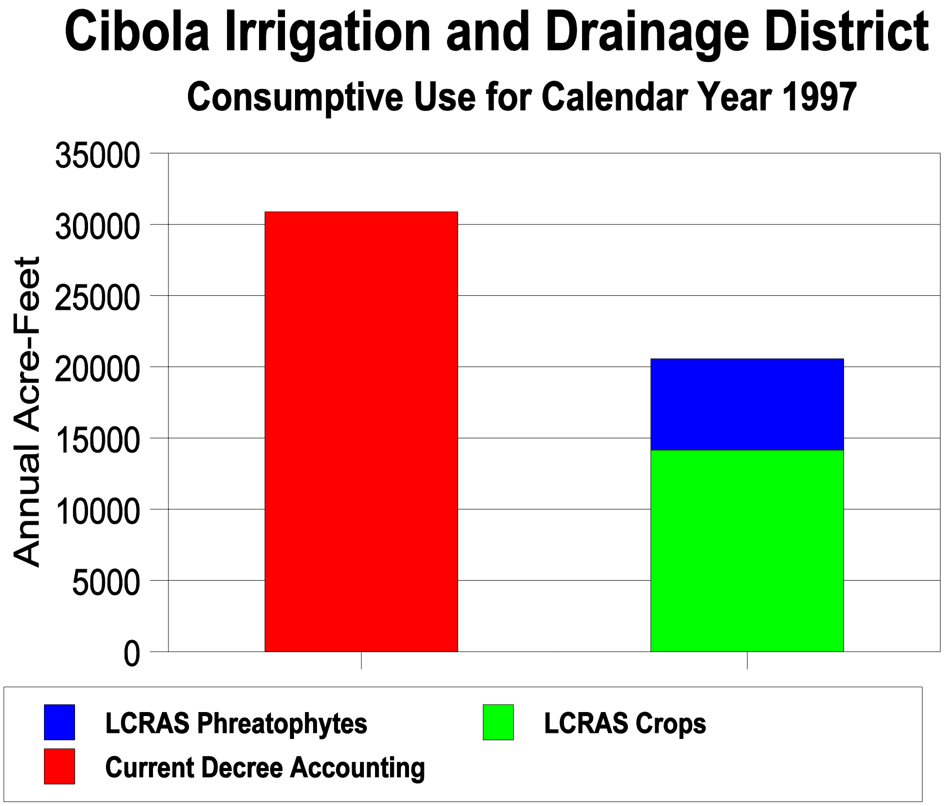


The bar chart for the Yuma County Water Users Association shows the crop, phreatophyte, and domestic consumptive uses within the district boundary developed by LCRAS, plus an estimate of the underflow to Mexico that results from applied but unconsumed water within the district, plus crop and phreatophyte use between the Mexican border and the district boundary; and the consumptive use value reported by Decree Accounting. The consumptive use value 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 should be considered part of the Yuma County Water Users Association's consumptive use because it is not accountable as part of the Mexican delivery and is not available for other uses in the United States. The domestic uses and crop and phreatophyte use between the district boundary and Mexico also represents water diverted from the Colorado River that does not return.



The bar chart for the Cibola National Wildlife Refuge shows the crop and phreatophyte consumptive 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 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 and phreatophyte consumptive 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 use that should be included in the consumptive use of a diverter is critical.

Attachment 5

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 surface within the project area. These technologies are used to classify crop types, phreatophytes, and open water surface, 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 5-A for metadata on this database. Five field border databases cover the project area (Fig. 5-1). The areal 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 was 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 5-B presents a comparison of acreage calculated for fields based on the field border database captured from SPOT data and acreage calculated using GPS control points. This was completed to ensure that acreage values derived from field borders captured from the SPOT satellite data fell 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 will be used for the 1998 LCRAS report.

Table Att-5-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

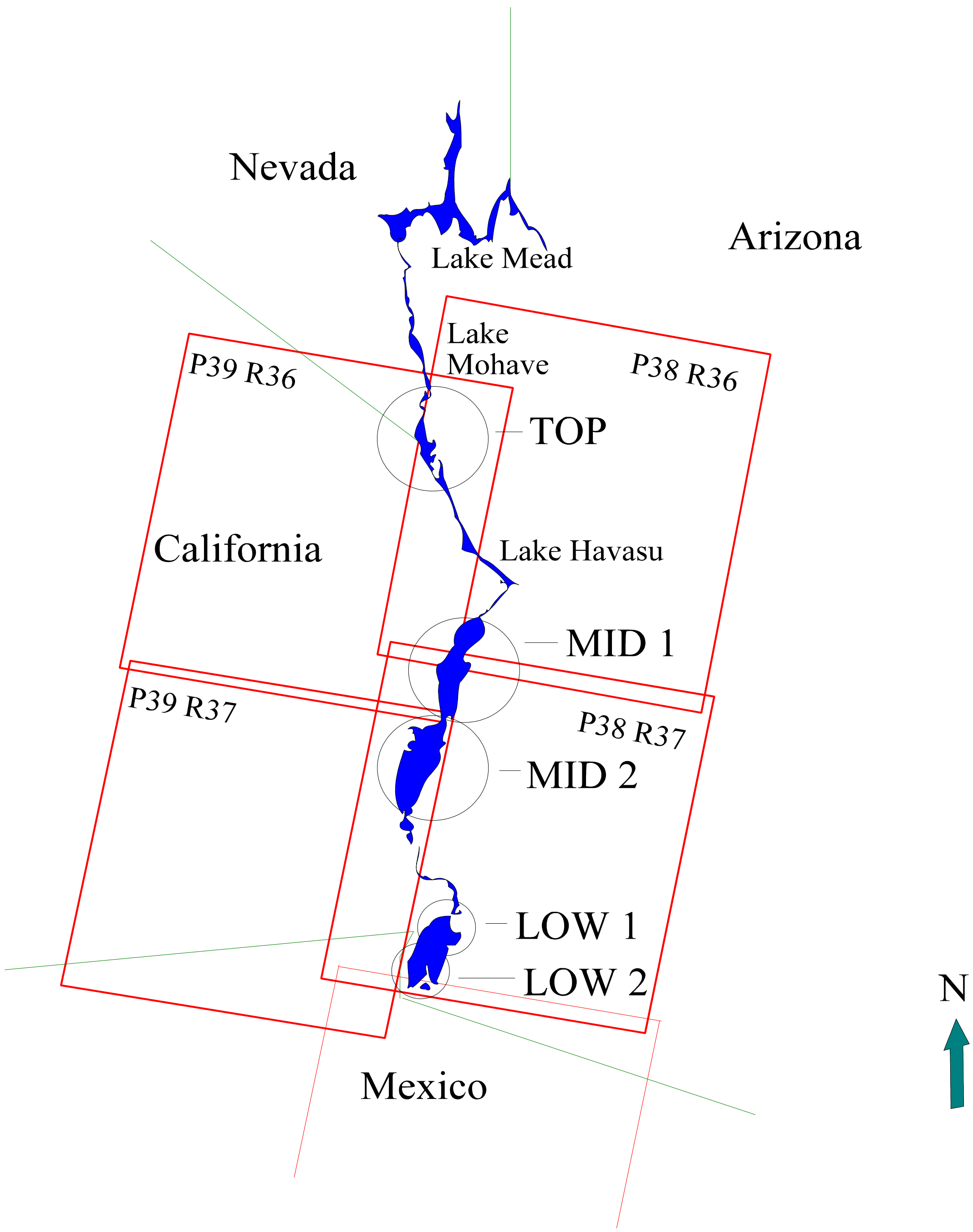


Figure Att-5.1 — Image processing areas for agriculture and Landsat scene boundaries.

Table Att-5-B — Field Acreage Derived From SPOT Satellite Data Versus GPS Generated Acreage

LOW2.PAT	SPOT IMAGE	GPS SURVEY	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**	**GPS SURVEY**	**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**	**GPS SURVEY**	**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**	**GPS SURVEY**	**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 Agricultural Areas

Introduction

Agricultural 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 fly-over date and crop planting practices.

Image classification processing areas are chosen as a function of the extent of agricultural 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 (Fig. 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 a person who records the data (coder). Ground reference collection periods are chosen to coincide as closely as possible with the Landsat satellite fly-over date(s).

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 what crop 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 using laptop computers, and a data collection program which was written for this project. Table 5-C lists ground reference attributes that are collected. Table 5-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-5-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 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 5.2, 5.3, and 5.4 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 was extremely time consuming and required considerable analyst manipulation and interpretation of signature sets to achieve the desired classification accuracy.

A new process was created to automatically extract training signatures for spectral classification. This process 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 6.5 shows ground reference fields partitioned into spectral regions. Note that these fields were 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 agricultural 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-5-D — 1997 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		

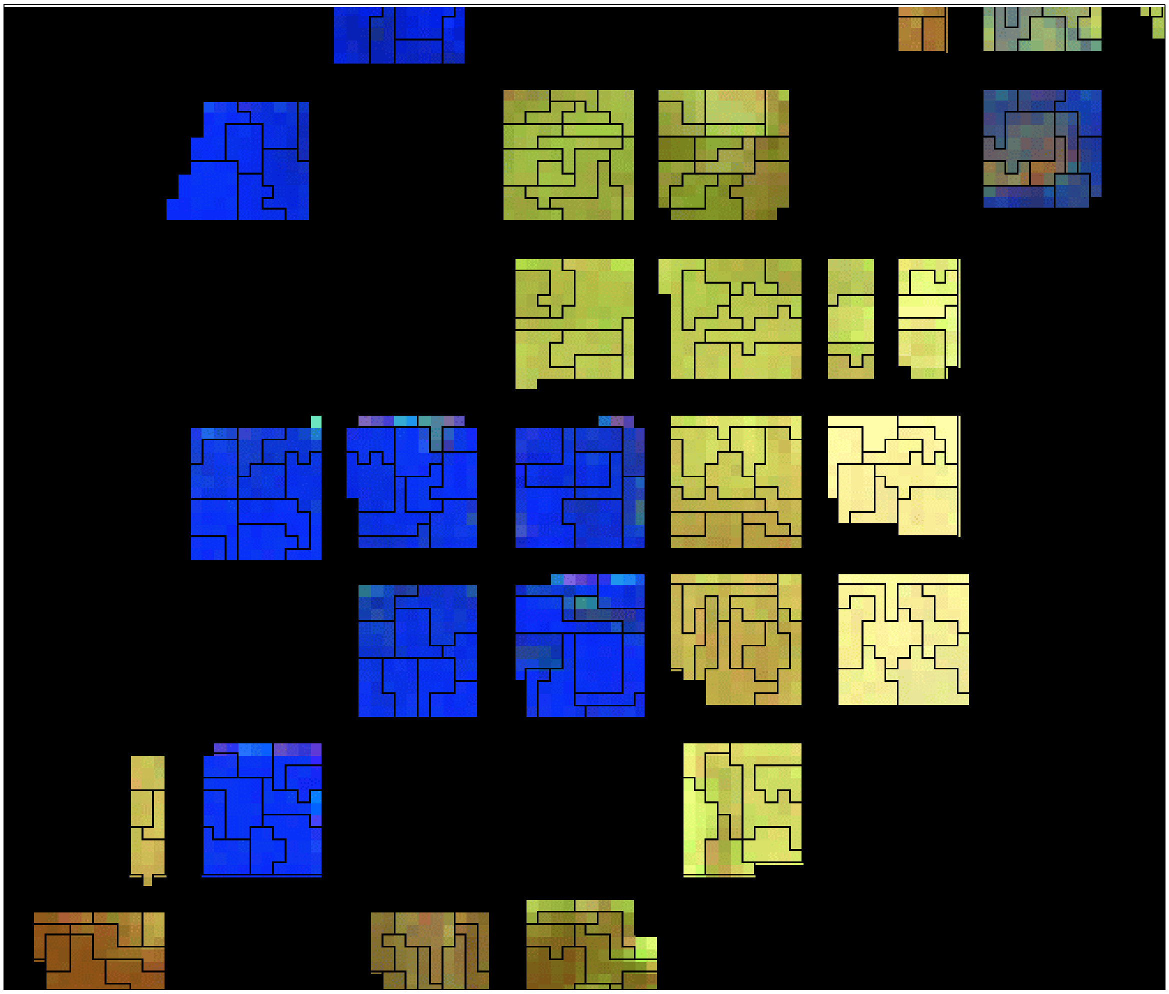


Figure Att-4.5 — Ground Reference Fields - masked and partitioned into spectral regions for signature generation. Black lines denote spectral regions plotted on Landsat bands 4, 3, 2.

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 at least 14 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, further investigation for determining optimum cutoffs is recommended. 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 agricultural 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 water consumptive modeling results.

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 water-use modeling. Accuracy figures reported on the number of fields correct help to easily define which crops are being confused in the classifier and are useful in determining ways of improving the classification process and creating annual crop summaries.

Tables Att-5-E, Att-5-F, Att-5-G, and Att-5-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 (commissions errors). An omission error occurs when an area (in this case an agricultural 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-5-E — March 1997 Accuracy Assessment Error Matrix - by Field
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**	**204**		10			1	**1**			3	1		3			**0**	??
Cotton	**2**		**4**											4			**8**	50.00%
Small Grain	**4**	2		**80**		2						1		1			**86**	93.02%
Corn	**5**				**1**												**1**	100.00%
Lettuce	**6**	1		1		**22**	1					2	3	1			**31**	70.97%
Melons	**7**						**1**										**1**	100.00%
Bermuda Grass	**8**	5		1				**13**				1		3			**23**	56.52%
Citrus	**9**								**31**								**31**	100.00%
Tomatoes	**10**																**0**	
Sudan Grass	**11**										**2**						**2**	100.00%
Other Vegs.	**12**					1	1					**3**					**5**	60.00%
Crucifers	**13**					2	1						**2**	1			**6**	33.33%
Fallow	**14**	**5**		**6**	**2**		**3**	**1**				**1**		**167**			**185**	90.27%
Dates	**15**																**0**	
Safflower	**16**																**0**	
TOTALS		**217**	**4**	**98**	**3**	**27**	**8**	**15**	**31**	**0**	**5**	**9**	**5**	**180**	**0**	**0**	**602**	Total Samples
%correct by crop		94%	100%	82%	33%	81%	12%	87%	100%		40%	33%	40%	93%		??	**530**	Total Correct
																	88%	**% correct**
total w/ fallow correction		212	4	92	1	27	5	14	31	0	5	8	5	198	0	0	602	
%correct w/ fallow correction		96%	100%	87%	100%	81%	20%	93%	100%		40%	38%	40%	94%		??	**91%**	
total berm OR alf correct		209						14										
%correct w/ b/a correction		96%						93%									**89%**	
% correct w/ b-a & fallow correction		99%						100%									**92%**	

March 1997 Accuracy Assessment - by Acreage - 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**	**7116.54**		189.81			16.19	**44.34**			80.78	8.56		93.79			**0.00**	??
Cotton	**2**		**105.19**											84.29			**189.48**	55.52%
Small Grain	**4**	17.42		**2123.69**		33.15						18.95		17.34			**2210.55**	96.07%
Corn	**5**				**17.3**												**17.30**	100.00%
Lettuce	**6**	9.42		10.18		**472.52**	11.62					35.49	51.11	39.69			**630.03**	75.00%
Melons	**7**						**16.71**										**16.71**	100.00%
Bermuda Grass	**8**	**75.80**		18.43				**253.61**				4.12		47.12			**399.08**	63.55%
Citrus	**9**								**619.92**								**619.92**	100.00%
Tomatoes	**10**																**0.00**	
Sudan Grass	**11**										**46.26**						**46.26**	100.00%
Other Vegs.	**12**					33.9	33.73					**92.42**					**160.05**	57.74%
Crucifers	**13**					17.62	18.81						**52.73**	12.6			**101.76**	51.82%
Fallow	**14**	**192.29**		**161.91**	**30.29**		**79.06**	**18.42**				**15.4**		**5759.15**			**6256.52**	92.05%
Dates	**15**																**0.00**	
Safflower	**16**																**0.00**	
TOTALS		**7411.47**	**105.19**	**2504.02**	**47.59**	**557.19**	**176.12**	**316.37**	**619.92**	**0.00**	**127.04**	**174.94**	**103.84**	**6053.98**	**0.00**	**0.00**	**18197.67**	Total Samples
%correct by crop		96%	100%	85%	36%	85%	9%	80%	100%		36%	53%	51%	95%		??	**16676.04**	Total Correct
																	92%	**% correct**
total w/ fallow correction		7219.18	105.19	2342.11	17.3	557.19	97.06	297.95	619.92	0	127.04	159.54	103.84	6551.35	0	0	18197.67	
%correct w/ fallow correction		99%	100%	91%	100%	85%	17%	85%	100%		36%	58%	51%	96%		??	**94%**	
total berm OR alf correct		7,192.34						297.95									**7490.29**	
%correct w/ b/a correction		97%						94%									**92%**	
% correct w/ b-a & fallow correction		100%						100%									**95%**	

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

Table Att-5-F — May 1997 Accuracy Assessment Error Matrix - by Field
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**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**		
Alfalfa	**1**	**205**	1	1				**4**			10	1					**222**	92.34%
Cotton	**2**	2	**99**	3							4			4			**112**	88.39%
Small Grain	**4**		1	**95**	4						1	1		1		1	**104**	91.35%
Corn	**5**	1			**20**												**21**	95.24%
Lettuce	**6**																**0**	
Melons	**7**	2	2	3			**18**				1	1					**27**	66.67%
Bermuda Grass	**8**	6						**10**			1						**17**	58.82%
Citrus	**9**								**72**								**72**	100.00%
Tomatoes	**10**																**0**	
Sudan Grass	**11**	4					1				**31**						**36**	86.11%
Other Vegs.	**12**											**2**					**2**	100.00%
Crucifers	**13**																**0**	
Fallow	**14**	**2**	**5**				**2**							**21**			**30**	70.00%
Dates	**15**														**10**		**10**	100.00%
Safflower	**16**			1			1									**3**	**5**	60.00%
TOTALS		**222**	**108**	**103**	**24**	**0**	**22**	**14**	**72**	**0**	**48**	**5**	**0**	**26**	**10**	**4**	**658**	Total Samples
%correct by crop		92%	92%	92%	83%		82%	71%	100%		65%	40%		81%	100%	75%	**586**	Total Correct
																	89%	**% correct**
total w/ fallow correction		220	103	103	24	0	20	14	72	0	48	5	0	35	10	4	658	
%correct w/ fallow correction		93%	96%	92%	83%		90%	71%	100%		65%	40%		88%	100%	75%	**90%**	
total berm OR alf correct		211						14										
%correct w/ b/a correction		95%						100%									**91%**	
% correct w/ b/a/f correction		96%						100%									**92%**	

May 1997 Accuracy Assessment - by Acreage - 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**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**		
Alfalfa	**1**	**6870.50**	39.59	35.81				**147.3**			372.61	6.52					**7472.33**	91.95%
Cotton	**2**	21.94	**3382.9**	38.03							80.51			142.19			**3665.57**	92.29%
Small Grain	**4**		35.78	**2136.12**	72.37						19.16	13.17		3.05		8.58	**2288.23**	93.35%
Corn	**5**	8.16			**512.25**												**520.41**	98.43%
Lettuce	**6**																**0.00**	
Melons	**7**	75.02	108.86	47.65			**647.04**				26.04	15.4					**920.01**	70.33%
Bermuda Grass	**8**	**104.60**						**186.41**			9.79						**300.80**	61.97%
Citrus	**9**								**1053.6**								**1053.60**	100.00%
Tomatoes	**10**																**0.00**	
Sudan Grass	**11**	100.97					5.16				**965.61**						**1071.74**	90.10%
Other Vegs.	**12**											**57.46**					**57.46**	100.00%
Crucifers	**13**																**0.00**	
Fallow	**14**	**92.59**	**124**				**111.01**							**547.43**			**875.03**	62.56%
Dates	**15**														**82.32**		**82.32**	100.00%
Safflower	**16**			19.33			36.74									**76.35**	**132.42**	57.66%
TOTALS		**7273.78**	**3691.13**	**2276.94**	**584.62**	**0.00**	799.95	**333.71**	1053.60	**0.00**	**1473.72**	**92.55**	**0.00**	**692.67**	**82.32**	**84.93**	**18439.92**	Total Samples
%correct by crop		94%	92%	94%	88%		81%	56%	100%		66%	62%		79%	100%	90%	**16517.99**	Total Correct
																	90%	**% correct**
total w/ fallow correction		7181.19	3567.13	2276.94	584.62	0	688.94	333.71	1053.6	0	1473.72	92.55	0	1020.27	82.32	84.93	18439.92	
%correct w/ fallow correction		96%	95%	94%	88%		94%	56%	100%		66%	62%		88%	100%	90%	**91%**	
total berm OR alf correct		6,975.10						333.71									**7308.81**	
%correct w/ b/a correction		96%						100%									**91%**	
% correct w/ b/a/f correction		97%						100%									**93%**	

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

Table Att-5-G — August 1997 Accuracy Assessment Error Matrix - by Field
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**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**		
Alfalfa	**1**	**190**	11					**4**			6	2		1			**214**	88.79%
Cotton	**2**	9	**97**		1							1					**108**	89.81%
Small Grain	**4**													2			**2**	0.00%
Corn	**5**																**0**	
Lettuce	**6**																**0**	
Melons	**7**																**0**	
Bermuda Grass	**8**	1						**3**			1						**5**	60.00%
Citrus	**9**								**49**								**49**	100.00%
Tomatoes	**10**																**0**	
Sudan Grass	**11**	8		1				2			**14**			1			**26**	53.85%
Other Vegs.	**12**										1						**1**	0.00%
Crucifers	**13**																**0**	
Fallow	**14**	**4**	**2**				**3**	**2**			**4**			**207**			**222**	93.24%
Dates	**15**														**11**		**11**	100.00%
Safflower	**16**																**0**	
TOTALS		**212**	**110**	**1**	**1**	**0**	**3**	**11**	**49**	**0**	**26**	**3**	**0**	**211**	**11**	**0**	**638**	Total Samples
%correct by crop		90%	88%	0%	0%		0%	27%	100%		54%	0%		98%	100%	??	**571**	Total Correct
																	89%	**% correct**
total w/ fallow correction		208	108	1	1	0	0	9	49	0	22	3	0	226	11	0	638	
%correct w/ fallow correction		91%	90%	0%	0%			33%	100%		64%	0%		98%	100%	??	**92%**	
total berm OR alf correct		191						7										
%correct w/ b/a correction		90%						64%									**90%**	
% correct w/ b-a & fallow correction		92%						78%									**93%**	

August 1997 Accuracy Assessment - by Acreage - 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**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**		
Alfalfa	**1**	**6639.82**	378.82					**128.09**			213.23	11.24		18.29			**7389.49**	89.85%
Cotton	**2**	177.43	**3124.36**		17.87							1.24					**3320.90**	94.08%
Small Grain	**4**													121.01			**121.01**	0.00%
Corn	**5**																**0.00**	
Lettuce	**6**																**0.00**	
Melons	**7**																**0.00**	
Bermuda Grass	**8**	**9.48**						**28.11**			23.17						**60.76**	46.26%
Citrus	**9**								**816.98**								**816.98**	100.00%
Tomatoes	**10**																**0.00**	
Sudan Grass	**11**	157.95		6.08				29.4			**671.76**			25.68			**890.87**	75.40%
Other Vegs.	**12**										18.16						**18.16**	0.00%
Crucifers	**13**																**0.00**	
Fallow	**14**	**53.21**	**60.46**				**64.07**	**93.69**			**83.72**			**5177.64**			**5532.79**	93.58%
Dates	**15**														**117.87**		**117.87**	100.00%
Safflower	**16**																**0.00**	
TOTALS		**7037.89**	**3563.64**	**6.08**	**17.87**	**0.00**	**64.07**	**279.29**	**816.98**	**0.00**	**1010.04**	**12.48**	**0.00**	**5342.62**	**117.87**	**0.00**	**18268.83**	Total Samples
%correct by crop		94%	88%	0%	0%		0%	10%	100%		67%	0%		97%	100%	??	**16576.54**	Total Correct
																	91%	**% correct**
total w/ fallow correction		6984.68	3503.18	6.08	17.87	0	-1.42e-14	185.6	816.98	0	926.32	12.48	0	5697.77	117.87	0	18268.83	
%correct w/ fallow correction		95%	89%	0%	0%			15%	100%		73%	0%		97%	100%	??	**93%**	
total berm OR alf correct		6,649.30						156.20									**6805.50**	
%correct w/ b/a correction		94%						56%									**91%**	
% correct w/ b-a & fallow correction		95%						84%									**93%**	

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

Table Att-5-H — January 1998 Accuracy Assessment Error Matrix - by Field
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	5	6	7	8	9	10	11	12	13	14	15	16		
Alfalfa	1	189		3								3	2	1			198	95.45%
Cotton	2																0	
Small Grain	4	7		18		2								1			28	64.29%
Corn	5																0	
Lettuce	6	1		2		75							4	1			83	90.36%
Melons	7																0	
Bermuda Grass	8																0	
Citrus	9								49								49	100.00%
Tomatoes	10																0	
Sudan Grass	11																0	
Other Vegs.	12					1						3	2	1			7	42.86%
Crucifers	13												13				13	100.00%
Fallow	14	7		21		26					2	2		132			190	69.47%
Dates	15														11		11	100.00%
Safflower	16																0	
TOTALS		204	0	44	0	104	0	0	49	0	2	8	21	136	11	0	579	Total Samples
%correct by crop		93%		41%		72%			100%		0%	38%	62%	97%	100%	??	490	Total Correct
																	85%	% correct
total w/ fallow correction		197	0	23	0	78	0	0	49	0	0	6	21	194	11	0	579	
%correct w/ fallow correction		96%		78%		96%			100%			50%	62%	98%	100%	??	95%	
total berm OR alf correct		189						0										
%correct w/ b/a correction		93%															85%	
% correct w/ b-a & fallow correction		96%															95%	

January 1998 Accuracy Assessment - by Acreage - 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	5	6	7	8	9	10	11	12	13	14	15	16		
Alfalfa	1	6864.83		125.58								74.38	72.37	62.61			7199.77	95.35%
Cotton	2																0.00	
Small Grain	4	180.08		853.64		30.69								4.72			1069.13	79.84%
Corn	5																0.00	
Lettuce	6	21.62		20.78		1440.99							61.3	34.2			1578.89	91.27%
Melons	7																0.00	
Bermuda Grass	8																0.00	
Citrus	9								619.67								619.67	100.00%
Tomatoes	10																0.00	
Sudan Grass	11																0.00	
Other Vegs.	12					10.38						53.42	39.07	26.84			129.71	41.18%
Crucifers	13												299.55				299.55	100.00%
Fallow	14	151.41		762.42		535.84					57.4	22.18		4669.41			6198.66	75.33%
Dates	15														74.46		74.46	100.00%
Safflower	16																0.00	
TOTALS		7217.94	0.00	1762.42	0.00	2017.90	0.00	0.00	619.67	0.00	57.40	149.98	472.29	4797.78	74.46	0.00	17169.84	Total Samples
%correct by crop		95%		48%		71%			100%		0%	36%	63%	97%	100%	??	14875.97	Total Correct
																	87%	% correct
total w/ fallow correction		7066.53	0	1000	0	1482.06	0	0	619.67	0	0	127.8	472.29	6327.03	74.46	0	17169.84	
%correct w/ fallow correction		97%		85%		97%			100%			42%	63%	98%	100%	??	96%	d/t w/ fallow correction
total berm OR alf correct		6,864.83						0.00									6864.83	
%correct w/ b/a correction		95%															87%	d/t w b/a correction
% correct w/ b-a & fallow correction		97%															96%	d/t w b/a/f correction

* 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).

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. Based on this statistical sample, error within mature crop types represents less than 6 percent of the total acreage.

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 all possible multi-temporal crop combinations (over 1,000 unique combinations in the 1997 database) and assigns acreage of crop type(s) for each field. Figure Att-5.6 is a graphic example of how this program functions. In Figure Att-5.6, 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 40 acres of Cotton and 40 acres of Lettuce as this combination is expected from crop planting practices. Fallow acreage is also reported.

Classification of Phreatophyte Areas

Introduction

Phreatophyte areas were initially classified in 1994. These data were updated in 1997. A May image is used for the spectral classification. Landsat Thematic Mapper imagery (bands 1-5,7) are the principle source data. Available aerial photography is routinely used as an ancillary data set to help in spectral classification processes and editing. Image classification processing areas are chosen as a function of image dates and a flood plain boundary (modified to include all phreatophyte communities) described in 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 1996 and May 1997) and focuses remapping efforts in areas of spectral change.

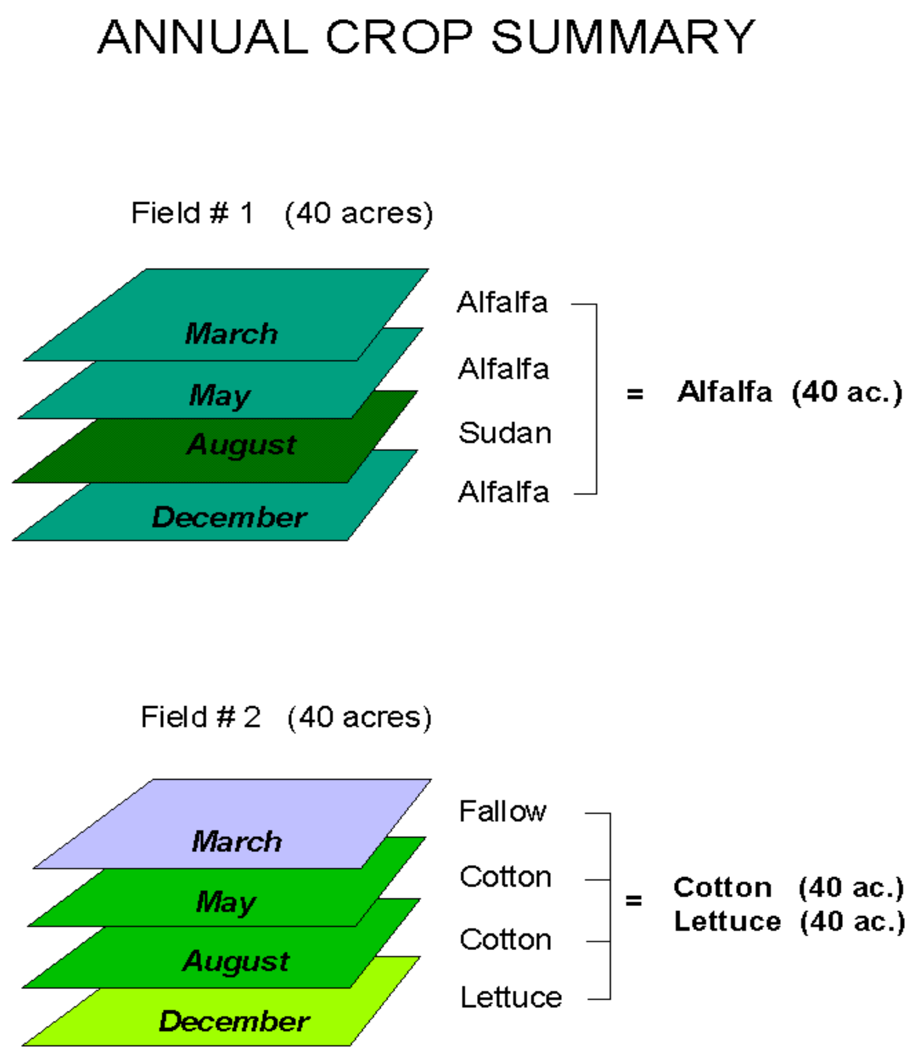
Ground Reference Data Collection

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. agriculture 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-5.6 — 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 was added to the Landsat Thematic Mapper (TM) 6-band image.

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

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

Each image was classified using both supervised and unsupervised algorithms. Signature files from the classifications were merged and analyzed using statistical clustering algorithms. The presence of the additional bands did 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 all of the spectral variability in the area of interest has not been accounted for.

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 will be updated using change detection methodologies. Landsat imagery is used for image-to-image comparison to identify spectral change from year to year. The phreatophytes were updated for 1997.

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 was 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 adequately address complexities associated with natural vegetation communities (Gopal, et. al., 1994).

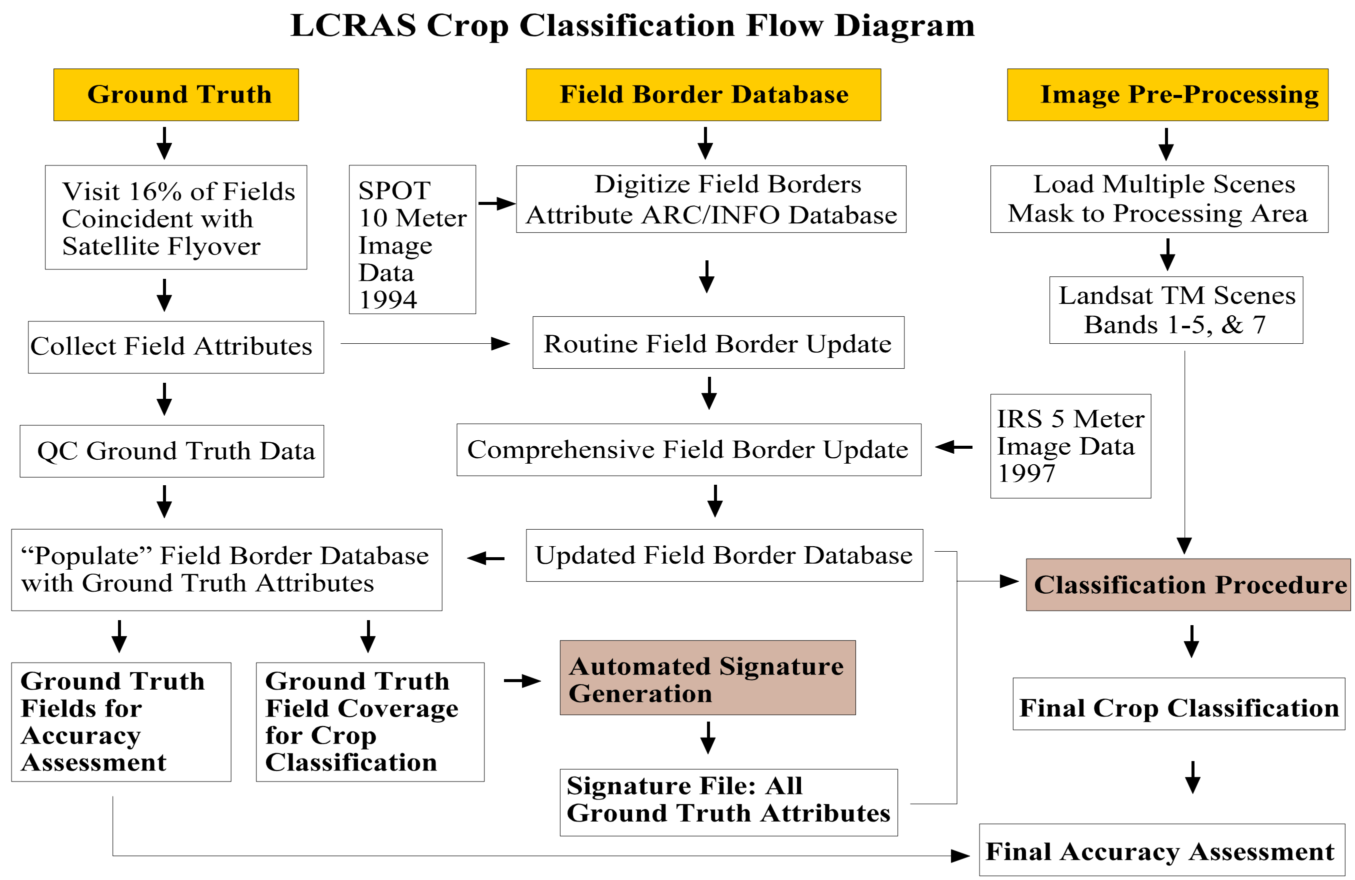


Figure Att-4.2 — LCRAS Crop Classification Flow Diagram.

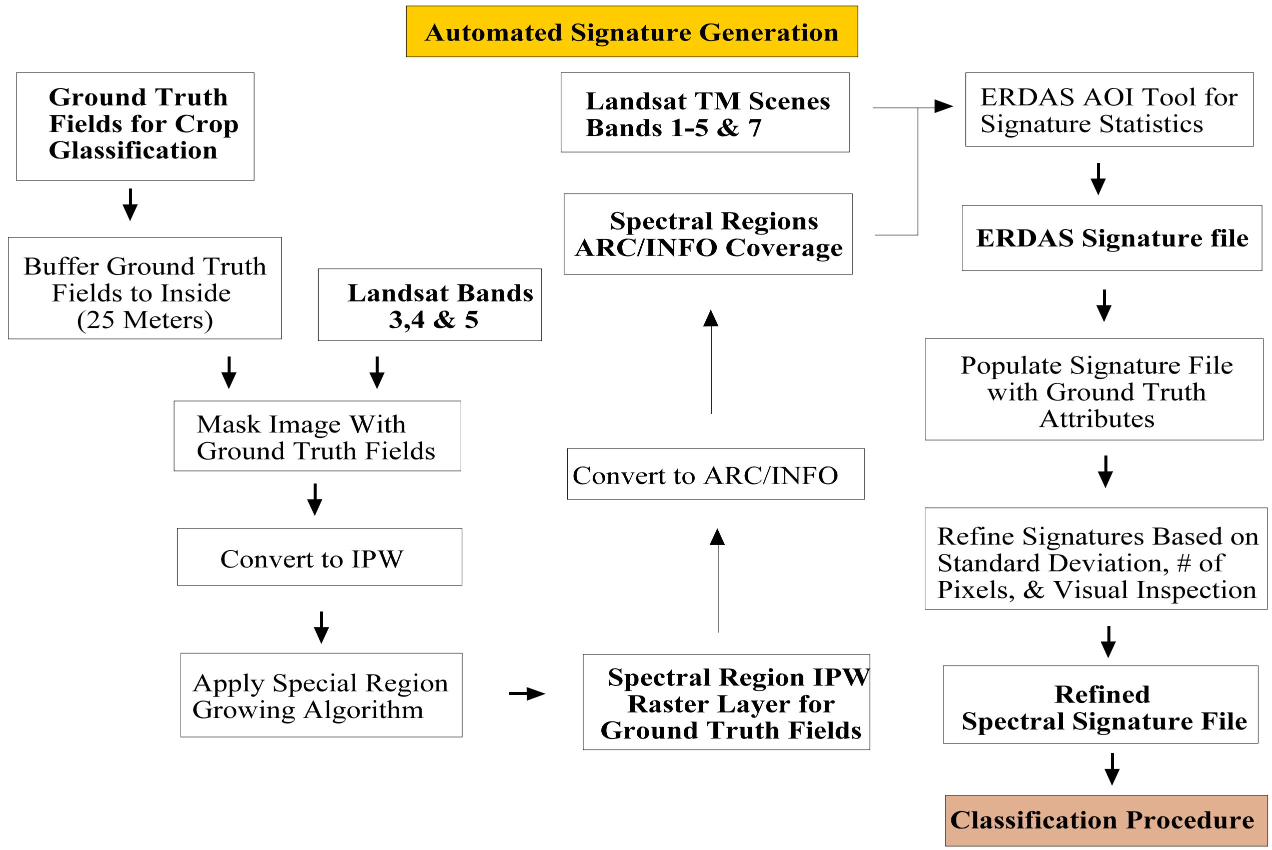


Figure Att-4.3 — Automated Signature Generation.

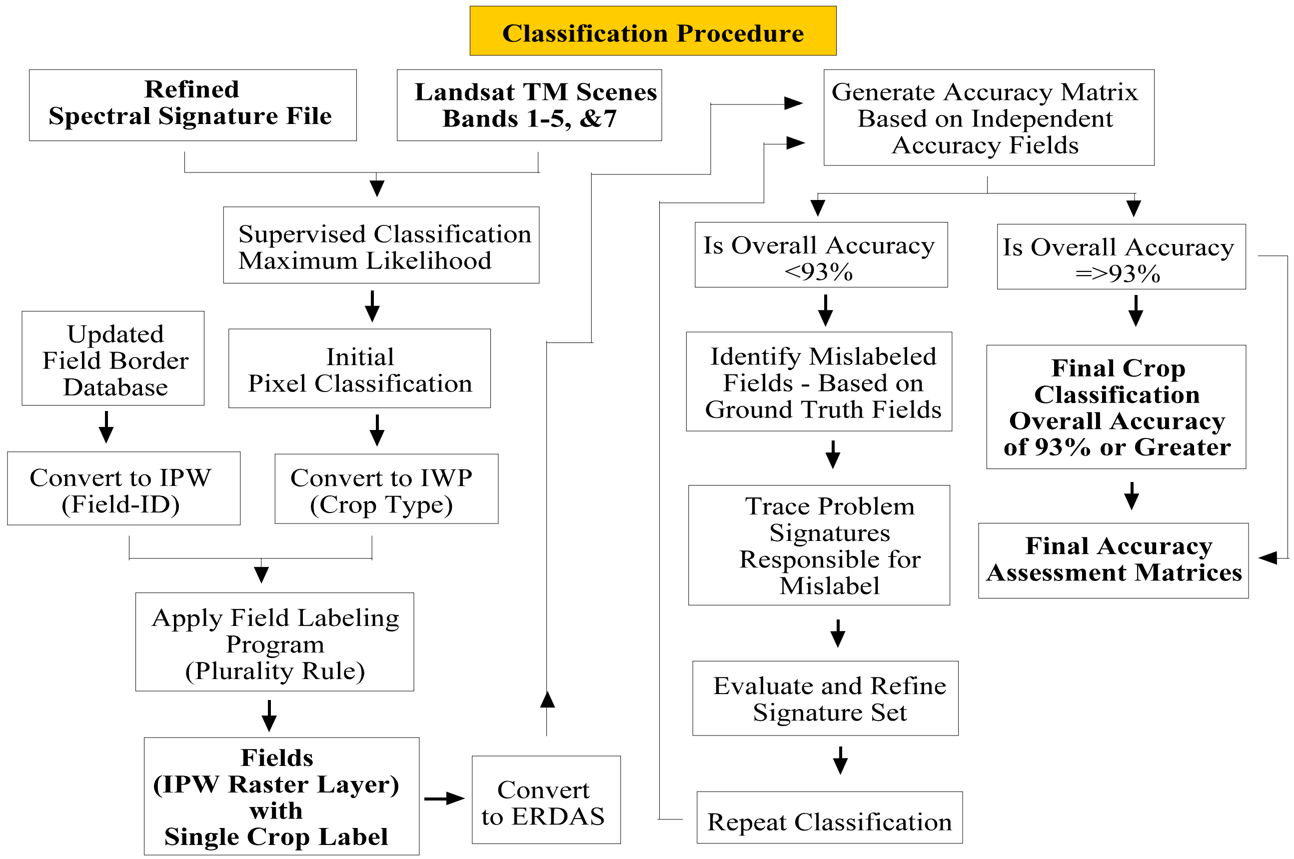


Figure Att-4.4 — Classification Procedure.

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