Lower Colorado River Accounting System

Demonstration of Technology

Calendar Year 1996

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

July 1998

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Boulder City, Nevada

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

0 100 MILES
0 100 KILOMETERS

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) provide detailed and accurate records of diversions, return flows, and consumptive use of water diverted from the mainstream "stated separately as to each diverter from the mainstream, each point of diversion, and each of the States of Arizona, California, and Nevada." 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 (USGS), 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 both measured and unmeasured flows. The USGS finished its development of LCRAS in the late 1980s, but a final report was not published until 1995. In 1990, Reclamation took over responsibility for continuing development of LCRAS. Reclamation has modified LCRAS and issued a report in 1995 entitled "Lower Colorado River Accounting System Demonstration of Technology for Calendar Year 1995" (1995 LCRAS report), which documents the first application of this modified version of LCRAS. This report also contains a more detailed history of events which led to the development of LCRAS. This report documents the application of LCRAS to calendar year 1996 and the changes made to the LCRAS method made since the 1995 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 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 balance because the residual can be either a positive or negative number.

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) acres 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 applying a consumptive use factor to a measured diversion (usually 0.6), or 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), or by subtracting a measured return flow from a measured diversion, or, in a few cases, by a method submitted by a domestic user.

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 agricultural vegetation classes. Reliable results were obtained for crops 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 (4 dates per year) in 1996.

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 1996 using remote-sensing-based change detection methodologies and the 1995 phreatophyte database. Accuracy assessment of updated maps is planned for 1997.

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 1996.

Water Balance Results

The water balance closure was evaluated for each reach by comparing the value of the residual to the measurement error of the upstream inflow to the reach. A second measure of water balance closure, used in 1996, 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 flow entering the reach. The residual was distributed in all reaches for 1996 to present the effect of the distribution, even though the residual was about equal to or less than the presumed measurement error of the upstream gauge in three of the four reaches.

The standard error of estimate values for the upstream flows for 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.

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})	9,972,100	9,931,500	7,300,500	6,106,432	9,972,100
Flow at the downstream boundary (Q_{ds})	9,931,500	7,300,500	6,106,432	1,587,334	1,587,334
Residual	-62,469	-198,208	14,051	142,625	-104,001
Residual as a percentage of the flow entering the reach (Q_{us})	-0.63%	-2.00%	0.19%	2.34%	-1.04%
Difference between upstream and downstream flow (Q_{dif})	40,600	2,631,000	1,194,068	4,519,098	8,384,766
Measured Tributary inflow (Trm)	0	3,527	0	9,406	12,933
Unmeasured Tributary inflow (Trum)	6,480	45,090	33,750	3,000	88,320
Exported flow (Q_{ex})	0	2,423,342	0	3,857,084	6,280,426
Evaporation (E)	148,638	130,673	63,100	11,073	353,484
Domestic consumptive[1] use (C_{ud})	393	38,982	4,657	29,968	74,000
Crop evapotranspiration (ET_{crop})	0	87,370	745,101	412,947	1,245,418
Phreatophyte evapotranspiration (ET_{pht})	12,118	196,358	395,459	77,807	681,742
Change in reservoir storage (ΔS_r)	-51,600	1,100	5,450	0	-45,050
Change in aquifer storage (ΔS_a)	0	0	0	0	0

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

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 1996 Decree Accounting Report)		231,400	231,400	Uses above Hoover Dam
Uses below Hoover Dam	29,443	17,704	17,847	Uses below Hoover Dam
			746	Unmeasured return flow credit
Nevada Total	29,443	249,104	248,501	Nevada Total
California				
	213,653	5,202,985	5,322,653	Sum of individual diverters
			96,487	Unmeasured return flow credit
California Total	213,653	5,202,985	5,226,166	California Total
Arizona				
Subtotal (below Hoover Dam, less Wellton-Mohawk IDD)	438,686	2,137,685	2,497,656	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (1996 Decree Accounting Report)		188	188	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (1996 Decree Accounting Report)		274,421	274,421	Wellton-Mohawk IDD
			57,368	Pumped from South Gila wells (drainage pump outlet channels [DPOCs]): returns
			161,955	Unmeasured return flow credit
Arizona Total	438,686	2,412,294	2,552,942	Arizona Total
Lower Basin Total				
Total Lower Basin Use	681,782	7,864,383	8,027,609	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})	10,114,702	10,011,692	7,189,509	6,008,755	10,114,702
Flow at the downstream boundary (Q_{ds})	10,011,692	7,189,509	6,008,755	1,573,204	1,573,204
Residual	0	0	0	0	0
Difference between upstream and downstream flow (Q_{diff})	103,010	2,822,183	1,180,754	4,435,551	8,541,498
Measured Tributary inflow (Trm)	0	3,550	0	9,402	12,952
Unmeasured Tributary inflow (Trum)	6,484	45,566	33,710	2,993	88,753
Exported flow (Q_{ex})	0	2,417,235	0	3,912,066	6,329,301
Evaporation (E)	148,587	130,562	63,104	11,076	353,329
Domestic consumptive[1] use (C_{ud})	393	38,980	4,657	29,971	74,001
Crop consumptive use (CU_{crop})	0	87,320	745,642	416,886	1,249,848
Phreatophyte consumptive use (CU_{phr})	12,118	196,107	395,611	77,947	681,783
Change in reservoir storage (ΔS_r)	-51,604	1,095	5,450	0	-45,059
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; river gauging; incidental use factors in crop ET calculations; open water surface evaporation and precipitation estimates; the appropriate assessment of phreatophyte use, if any, to diverters; and a method of estimating changes in groundwater storage.

Conclusions

Reclamation is directed to manage the lower Colorado River. Currently, the demand for water exceeds the 7.5 million acre-feet apportioned for annual consumptive use. Because of the scarcity of this resource, Reclamation must manage the river in a manner that is fair for all diverters. To achieve this goal, Reclamation has taken the lead in the development of LCRAS, which can be characterized as 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 water use for all diverters in the lower Colorado River basin

The goal of the LCRAS program is to improve the Decree Accounting Report 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 which provides 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 current Decree Accounting method for calendar year 1997 and the next several years and 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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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 in 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 request of this response 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 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 1996.

The LCRAS Method

LCRAS is an accounting method that estimates and distributes consumptive use by vegetation 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 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 ET plus a proportion of the residual. 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 balance because the residual can be either a positive or negative number.

Evapotranspiration 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) acres 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 applying a consumptive use factor to a measured diversion (usually 0.6), or 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), or by subtracting a measured return flow from a measured diversion, or, in a few cases, by a method provided Reclamation by a domestic user.

Water Balance

A water balance performs a summation of all, or a selection of, inflows, outflows, and water uses of a stream. The result of this summation is called a residual, and it represents unaccounted for water. 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.

The water balance applied to the lower Colorado River in 1996 by LCRAS postulates that all inflows, outflows, and water uses can be measured or estimated with sufficient accuracy and resolution to meet the water accounting needs of the Supreme Court Decree. The residual of the water balance is considered to be the result of the impreciseness of measurement or estimation in some or all of the inflow, outflow, and water use values.

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

Table A1, 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. Below is a description of the conceptual differences in the way consumptive use is compiled for the Decree Accounting Report and calculated by LCRAS.

Agricultural Diverters

Decree Accounting Report

The Decree Accounting Reports are a compilation of measured diversions and measured return flows and can be used as an estimate of consumptive use for agricultural diverters, wildlife refuges, and other reservations of land. Beginning in 1991, in parallel with the continued development of LCRAS, the calculation of consumptive use for the Decree

Accounting Report has been augmented with estimates of unmeasured return flow to address the question of unmeasured returns to the river.

These estimates of unmeasured return flow are based upon crop reports from 1990 and ET calculations using the Blaney-Criddle method. Unmeasured return flow factors, relating estimates of unmeasured return flow to diversions, were calculated in 1990 for large agricultural diverters along the river. These unmeasured return flow factors have since been applied to all agricultural diverters, wildlife refuges, and other reservations of land to estimate unmeasured return flow from each of these diverters. These estimates are then summed and reported as a total for each State and are not attributed to individual diverters.

LCRAS

The LCRAS method of calculating consumptive use is an implicit expression of diversion less return, and it also assesses the availability of any return flows for downstream use. The LCRAS method calculates ET as an initial estimate of water use by vegetation, which allows such estimates to be made without measured diversions and measured return flows. This was done because the ability to measure all return flows was in question, and not all irrigated areas have measured diversions or return flows. LCRAS addresses the availability of return flows for downstream consumptive use by performing a water balance on the lower Colorado River between the major dams and Mexico.

LCRAS makes the final estimate of water use— consumptive use—by adding a proportionate share of the residual from the water balance to the ET calculated as an initial estimate of water use (distributing the residual). Consumptive use can be either larger or smaller than the calculated ET because the residual from the water balance can be either a positive or a negative number.

Domestic Diverters

Decree Accounting Report

The consumptive use of domestic diverters has been compiled primarily using measured diversions and measured return flows in the Decree Accounting Reports. Beginning in 1991, in parallel with the continued development of LCRAS, the calculation of consumptive use for the Decree Accounting Report has been augmented with estimates of unmeasured return flow as an interim method of addressing the unmeasured-return-flow issue. Most domestic diverters do not have measured return flows; therefore, the consumptive use attributed to the diverter is equal to their diversion.

Estimates of unmeasured return flow for domestic diverters are derived from factors supplied by Arizona for Bullhead City and by California for the city of Needles in 1990. The return flow factor, which relates estimates of unmeasured return flow to diversion, has been applied to all domestic users. These estimates of unmeasured return flow are also summed and included in the unmeasured return flow totals reported for each State and not attributed to individual diverters.

LCRAS

Domestic uses are initially estimated by applying a consumptive use factor to a measured diversion (usually 0.6), or by applying a per-capita consumptive use factor to a population (usually 0.14 acre-feet per capita if turf irrigation is not significant), or by subtracting a measured return flow from a measured diversion, or, in a few cases, or by a method supplied to Reclamation by a domestic user. A more detailed explanation of the consumptive use factors used by LCRAS for 1996 can be found in attachment 3.

LCRAS makes the final estimate of domestic use—consumptive use—by adding a proportionate share of the residual from the water balance to the initial estimate of domestic use described above (distributing the residual). Consumptive use can be either larger or smaller than the initial estimate of domestic use used in the water balance because the residual from the water balance can be either a positive or a negative number.

Chapter 2

LCRAS in Calendar Year 1996

Reclamation's activities for the 1996 LCRAS Demonstration of Technology began at the beginning of the year with continued onsite visits to selected fields to record the crop and field conditions (ground reference data collection). As the year progressed, Reclamation finalized the image classification process that would be used in 1996, selected and purchased image data from the Landsat satellite, and processed the image data. Reclamation also finalized the district boundaries that would be used in 1996, after consultation with several irrigation districts to confirm and update the district boundaries used in 1995.

Reclamation gathered ET rate 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 1996. Reclamation compiled domestic uses and change in reservoir storage values during 1996 for Lakes Mohave and Havasu and Senator Wash Reservoir.

As calendar year 1996 came to a close, analysis of all the data for the year could begin. From the image classification process came the acreage of each crop grown, the 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. This information, combined with the finalized diverter boundaries for 1996, 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 this information, the ET coefficients and the reference ET rate and precipitation data from AZMET and CIMIS stations, Reclamation calculated the evapotranspiration of crops and phreatophytes 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. Also, Reclamation compiled and analyzed the records of flow at major dams and major diversion and delivery points.

Reclamation finalized the form of the water balance that would be used in 1996 and calculated and proportionally distributed the residual to each water balance inflow and outflow, 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 1996.

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.

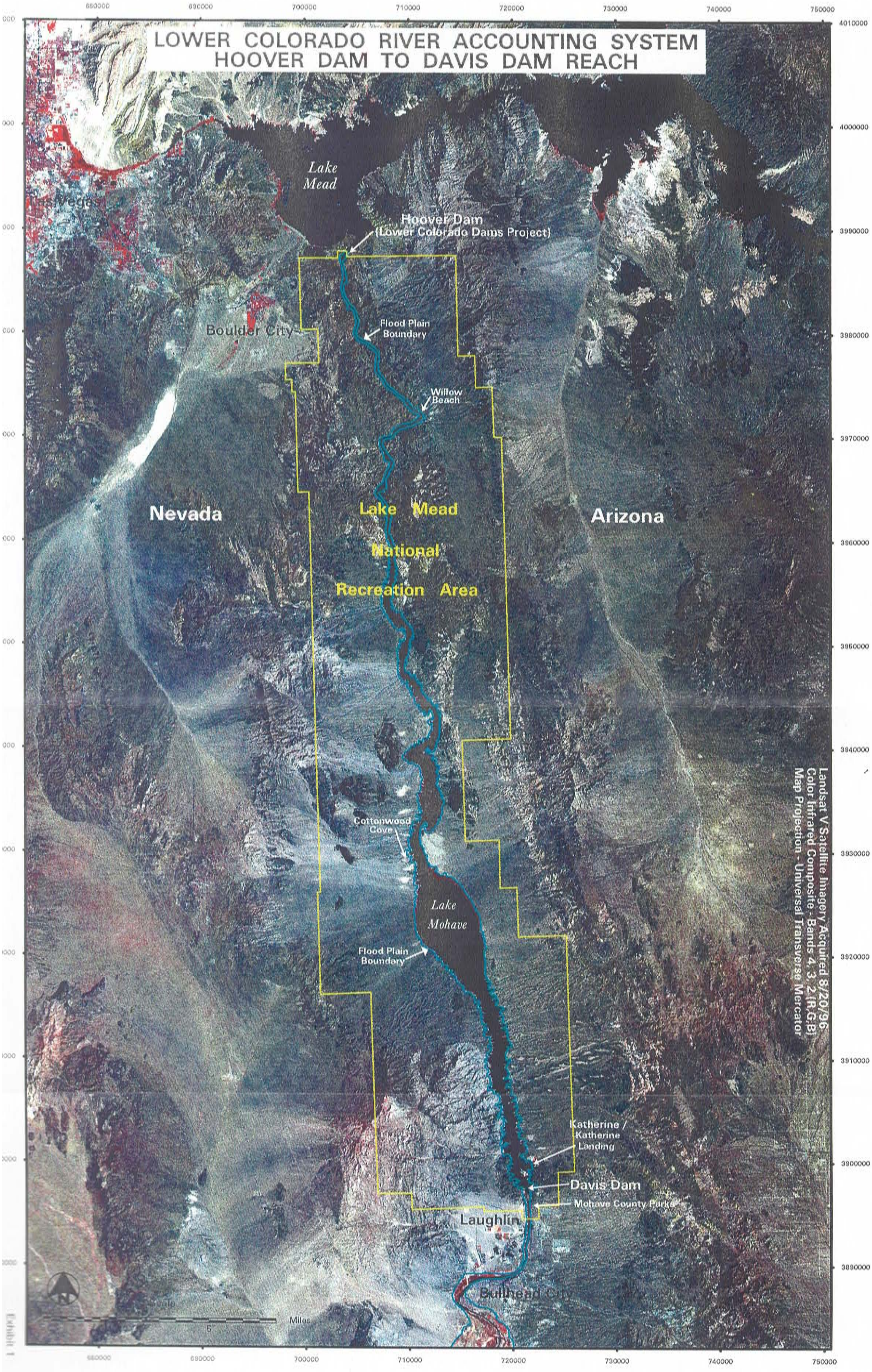
The flood plain boundary (shown in exhibits 1 through 7) used in 1996 is the same as the flood plain boundary used in 1995 except for some minor corrections in the Hoover Dam to Davis Dam reach. The flood plain boundary was used to identify phreatophyte areas that should be included in the image classification 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 were 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 relating to the aerial extent of each crop class and phreatophyte community for each diverter and relating to 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 1996. 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 regions of the electromagnetic spectrum. At any given instant, it focuses on only one small area of the 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



LOWER COLORADO RIVER ACCOUNTING SYSTEM
HOOVER DAM TO DAVIS DAM REACH
Lake Mead
Hoover Dam
(Lower Colorado Dams Project)
Boulder City
Flood Plain Boundary
Willow Beach
Nevada
Arizona
Lake Mead National Recreation Area
Cottonwood Cove
Lake Mohave
Flood Plain Boundary
Katherine / Katherine Landing
Davis Dam
Mohave County Parks
Laughlin
Bullhead City
Miles
Landsat V Satellite Imagery Acquired 8/20/96
Color Infrared Composite - Bands 4, 3, 2 (R,G,B)
Map Projection - Universal Transverse Mercator

Exhibit 1

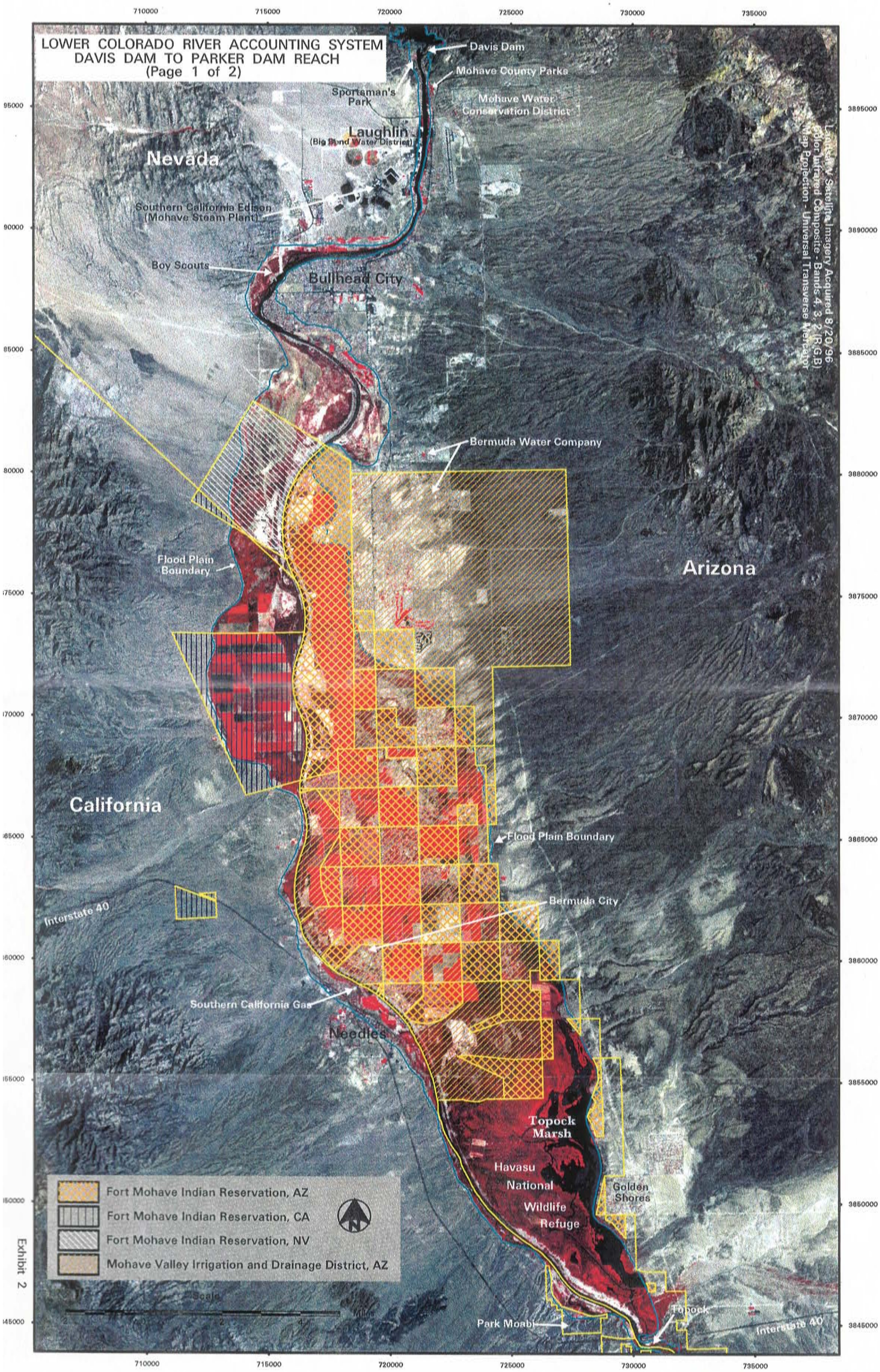

LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH
(Page 1 of 2)
710000
715000
720000
725000
730000
735000
3895000
3890000
3885000
3880000
3875000
3870000
3865000
3860000
3855000
3850000
3845000
Davis Dam
Mohave County Parks
Sportsman's Park
Mohave Water Conservation District
Laughlin
(Big Bend Water District)
Nevada
Southern California Edison
(Mohave Steam Plant)
Boy Scouts
Bullhead City
Landsat Satellite Imagery Acquired 8/20/96
Color Infrared Composite - Bands 4, 3, 2 (R,G,B)
Map Projection - Universal Transverse Mercator
Bermuda Water Company
Flood Plain Boundary
Arizona
California
Flood Plain Boundary
Interstate 40
Bermuda City
Southern California Gas
Needles
Topock Marsh
Havasu National Wildlife Refuge
Golden Shores
Fort Mohave Indian Reservation, AZ
Fort Mohave Indian Reservation, CA
Fort Mohave Indian Reservation, NV
Mohave Valley Irrigation and Drainage District, AZ
Scale
Miles
Park Moabi
Topock
Interstate 40

Exhibit 2

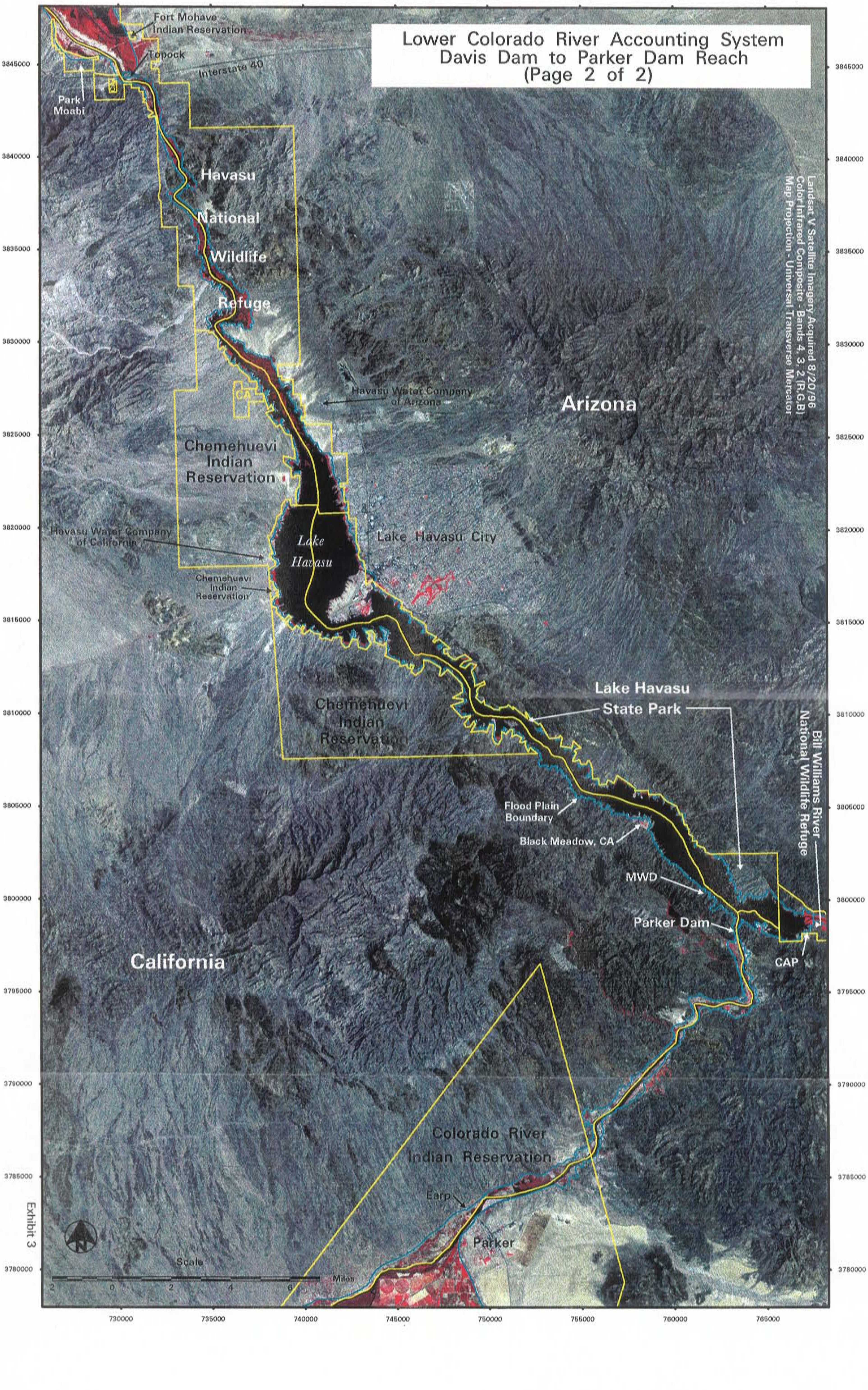
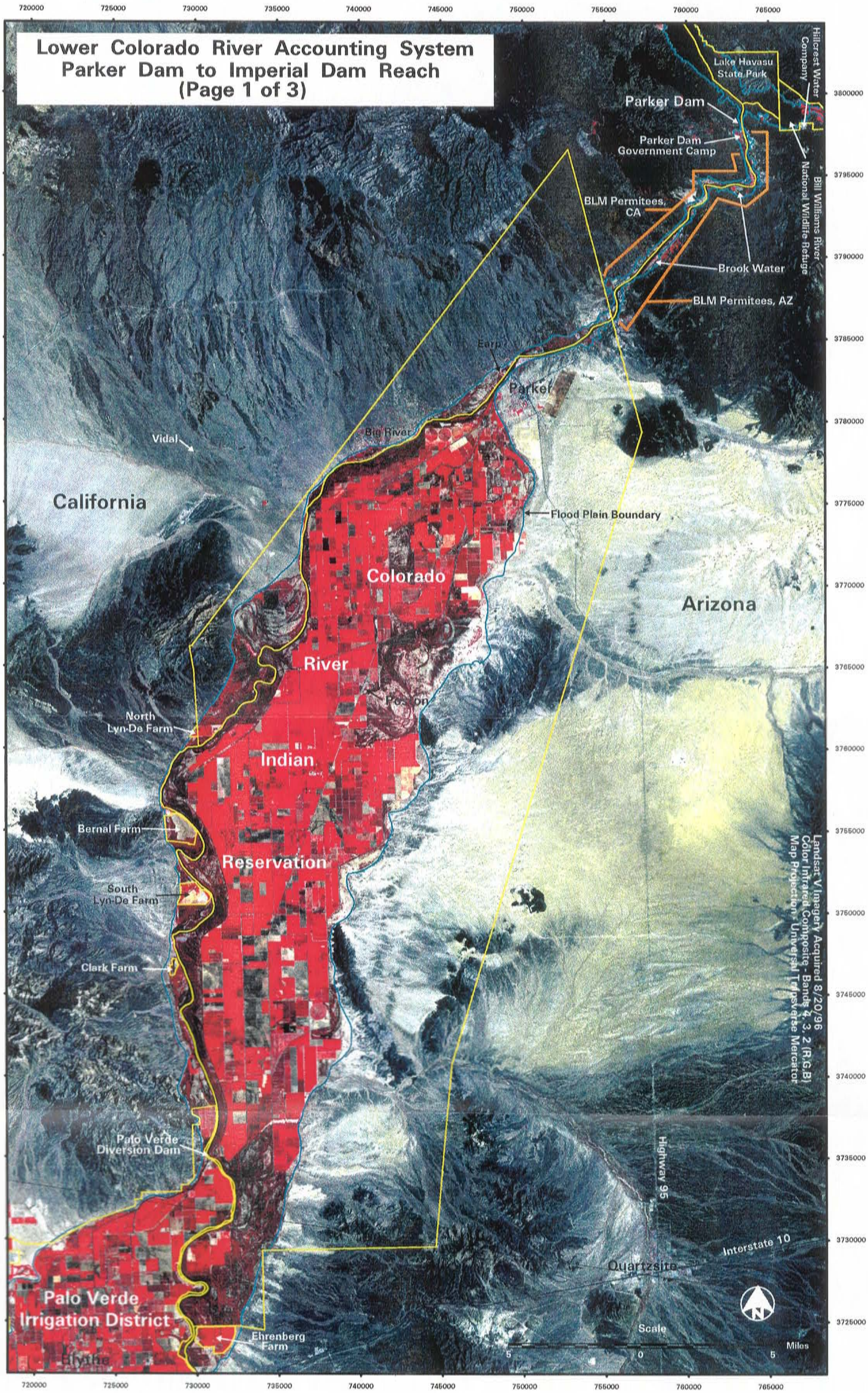

Lower Colorado River Accounting System
Davis Dam to Parker Dam Reach
(Page 2 of 2)
Fort Mohave Indian Reservation
Topock
Interstate 40
Park Moabi
Havasu National Wildlife Refuge
CA
Havasu Water Company of Arizona
Arizona
Chemehuevi Indian Reservation
Havasu Water Company of California
Lake Havasu
Lake Havasu City
Chemehuevi Indian Reservation
Chemehuevi Indian Reservation
Lake Havasu State Park
Bill Williams River National Wildlife Refuge
Flood Plain Boundary
Black Meadow, CA
MWD
Parker Dam
CAP
California
Colorado River Indian Reservation
Earp
Parker
Scale
Miles
Landsat V Satellite Imagery Acquired 8/20/96
Color Infrared Composite - Bands 4, 3, 2 (R,G,B)
Map Projection - Universal Transverse Mercator

Exhibit 3


Lower Colorado River Accounting System
Parker Dam to Imperial Dam Reach
(Page 1 of 3)
Lake Havasu State Park
Hillcrest Water Company
Parker Dam
Parker Dam Government Camp
Bill Williams River National Wildlife Refuge
BLM Permitees, CA
Brook Water
BLM Permitees, AZ
Earp
Parker
Big River
Vidal
California
Flood Plain Boundary
Colorado
River
Indian
Reservation
Arizona
Poston
North Lyn-De Farm
Bernal Farm
South Lyn-De Farm
Clark Farm
Landsat V Imagery Acquired 8/20/96
Color Infrared Composite - Bands 4, 3, 2 (R,G,B)
Map Projection: Universal Transverse Mercator
Palo Verde Diversion Dam
Highway 95
Interstate 10
Quartzsite
Palo Verde Irrigation District
Ehrenberg Farm
Blythe
Scale
Miles
5
0
5
N
720000
725000
730000
735000
740000
745000
750000
755000
760000
765000
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3795000
3790000
3785000
3780000
3775000
3770000
3765000
3760000
3755000
3750000
3745000
3740000
3735000
3730000
3725000

Exhibit 4

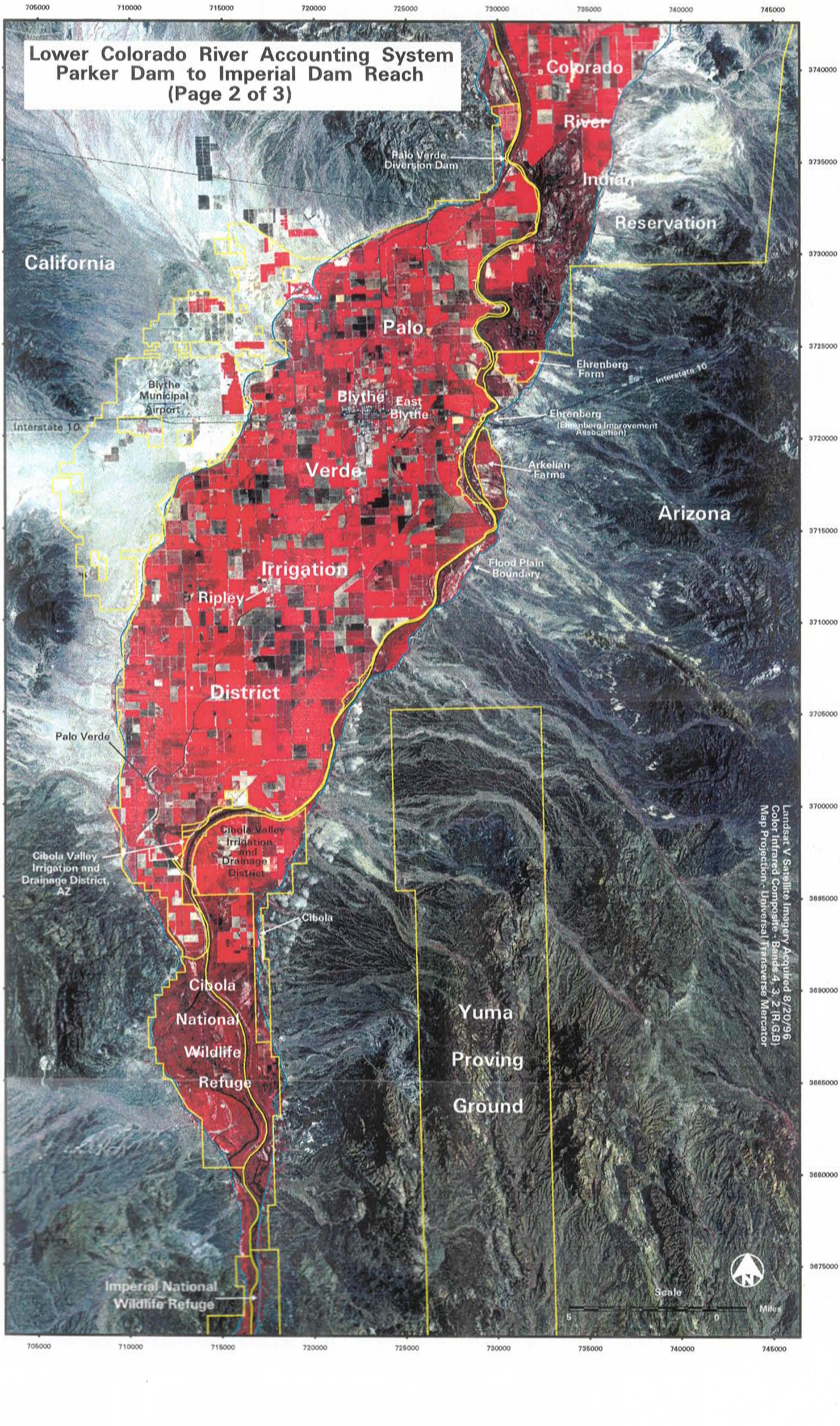

Lower Colorado River Accounting System
Parker Dam to Imperial Dam Reach
(Page 2 of 3)
Colorado
River
Indian
Reservation
Palo Verde Diversion Dam
California
Palo
Blythe Municipal Airport
Interstate 10
Blythe
East Blythe
Verde
Ehrenberg Farm
Interstate 10
Ehrenberg (Ehrenberg Improvement Association)
Arkelian Farms
Arizona
Flood Plain Boundary
Irrigation
Ripley
District
Palo Verde
Cibola Valley Irrigation and Drainage District
Cibola Valley Irrigation and Drainage District, AZ
Cibola
Cibola
National
Wildlife
Refuge
Yuma
Proving
Ground
Imperial National Wildlife Refuge
Landsat V Satellite Imagery Acquired 8/20/96
Color Infrared Composite - Bands 4, 3, 2 (R,G,B)
Map Projection: Universal Transverse Mercator
Scale
5
0
Miles
705000
710000
715000
720000
725000
730000
735000
740000
745000
3740000
3735000
3730000
3725000
3720000
3715000
3710000
3705000
3700000
3695000
3690000
3685000
3680000
3675000

Exhibit 5

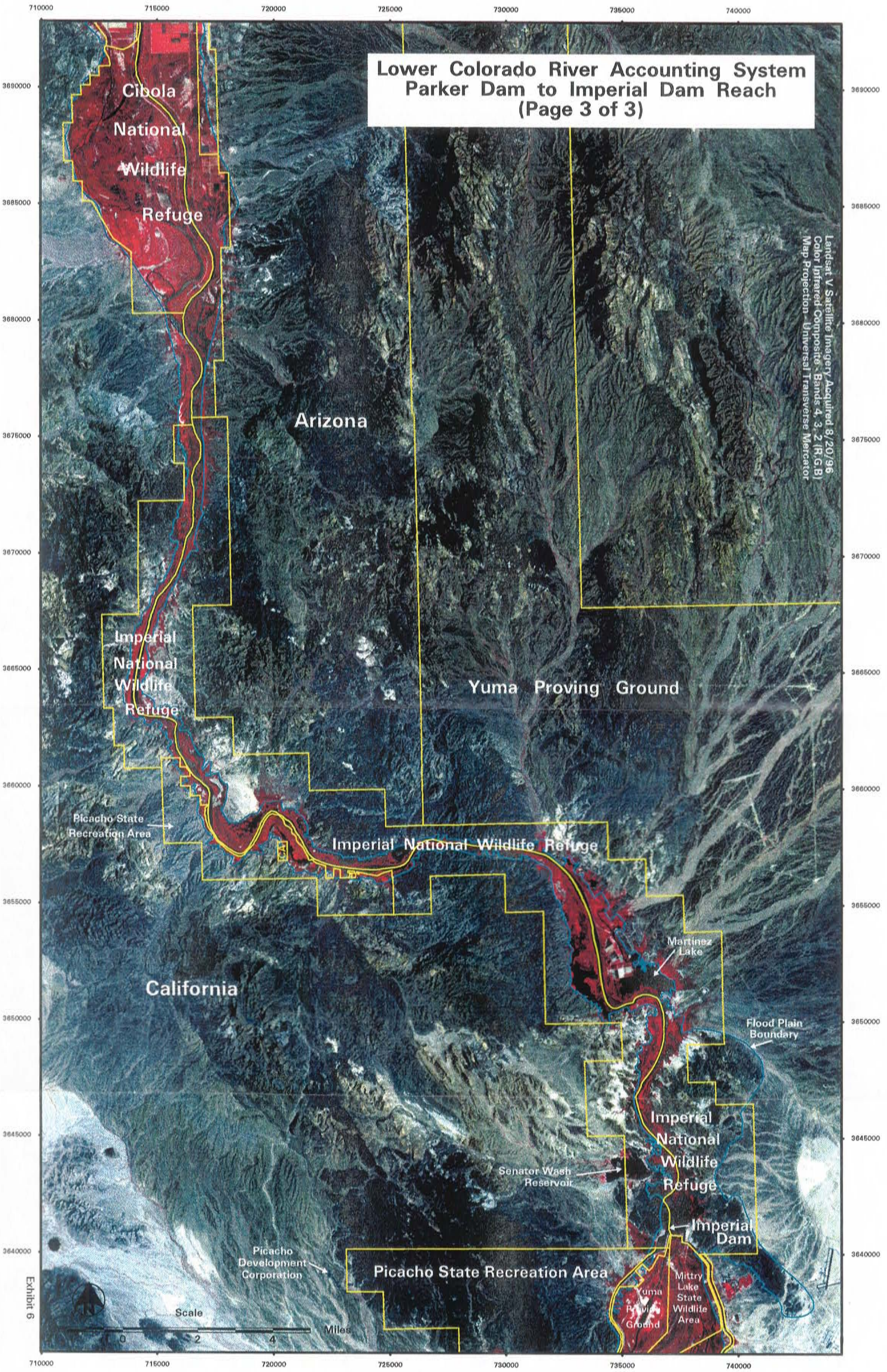
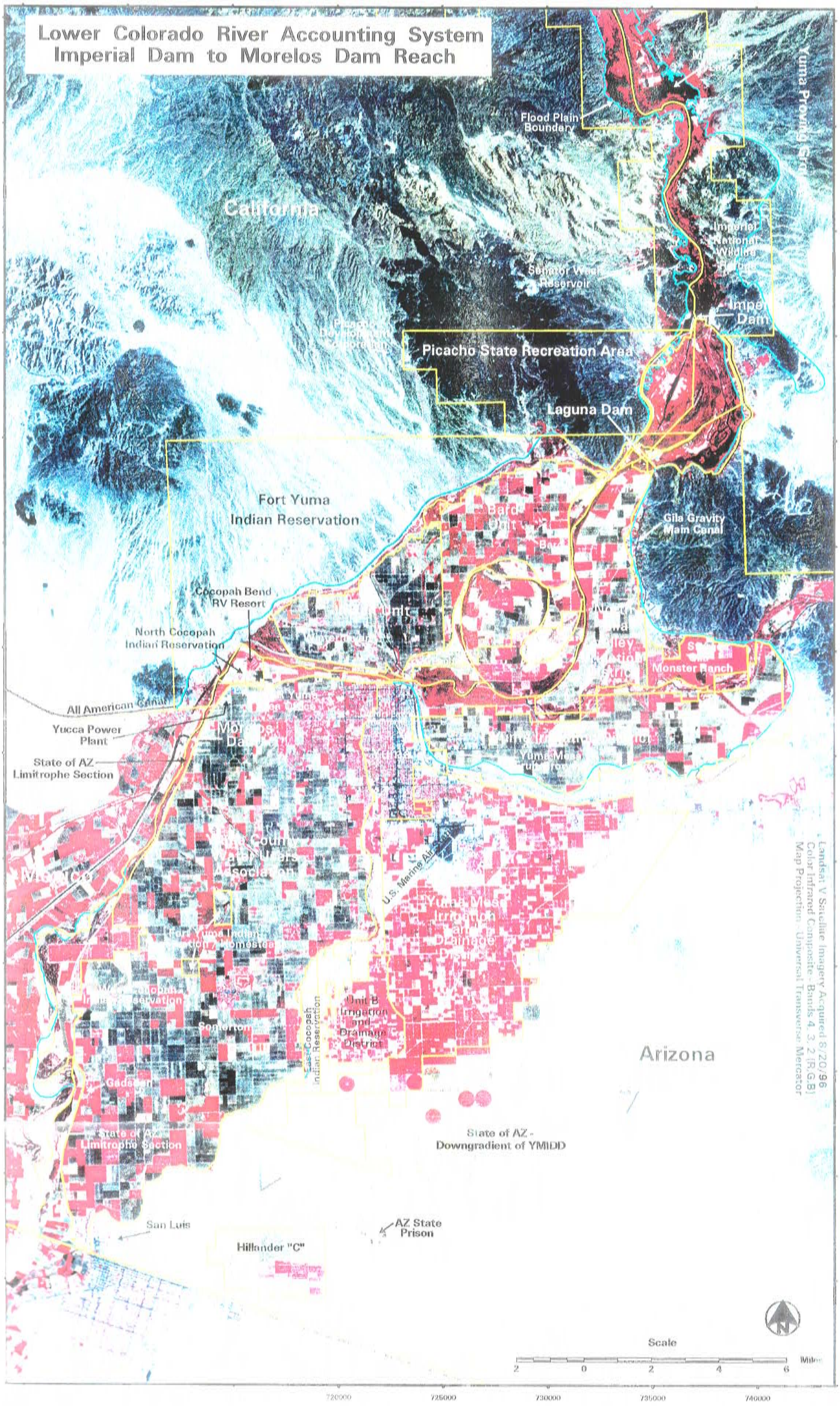

Lower Colorado River Accounting System
Parker Dam to Imperial Dam Reach
(Page 3 of 3)
Landsat V Satellite Imagery Acquired 8/20/96
Color Infrared Composite - Bands 4, 3, 2 (R,G,B)
Map Projection - Universal Transverse Mercator
Cibola National Wildlife Refuge
Arizona
Imperial National Wildlife Refuge
Yuma Proving Ground
Picacho State Recreation Area
Imperial National Wildlife Refuge
Martinez Lake
California
Flood Plain Boundary
Imperial National Wildlife Refuge
Senator Wash Reservoir
Imperial Dam
Picacho Development Corporation
Picacho State Recreation Area
Yuma Proving Ground
Mittry Lake State Wildlife Area
Scale
0 2 4
Miles
710000
715000
720000
725000
730000
735000
740000
3690000
3685000
3680000
3675000
3670000
3665000
3660000
3655000
3650000
3645000
3640000

Exhibit 6


Lower Colorado River Accounting System
Imperial Dam to Morelos Dam Reach
Flood Plain Boundary
California
Senator Wash Reservoir
Imperial Dam
Picacho State Recreation Area
Laguna Dam
Fort Yuma Indian Reservation
Gila Gravity Main Canal
Cocopah Bend RV Resort
North Cocopah Indian Reservation
Monster Ranch
All American Canal
Yucca Power Plant
State of AZ Limitrophe Section
Morelos Dam
U.S. Marine Air Station
Somerton
Gadsden
East Cocopah Indian Reservation
Unit B Irrigation and Drainage District
Arizona
State of AZ - Downgradient of YMIDD
San Luis
AZ State Prison
Hillander "C"
Landsat V Satellite Imagery Acquired 8/20/96
Color Infrared Composite - Bands 4, 3, 2 (R,G,B)
Map Projection - Universal Transverse Mercator
Scale
2 0 2 4 6 Miles
720000
725000
730000
735000
740000

Landsat TM data being used for image analysis is 25 meters. TM image data were acquired for analysis for the World Reference System[2] locations and on the dates shown below during calendar year 1996:

Path 38, rows 36 and 37	March 22, 1996	Path 39, row 35	March 29, 1996
Path 38, rows 36 and 37	May 9, 1996	Path 39, row 35	April 30, 1996
Path 38, rows 36 and 37	August 13, 1996	Path 39, row 35	August 20, 1996
Path 38, rows 36 and 37	December 12, 1996	Path 39, row 35	November 25, 1996

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

Ground Reference Data Collection

Correct identification of vegetation 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 vegetation 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 75 to 80 percent of the agricultural ground reference data were used in image classification, and the remaining 20 to 25 percent were used to assess the accuracy of the vegetation mapping. Selection of 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

[2] 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.

fields and their borders. During 1996, ground reference data were collected four times. These times coincided with the acquisition times of the satellite imagery. Variability in planting and harvesting times for each crop was also considered in the selection of data collection dates during the year.

Table 1 presents the crop classes sampled. Classes such as Other Vegetables and Crucifers are general class names that actually 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 image classification process results show that the spectral characteristics of the Landsat V image data are satisfactory for discriminating crop classes. Excellent results were obtained for crop classes listed in table 1, using a single-date image classification process. Postclassification accuracy assessment shows that, overall, the crops can be mapped with an average accuracy of approximately 93 percent.

Field reconnaissance was performed during 1996 to document phreatophyte changes since the 1994 phreatophyte data base was created. Areas of spectral change were delineated using image to image comparisons (change detection methodologies) from May 1994 and May 1996 Landsat TM imagery. Areas of spectral change were then visited in the field 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 1994 phreatophyte data base.

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

A separate class for open water was also developed, and image classification processes were also 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. 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 1996.

A detailed description of the image processing and GIS processes used for this LCRAS Demonstration of Technology can be found in attachment 6.

Delineation of Total Vegetated Area

A relational data base (GIS coverage) was 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 was linked to this field border data base. These borders were derived from Systemme Pour l'Observation de la Terre (SPOT) image data acquired in June and August 1992. All field borders were on-screen digitized using the SPOT data as a backdrop. The 10-meter spatial resolution of the SPOT image data provided an excellent backdrop for identifying and digitizing agricultural field borders. An example of a map with field borders highlighted is provided as exhibit 8. Field borders are routinely updated using information gathered during ground reference data collection over the course of the year.

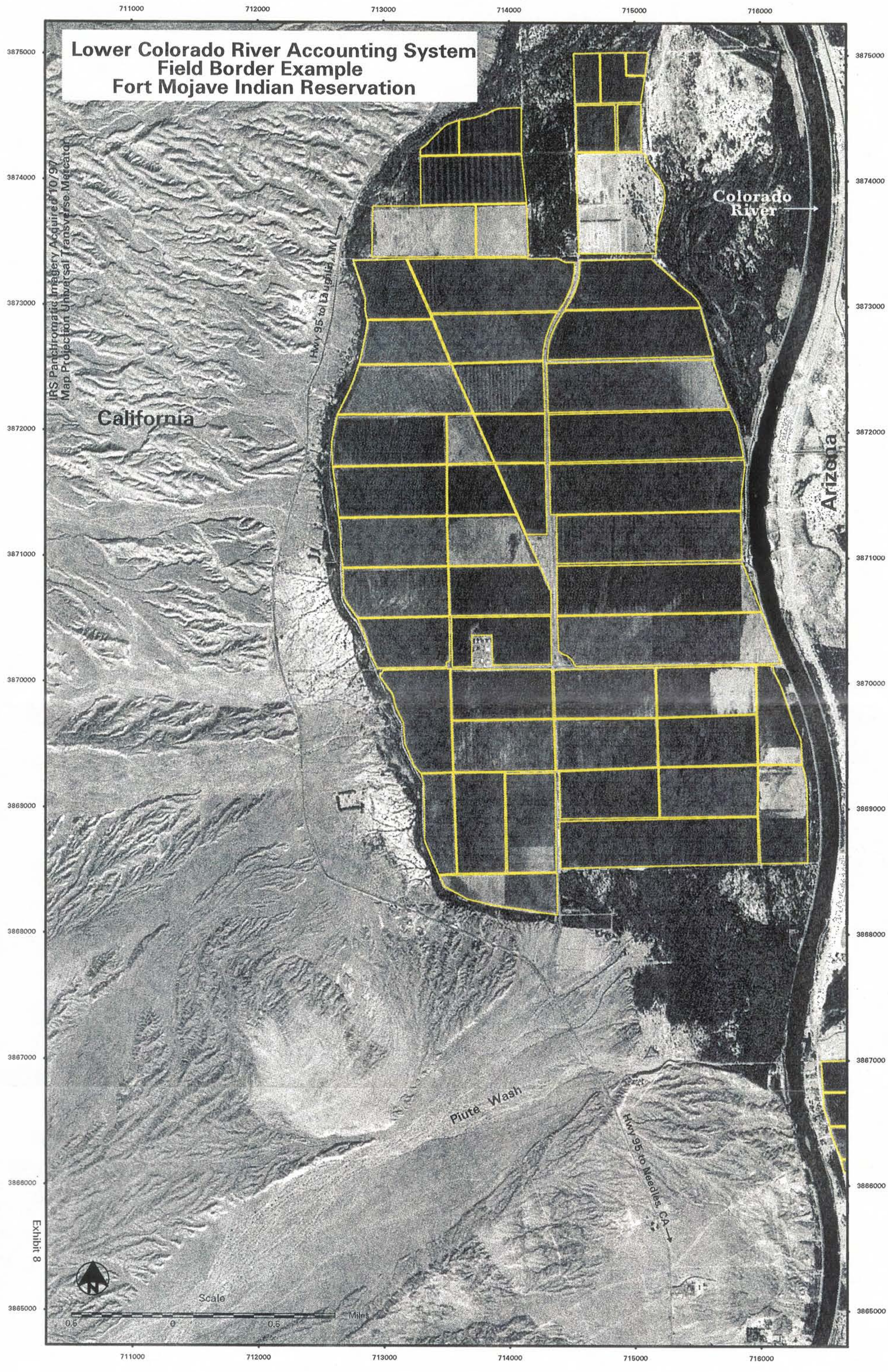

Lower Colorado River Accounting System
Field Border Example
Fort Mojave Indian Reservation
IRS Panchromatic Imagery Acquired 10/97
Map Projection Universal Transverse Mercator
California
Arizona
Colorado River
Hwy 95 to Laughlin, NV
Piute Wash
Hwy 95 to Needles, CA
Scale
0.5
0
0.5
Miles
711000
712000
713000
714000
715000
716000
3875000
3874000
3873000
3872000
3871000
3870000
3869000
3868000
3867000
3866000
3865000

Exhibit 8

All areas along the mainstream of the lower Colorado River that divert or pump water were included in this analysis. The boundaries for these areas are shown in exhibits 1 through 7 and 9.

Water Balance Equation

The water balance equation used for 1996 includes minor modifications from that used for 1995. These modifications are (1) the introduction of the Q_{dif} term, as suggested by Lane 1998, (2) the incorporation of precipitation as a reduction in crop ET (ET_{crop}) and open water surface evapotranspiration (E) as described in the 1995 LCRAS report, (3) the inclusion of the underflow to Mexico in the Q_{ds} term for the Imperial Dam to Mexico reach instead of the separate term as described in the 1995 LCRAS report and, (4) the separation of measured and unmeasured tributary inflow into separate terms to allow the use of different estimates of error when distributing the residual. The water balance equation used for 1996 is shown below:

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

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.

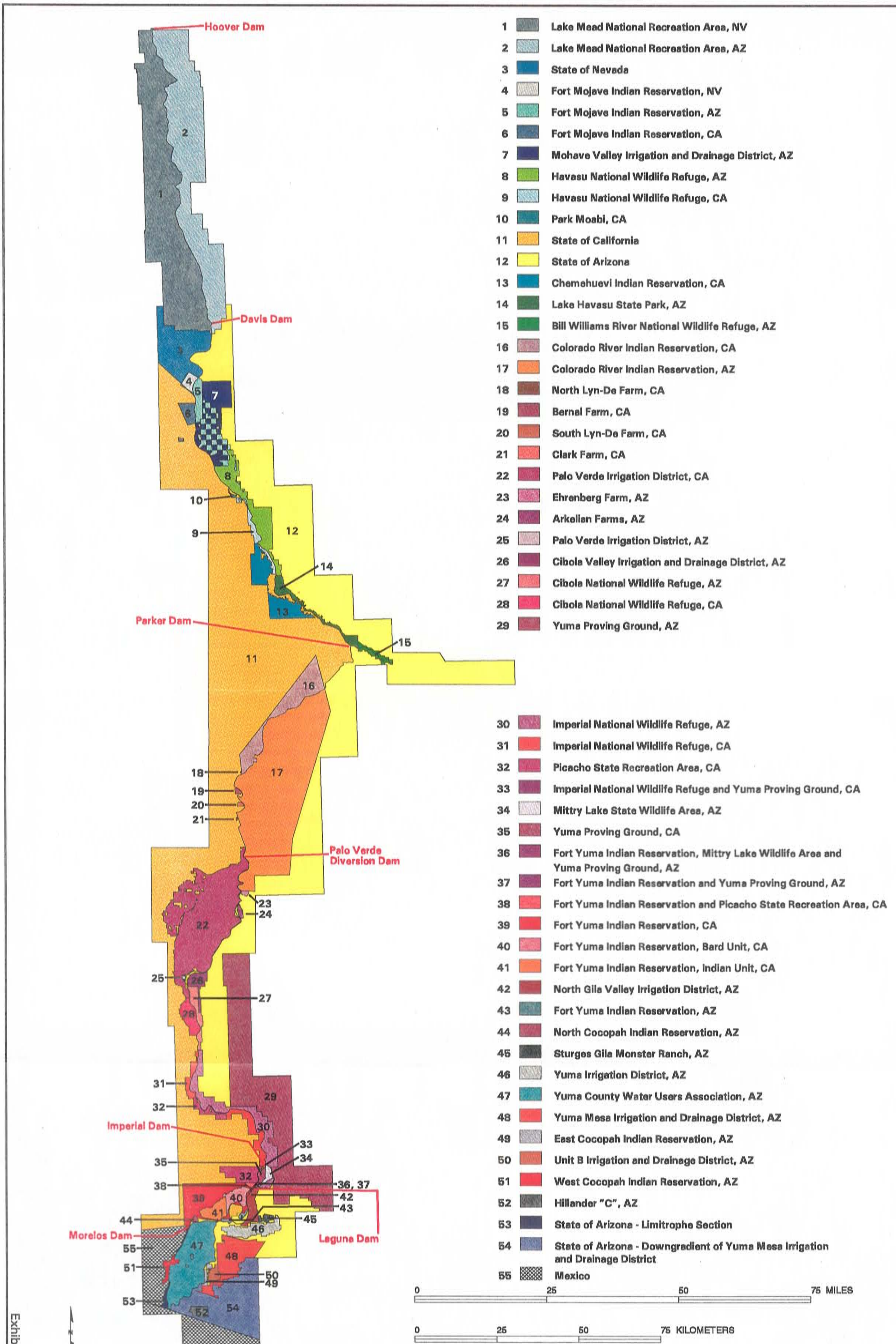
C_{ud} = Domestic, municipal, and industrial use.

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.



1996 LCRAS Diverter Boundaries

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.[3]

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 USGS, 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 the upstream (entering a reach) and downstream (exiting a reach) flow measurements were provided by USGS.[4] The exceptions—the downstream outflows and two of the upstream inflows of the Imperial Dam to Mexico reach—are explained below.

The outflow from Imperial Dam to Mexico reach (flows to Mexico at the northerly and southerly international boundaries, and the limitrophe section) was measured and reported by IBWC using stage discharge relationships and standard flow measurement devices. The underflow to Mexico is also included in the downstream flow of the Imperial Dam to Mexico reach. This underflow was estimated by Reclamation using a groundwater model.

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

[4] USGS provided flow information in *U.S. Supreme Court Decree Stations of the Lower Colorado River, Diversions and Return Flows Data for Calendar Year 1996.*

The inflow to the Imperial Dam to Mexico reach (flow below Imperial Dam) was a summation of flow within the Colorado River channel, diversions to Mittry Lake, and flows in the All-American and Gila Gravity Canals. Flows in the Gila Gravity and Wellton-Mohawk Canals were measured by Reclamation using acoustic velocity meters (AVMs).

For a more detailed explanation of the use of AVMs on the lower Colorado River by Reclamation, see Madigan and Weiss (1996).

Most of the data reported by USGS were measured using stage-discharge relationships developed over the period of record for each gauge. An exception occurs at Hoover Dam, where flow through the dam was measured by closed conduit AVMs located in the penstocks. The devices conform to American Society of Civil Engineers[5] standards for AVM installations, and USGS reports the flow data annually.

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 USGS . The initial estimate of export for these users was the measured values.

The initial estimates, final estimates after the distribution of the residual, and percentage change between the two values for the exports described above can be found in table 3 below. The presumed standard error of estimate for export flows is 2 percent.

[5] ASCE.

Table 3. — Changes in export values after residual distribution

Export	Initial Estimate	Final Estimate	Change in Percent
MWD	1,227,283	1,224,190	-0.25
CAP	1,196,059	1,193,045	-0.25
Wellton-Mohawk	371,484	376,780	1.43
IID & Coachella	3,485,600	3,535,286	1.43

The sum of the final estimates of export flows accounts for about 82 percent of the total lower Colorado River basin consumptive use (crop, domestic, and export).

Measured Tributary Inflow Data (T_m)

The flows of two tributaries were measured—the Gila River in southwestern Arizona and the Bill Williams River in west-central Arizona. Gila River flows were measured near Dome and reported by USGS. The Bill Williams River was measured below Alamo Dam and reported by USGS.

Because there are some uses on the Bill Williams River and it flows many miles through established stands of phreatophytes between Alamo Dam and its mouth at Lake Havasu, LCRAS estimates the flow entering the Colorado River at Lake Havasu with a water balance, much the same as for other reaches of the river. The exception is that no residual is calculated or distributed because the downstream outflow is the unknown. The 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 the Bill Williams River below Alamo Dam.

The flow reported below Alamo Dam and estimates of unmeasured tributary inflow comprised the inflow to the Bill Williams reach. Outflows consist of evaporation and vegetative water use. Evaporation and water uses were calculated using the same remote sensing and reference ET methods as used along the mainstream of the Colorado River and subtracted from the flow below Alamo Dam to provide the inflow to the Colorado 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 extent of the connected and contiguous alluvium from Lake Havasu upstream into the Bill Williams River at the normal high annual operating level of Lake Havasu. This represents the maximum influence Lake Havasu can have on the Bill Williams River in a normal operating year.

The estimated water uses on the Bill Williams River above Lake Havasu exceed the estimated inflow for several months during 1996. When this occurred, the inflow to the Colorado River from the Bill Williams River was considered to be zero. The Bill Williams reach is shown on exhibit 10.

Unmeasured Tributary Inflow Data (T_{rum})

Unmeasured tributary inflow values were taken directly from Owen-Joyce (1987). The flow values presented in this USGS report use a 10-year average flow estimate. These flow estimates have been reprinted in Owen-Joyce and Raymond (1996). The sum of the unmeasured tributary inflows was 88,320 acre-feet,[6] or about 1 percent of the flow below Hoover Dam. 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:

- Daily reference ET
- Daily vegetation class (crop or phreatophyte) ET coefficients
- Number of acres covered by each vegetation class

Daily reference ET values were obtained from AZMET and CIMIS stations; daily ET coefficients for each vegetation class were developed specifically for the LCRAS program and are documented in Jensen (1996). These coefficients were updated in July of 1997 based upon changes in growing season patterns observed since Dr. Jensen's

[6] 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).

initial work for LCRAS. Reclamation developed the area covered by each vegetation class through the analysis of remotely sensed data.

The CIMIS and five AZMET automated weather stations located in irrigation districts within the flood plain continuously collect maximum, minimum, and average temperature and relative humidity; 2- and 4-inch average soil temperature, wind speed, precipitation, and calculate net radiation. These parameters (except precipitation) are used to calculate hourly and daily reference ET (ET_0) .

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. Daily ET_0 values (inches) from the nearest AZMET or CIMIS station 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 an appropriate rain gauge by an effective precipitation coefficient. The effective precipitation coefficients used for this LCRAS Demonstration of Technology were documented in Jensen (1993).

The equation used to calculate effective precipitation is:

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

The depth of precipitation that fell over the lower Colorado River Valley in 1996 ranged from 0.34 inch, measured at the Yuma Mesa AZMET station, to 3.78 inches, measured at the Palo Verde CIMIS station. The unweighted precipitation average recorded across the valley for 1996 was 2.06 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 remote sensing processes. 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

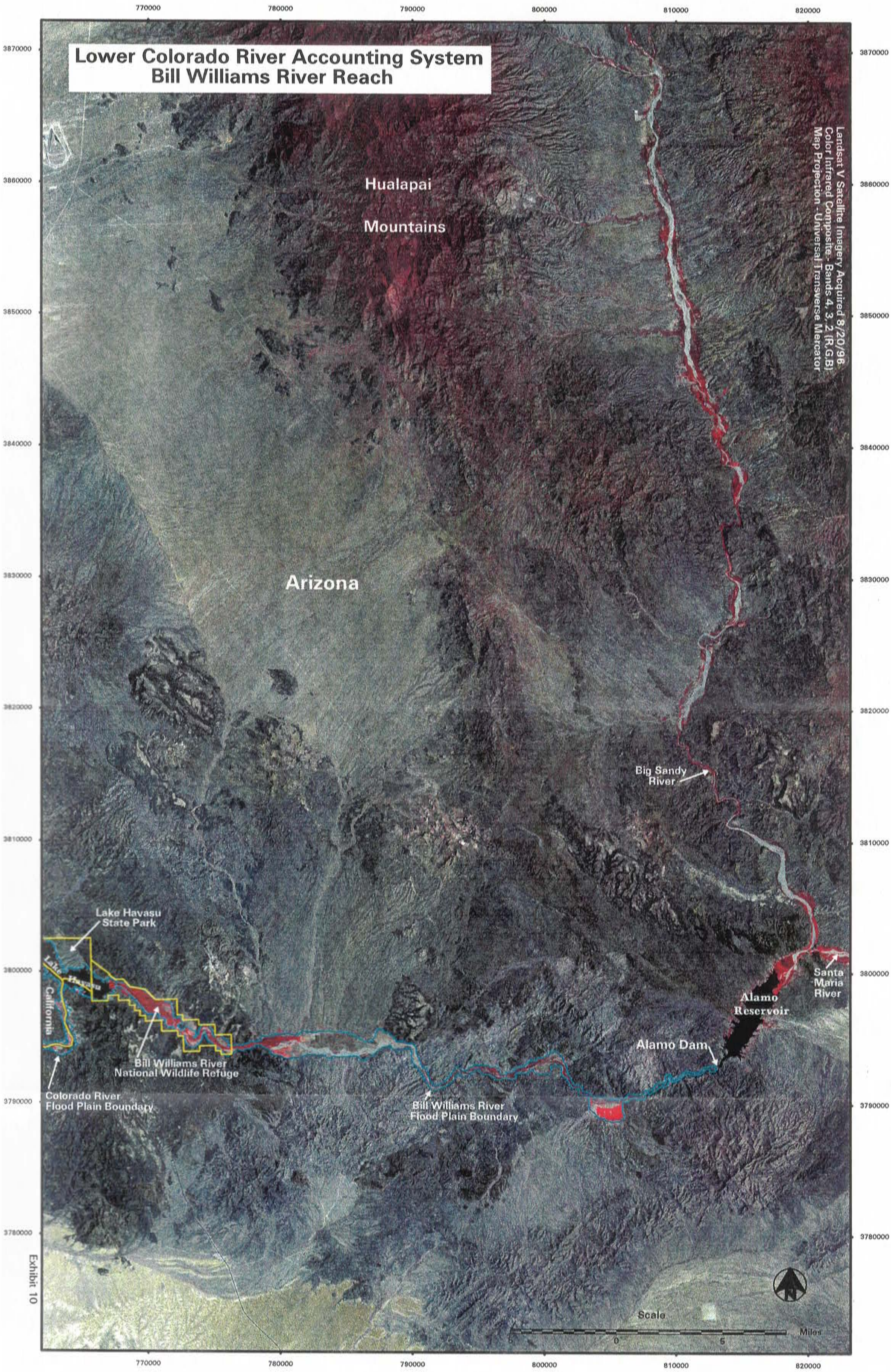

Lower Colorado River Accounting System
Bill Williams River Reach
Landsat V Satellite Imagery Acquired 8/20/96.
Color Infrared Composite. Bands 4, 3, 2 (R,G,B)
Map Projection - Universal Transverse Mercator
Hualapai
Mountains
Arizona
Big Sandy River
Santa Maria River
Alamo Reservoir
Alamo Dam
Lake Havasu State Park
Lake Havasu
California
Bill Williams River National Wildlife Refuge
Colorado River Flood Plain Boundary
Bill Williams River Flood Plain Boundary
Scale
0
5
Miles
770000
780000
790000
800000
810000
820000
3870000
3860000
3850000
3840000
3830000
3820000
3810000
3800000
3790000
3780000

Exhibit 10

quantify the area covered by each crop class within a diverter's boundaries. 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.

Using cotton as an example, the equation looks like this:

$$ET_{cotton} = \sum_n [(ET_0 \times K_{cotton}) - \text{Effective PPT}]AC_{cotton}$$

Where:

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

$\sum_n$ = Summation for $_n$ time, either monthly or annually.

ET_0 = Daily reference ET value calculated by AZMET or CIMIS stations.

K_{cotton} = Daily crop coefficient (Jensen, 1996) 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 1996 was 1,245,453 acre-feet. After the residual from the water balance was distributed, the final calculation of crop consumptive use increased to 1,249,891 acre-feet, a change of about 3.6 percent. Crop consumptive use accounts for about 16 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 noted above in the section entitled "Crops (ET_{crop})," except that the ET rates for phreatophytes were not corrected for effective precipitation. Phreatophytes along the lower Colorado River are mostly deep-rooted plants that benefit little from 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 14 classes. These phreatophyte classes used to calculate phreatophyte ET are listed in table 2 in the section "Ground Reference Data Collection." Remote sensing processes, combined with the analysis of aerial photography, were used to develop the number of acres covered by each phreatophyte class used to calculate ET_{pht}.

The sum of the ET_{pht} calculated for calendar year 1996 was 681,449 acre-feet. After the residual from the water balance was distributed, the final calculation of phreatophyte use increased to 681,489 acre-feet, a change of less than one-tenth of 1 percent. Phreatophyte use accounts for about 8 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 in 1996 as the product of the sum of daily AZMET and CIMIS ET_0 values times an average monthly evaporation coefficient. Monthly precipitation measured at the AZMET or CIMIS stations 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 1996 ranged from 0.34 inch, measured at the Yuma Mesa AZMET station, to 3.78 inches, measured at the Palo Verde CIMIS station. The unweighted precipitation average recorded across the valley for 1996 was 2.06 inches.

The open water surface area (acres) for Lakes Mohave and Havasu was derived from area estimates developed by analyzing the August 1996 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 1996 was 353,484 acre-feet. After the residual from the water balance was distributed, the final calculation of evaporation dropped to 353,329 acre-feet, a change of less than one-tenth of 1 percent. Evaporation accounts for about 4 percent of the combined lower Colorado River basin water use and loss from crops, domestic uses, exports, phreatophytes, and evaporation.

Domestic Use (C_{ud})

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.

The initial estimates of domestic use were compiled from two basic sources. The majority of domestic uses were calculated as the diversion reported by Decree Accounting Report for 1996 times a consumptive use factor of 0.6. Where diversion values from the Decree Accounting Report were not available, initial estimates of domestic consumptive uses were calculated by applying an acre-foot per capita per year factor of 0.14 (assuming turf irrigation for the domestic diverter is not significant) to the most recent estimates of population available (usually the 1990 census or a population estimate from a local Chamber of Commerce). For a few domestic users (usually where a measured diversion and a measured return flow value were available), the initial estimate of consumptive use was made by applying the consumptive use reported in the 1996 Decree Accounting Report.

The list of domestic diverters was compiled from those listed in Owen-Joyce and Raymond (1996) and in 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 name of the diverter was used to identify domestic users in the Decree Accounting Report because the type of use was not always clearly defined.

There may be some domestic diverters that were not included, but their impact on the total consumptive uses calculated by this LCRAS Demonstration of Technology would be very small. 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 1996 was 74,000 acre-feet. After the residual from the water balance was distributed, the final estimate of total domestic use increased to 74,001 acre-feet, a change of 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 one percent of the combined lower Colorado River basin use and loss from crops, domestic uses, exports, evaporation, and phreatophytes.

Attachment 3 contains the documentation of the consumptive use study which is the basis for the 0.6 consumptive use and the 0.14 acre-foot per capita per year factors.

Change in Reservoir Storage (ΔS_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 was 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 4.

Change in Aquifer Storage (ΔS_a)

A value of zero was used for all reaches of the river for calendar year 1996 (as was done in the 1995 LCRAS report). 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 4.

Table 4.—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})	9,972,100	9,931,500	7,300,500	6,106,432	9,972,100
Flow at the downstream boundary (Q_{ds})	9,931,500	7,300,500	6,106,432	1,587,334	1,587,334
Residual	-62,469	-198,208	14,051	142,625	-104,001
Residual as a percentage of the flow entering the reach (Q_{us})	-0.63%	-2.00%	0.19%	2.34%	-1.04%
Difference between upstream and downstream flow (Q_{dif})	40,600	2,631,000	1,194,068	4,519,098	8,384,766
Measured Tributary inflow (Trm)	0	3,527	0	9,406	12,933
Unmeasured Tributary inflow (Trum)	6,480	45,090	33,750	3,000	88,320
Exported flow (Q_{ex})	0	2,423,342	0	3,857,084	6,280,426
Evaporation (E)	148,638	130,673	63,100	11,073	353,484
Domestic consumptive[1] use (C_{ud})	393	38,982	4,657	29,968	74,000
Crop evapotranspiration (ET_{crop})	0	87,370	745,101	412,947	1,245,418
Phreatophyte evapotranspiration (ET_{pht})	12,118	196,358	395,459	77,807	681,742
Change in reservoir storage (ΔS_r)	-51,600	1,100	5,450	0	-45,050
Change in aquifer storage (ΔS_a)	0	0	0	0	0

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

The residuals in 1996 were less than the presumed standard error of estimate in three of the four reaches. Even in this fourth reach the residual was less than 2 ½ percent of the flow entering the reach. 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 1.6 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 as a method 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 1996, 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 was 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 three of the four reaches.

The standard error of estimate and variance values used in this report are based upon values recommended in Lane 1998. Some minor adjustments were made to some of the recommended values based upon judgement. The standard error of estimate and variance values used for 1996 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, left open in the 1995 LCRAS report. 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 from 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 was different in the Hoover Dam to Davis Dam reach than it was in the Davis Dam to Parker Dam reach in the 1995 LCRAS report. When the interaction between reaches is treated properly, 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 1996 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. 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} from the reaches above each dam and the flow to Mexico,

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 5 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 5. —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 [7]	
Measured flow	9,972,100	9,931,500	7,300,500	6,106,432	1,587,334	
Amount of residual apportioned to Q_{dif} of the reach below each dam from the water balance	-62,410	-191,185	13,314	83,547	N/A	Average
Initial adjustment value (start with zero at most upstream dam and cumulative to most downstream flow)	0	-62,410	-253,595	-240,281	-156,734	-142,604
Initial adjusted flow (measured flow + initial adjustment)	9,972,100	9,869,090	7,046,905	5,866,151	1,430,600	
Final adjusted flows below each dam and to Mexico (initial adjusted flow - average of initial adjustment values)	10,114,702	10,011,692	7,189,509	6,008,755	1,573,204	
Final adjustments to measured flows (final adjusted value - measured value)	142,602	80,192	-110,991	-97,677	-14,130	
Final adjustments to measured flows in percent	1.43%	0.81%	-1.52%	-1.60%	-0.89%	

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 required to the flow at these dams and the flow to Mexico, to reduce the residual to zero, can be used as an additional measure of the quality of the water balance closure. If the magnitude of the adjustments to the flows at these dams and the flow to Mexico is minor, the closure of the water balance is considered excellent.

As can be seen from examining table 5, the final adjustments to the measured flows below the Hoover, Davis, and Parker Dams, at Imperial Dam, and the flow to Mexico are minor, implying excellent water balance closure. The final results of this successful water balance are shown on table 6.

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

Table 6. —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})	10,114,702	10,011,692	7,189,509	6,008,755	10,114,702
Flow at the downstream boundary (Q_{ds})	10,011,692	7,189,509	6,008,755	1,573,204	1,573,204
Residual	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	103,010	2,822,183	1,180,754	4,435,551	8,541,498
Measured Tributary inflow (Trm)	0	3,550	0	9,402	12,952
Unmeasured Tributary inflow (Trum)	6,484	45,566	33,710	2,993	88,753
Exported flow (Q_{ex})	0	2,417,235	0	3,912,066	6,329,301
Evaporation (E)	148,587	130,562	63,104	11,076	353,329
Domestic Consumptive Use	393	38,980	4,657	29,971	74,001
Crop Consumptive Use	0	87,320	745,642	416,886	1,249,848
Phreatophyte Consumptive Use	12,118	196,107	395,611	77,947	681,783
Change in reservoir storage (ΔS_r)	-51,604	1,095	5,450	0	-45,059
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 images and a GIS data base.

Second, the ET for each crop and phreatophyte class was calculated using reference ET, vegetation coefficients, and vegetated acreages. The ET for all vegetation classes were 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 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.[8]

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 sample calculation will proceed 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 daily reference ET (ET_0), from the Parker AZMET station,[9] times the daily crop coefficient (K_c) for alfalfa; then subtracting the effective precipitation.

The daily ET_0 values from the Parker AZMET station, 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 ET_0 value for January 1 is 0.213 inch, and the total ET_0 value for the month of January is 3.92 inches. The K_c for alfalfa on January 1 is 1.020 (listed on page 2 of 2, sheet E). Since there was no rain that day, the product of the ET_0 and K_c values (0.22) is the ET rate, in inches, for alfalfa on January 1, as shown on sheet E, page 1 of 2.

Let us look at February 25 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 February 25, the effective precipitation coefficient of 0.4 (the value for the month of February from sheet C), was multiplied by the measured precipitation (0.276 from sheet B), to yield an effective precipitation of 0.11 inch (0.4×0.276), as shown on sheet C.

Then we calculated the ET rate[10] for alfalfa for February 25 as ($ET_0 \times K_c$) − effective precipitation. With ET_0 equal to 0.118 (from sheet D), K_c for alfalfa equal to 1.020 (from

[8] 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.

[9] The Parker AZMET station is the automated weather station within the CRIR in Arizona.

[10] 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.

sheet E, page 2 of 2), and effective precipitation equal to 0.11(from sheet C), the ET rate for February 25 was 0.01 inch (shown on sheet E).

Let us continue our example with the month of February. The ET rate for alfalfa was calculated for each day of February and summed to derive the cumulative alfalfa ET rate for February (4.04 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 February ET for alfalfa, find the cumulative February ET rate for alfalfa (4.04 inches, from the Parker Crops Table, sheet E, page 1 of 2) and the acreage of alfalfa on CRIR in February (38,108 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 (12,820 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 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, 7,300,500 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 USGS 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 5,018,900 acre-feet, 846,813 acre-feet, 9,859 acre-feet, and 230,860 acre-feet, respectively. The sum of these outflows resulted in the downstream outflow (flow at Imperial Dam) of 6,106,432 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 allows for the use of ET_0 values from the nearest AZMET stations. For the purpose of demonstration, the evaporation calculation for February in River Section 1 in the Parker Dam to Imperial Dam reach is described below:

The February evaporation rate was derived by multiplying the monthly ET_0 (4.43 inches, from sheet D of the Parker Crops Table) times the evaporation coefficient (0.59, from sheet H of the Parker Dam to Imperial Dam Water Balance Table) less precipitation in February (0.28 inches, from sheet B of the Parker Crops Table), divided by 12, times the area of open water in river section 1 (3,538 acres from sheet H of the Parker Dam to Imperial Dam Water Balance Table). The result of this calculation was 689 acre-feet, 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 February was 1,574 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 provided by each State.[11] 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 (C_{ud})."

[11] Per capita consumptive use rates were provided to USGS and are published in Owen-Joyce and Raymond (1996).

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, 1995) was 2,290 acre-feet, the end-of-month storage (as measured midnight January 31, 1996) was 7,761 acre-feet. The difference was a gain of 5,471 acre-feet. The monthly reservoir changes were summed to confirm the total change in reservoir storage of 5,471 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 14,051 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 below:[12]

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

Where:

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

The UAV of crop ET in the Parker Dam to Imperial Dam reach was 745,101 acre-feet, and the SEE was 5 percent, yielding a variance of 1,387,938,751 acre-feet squared. The TVAR was 36,077,195,582 acre-feet squared, and the residual was 14,051 acre-feet. Substituting these values into the equation results in

$$DAV_{ETcrop} = 745{,}101 + [(1{,}387{,}938{,}751 \div 36{,}077{,}195{,}582) \times (14{,}051)]$$

$$DAV_{ETcrop} = 745{,}642 \text{ acre-feet}$$

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:

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

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

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:

$$DDET_{crop\ CRIR} = 361{,}079 \text{ acre-feet} \div (745{,}101 \text{ acre-feet} \div 745{,}642 \text{ acre-feet})$$

$DDET_{crop\ CRIR}$ = 361,341 acre-feet [13] = Consumptive Use

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 161,854 acre-feet. These values were considered to be the consumptive use by crops and phreatophytes at CRIR. The distributed values of domestic use (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 1996 are presented in the numerous tables and charts found below and in the attachments. Table 7 presents a summary of consumptive use prepared by LCRAS and by the Decree Accounting method.

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

Table 7.—Consumptive use
(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 1996 Decree Accounting Report)		231,400	231,400	Uses above Hoover Dam
Uses below Hoover Dam	29,443	17,704	17,847	Uses below Hoover Dam
			746	Unmeasured return flow credit
Nevada Total	29,443	249,104	248,501	Nevada Total
California				
	213,653	5,202,985	5,322,653	Sum of individual diverters
			96,487	Unmeasured return flow credit
California Total	213,653	5,202,985	5,226,166	California Total
Arizona				
Subtotal (Below Hoover Dam, less Wellton-Mohawk IDD)	438,686	2,137,685	2,497,656	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (from the 1996 Decree Accounting Report)		188	188	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (from the 1996 Decree Accounting Report)		274,421	274,421	Wellton-Mohawk IDD
			57,368	Pumped from South Gila wells (DPOCs): returns
			161,955	Unmeasured return flow credit
Arizona Total	438,686	2,412,294	2,552,942	Arizona Total
Lower Colorado River Basin Total				
Total Use	681,782	7,864,383	8,027,609	Total Use

Some of the differences 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. Figure 1 presents data for the states of California and Arizona and shows a good comparison between the total consumptive uses of crops and phreatophytes produced by LCRAS and the total consumptive uses reported by the Decree Accounting Report. These differences are also displayed and discussed in the bar chart section of attachment 5.

The table and bar charts found in attachment 5 present the results of the LCRAS Demonstration of Technology for Calendar Year 1996 and also present a comparison between the LCRAS results and the values published in the Decree Accounting Report. There are several notes on table A1 and the bar charts that assist in interpreting the results.

The differences in attachment 5 between consumptive uses reported by the Decree Accounting Report and those developed by LCRAS on a district-by-district basis have given rise to two outstanding 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?

The resolution of the two questions, as well as other questions and concerns, is addressed in the following chapter.

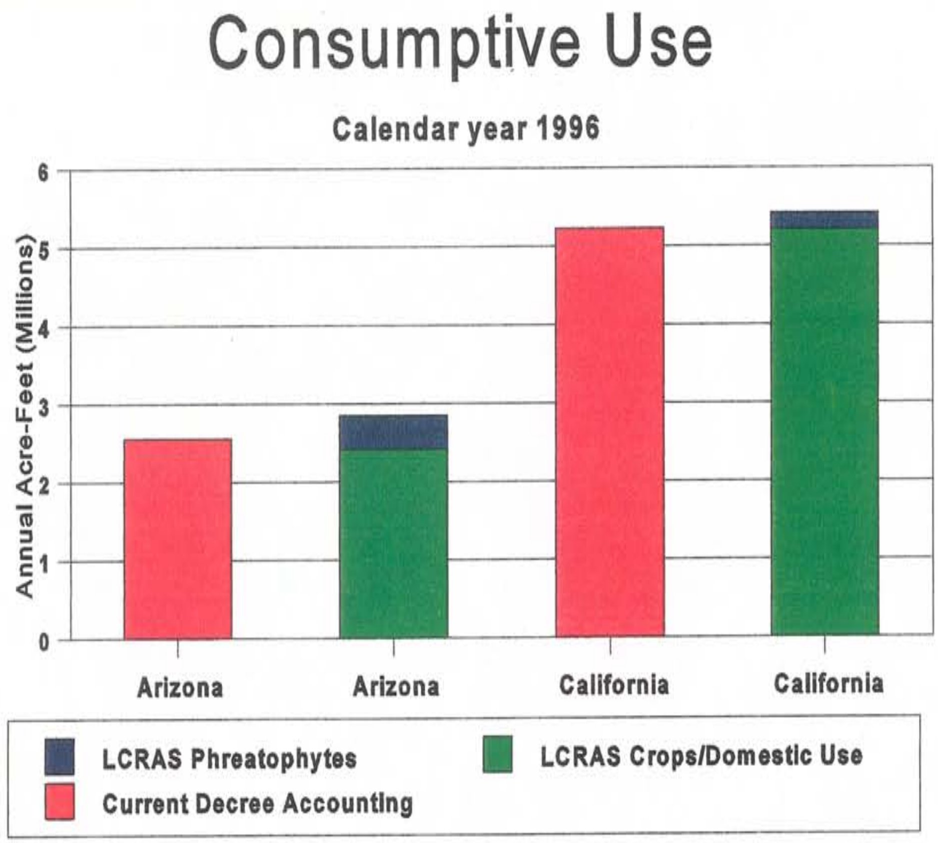


Figure 1.—State totals, Arizona and California (consumptive use for calendar year 1996).

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 improvements identified in the 1995 LCRAS report. Below each of these items are the descriptions of the changes made for this 1996 report. Also shown below, are improvements made to the LCRAS method processing identified while reviewing the 1995 LCRAS Report as part of the development of this 1996 report.

Diverter Boundaries

Reclamation has consulted with several irrigation districts to resolve discrepancies in diverter boundaries that may exist between Reclamation's GIS coverage used for the 1995 LCRAS report and the districts' service areas. Information gained through these meetings has been used to update the diverter boundaries used by LCRAS in 1996. Such information sharing and gathering will be an ongoing effort.

The following diverter boundaries were deleted for 1996 (these areas were included in other diverter boundaries):

Parker Dam to Imperial Dam reach:

> Yuma Proving Ground, Arizona (the Yuma Proving Ground is adjacent to the Colorado River only in the Imperial Dam to Mexico reach).
> Cibola Island, Arizona (no crop or phreatophyte use)

Imperial Dam to Mexico reach:

> Fort Yuma Indian Reservation and Yuma Proving Ground, Arizona
> Imperial National Wildlife Refuge and Yuma Proving Ground, Arizona
> Mittry Lake State Wildlife Area and Yuma Proving Ground, Arizona
> Mittry Lake State Wildlife Area, California

The following diverter boundaries were added for 1996:

Davis Dam to Parker Dam reach:

Bill Williams National Wildlife Refuge.

Imperial Dam to Mexico reach:

Fort Yuma Indian Reservation, Arizona / Homesteads.
Hillander "C" Irrigation and Drainage District (this district was included in "State of Arizona" in the 1995 LCRAS report).

Crop Consumptive Use

As part of an ongoing contract, Dr. Marvin Jensen made some minor modifications to the crop coefficients for 1996 based upon information acquired during ground-reference data collection. These modifications change the growth window of some crop classes in the Parker and Blythe areas. The crop coefficient values used in 1996 can be found in Appendix I, Part 1, Evapotranspiration Rate Calculations.

The revised growth windows for the Parker and Blythe areas are as follows:

Alfalfa (seed)	December 1	-	July 31
Cotton	April 1	-	September 17
Corn	March 1	-	June 28
Lettuce (Early)	September 1	-	December 15
Lettuce (Late)	December 1	-	February 28
Melons (Spring)	March 15	-	July 12
Melons (Fall)	August 15	-	December 12
Sudan	April 1	-	August 3
Other Vegetables	November 15	-	May 23

The revised growth windows for the Yuma area are as follows:

Alfalfa (seed)	December 1	-	July 31
Cotton	April 1	-	September 27
Sudan	April 1	-	August 3

The agricultural field borders in the Laughlin, Nevada, area (center pivots) were removed from the field-border data base. These center pivots were (and to some small extent appear to still be) used for disposing treated sewage from the domestic water delivery system in the area. Therefore, these uses are included in the domestic use for Big Bend Water District.

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.

This issue remains unresolved and will be discussed in the LCRAS public process.

Remote Sensing, Image Processing, and Geographic Information System Analysis

LCRAS currently uses image data from the Landsat V satellite. This satellite is well beyond its service life, and its replacement is not scheduled to be launched until sometime in 1998. Reclamation is currently investigating other data sources to provide backup and/or replacement for Landsat V.

Reclamation will evaluate the potential for multispectral and multitemporal composite analysis to provide more accurate and, possibly, more timely annual crop summaries. Reclamation will also evaluate the potential for multidate open water surface classification to improve open water surface area estimates.

Change detection procedures are being developed for mapping phreatophyte areas. These procedures will eliminate the need to perform image classification each year to develop the phreatophyte acreages.

Reclamation will reinstate investigations into estimating ET using surrogate crop coefficients derived from a Normalized Difference Vegetation Index. Application of this technique would provide a means to check the ET estimates developed using single-date image classification.

Reclamation has investigated sources of image data other than TM data from the Landsat V satellite. Reclamation has determined that a number of alternate imagery sources can meet the needs of the LCRAS program. These alternate imagery sources include Indian Remote Sensing (IRS) LISS-III multi-spectral data, Japanese (JERS) multi-spectral data, and SPOT multi-spectral data.

Reclamation has concluded that our current multispectral classification process is quicker, more streamlined, and at least as accurate, if not more accurate, than multitemporal processes. Reclamation has therefore terminated investigations into multitemporal processing at this time. Reclamation will evaluate processes to improve our current multispectral classification techniques and investigate the use of GIS stratification to help minimize classification error between some crop types.

Change detection procedures have been developed for mapping phreatophyte areas and used in this application of LCRAS for 1996. These procedures greatly reduce the time needed to update the phreatophyte data base each year, as only areas of spectral change are re-mapped rather than all phreatophyte areas.

Reclamation has determined that, at this time, estimating ET from surrogate crop coefficients developed using a Normalized Difference Vegetative Index (NDVI) derived from remote sensing does not offer a potential to improve upon the technique currently used by Reclamation. Reclamation will monitor research investigating correlations between crop ET coefficients and continuous curves derived from remote sensing using NDVI, and possibly apply it in the future if it proves useful to LCRAS.

River Gauging

A penstock modeling study at Hoover, Davis, and Parker Dams was performed by Reclamation to determine if

- *Closed conduit AVM installations conform to American National Standards Institute/American Society of Mechanical Engineers installation standards*

- *AVM installations were performing to manufacturer's specified accuracies of ±0.5 percent of true discharge*

The resulting report (Laboratory and Field Evaluations of Acoustic Velocity Meters at Davis and Parker Dams) (Bureau of Reclamation, 1995b) shows that the installations in Davis and Parker Dams do not fully meet the installation standards due partially to the transducer orientation and their proximity to bends in the penstocks. The modeling study indicates that this has an adverse effect on the accuracy of the AVMs, which could be partially corrected with the installation of a second AVM path to create a cross-flow path system.

Reclamation is reviewing how flow below the dams is calculated. The review includes a comparison of flow measurements taken by a Broad Band Acoustic Doppler Current Profiler (BB ADCP) to those taken by the closed conduit AVM, turbine curve, and USGS stream-gauging method currently in progress. The BB ADCP is being used to rate the open-channel AVMs.

Reclamation continues to operate the AVM's at station 30 on the Gila Gravity Main Canal and at the Wellton-Mohawk Canal. No additional AVM's were installed in 1996.

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 are expected to be addressed in the LCRAS public process. Incidental use factors have not been developed to date.

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 1996 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 1996. 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.

Domestic Use

The domestic use values presented in this report are mostly diversions from the Decree Accounting Report. (A complete description and listing of the domestic use values are included in attachment 5 in this report.) The use of diversions instead of consumptive uses overestimates domestic use by a factor of about 2.

Domestic uses must eventually be developed as consumptive use values. The total volume of water diverted by domestic users is small (about 72,000 acre-feet in 1995). Reclamation will provide estimates of consumptive use for domestic diverters currently reported as diversions in future applications of LCRAS.

Upon review of this Demonstration of Technology, Reclamation has discovered that some small domestic diverters were placed in the wrong reach and that some wells thought to be used for an industrial use (Huerta Packing) are probably used for irrigation. These errors will be corrected in subsequent applications of LCRAS.

A detailed explanation of the methods used to make initial estimates of domestic use can be found in attachment 3. The domestic diverters found to be modeled in the wrong reach in the 1995 LCRAS report were moved to their proper place for 1996. Consumptive use from a few wells thought to be domestic users, but identified as agricultural users upon site visits, were removed from the domestic use portion of the calculations.

The accounting for the following domestic users was modified for 1996:

Davis Dam to Parker Dam reach:

The diverter listed as "BLM Permitees" in the 1995 LCRAS report was split into two groups, "BLM Permitees-AZ", and, "BLM Black Meadow-CA".

The diverter listed as "Brook Water, AZ" was moved from the Davis Dam to Parker Dam reach to the Parker Dam to Imperial Dam reach (Brook Water is located just below Parker Dam in Arizona).

Parker Dam to Imperial Dam reach:

The diverter listed as "BLM Permitees" in the 1995 LCRAS report was split into two groups, "BLM Permitees-AZ" and "BLM Permitees-CA".

The diverters listed as "Yucca Power Plant" and "Cocopah Bend RV" were moved from the Parker Dam to Imperial Dam reach into the Imperial Dam to Mexico reach to match their physical locations.

The two diverters listed as "Huerta Packing" were deleted as domestic uses. These wells were found to be irrigation wells on the North Cocopah Indian Reservation.

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, we should be calculating a reference ET 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.

Evaporation and precipitation are expected to be addressed as part of the LCRAS public process.

Changes in Groundwater Storage

Currently, LCRAS has no mechanism to estimate the changes in aquifer storage. Reclamation and interested parties should investigate potential methods to acquire this information in the future. This item is currently assigned a low priority.

This situation has not changed. Changes in groundwater storage are expected to be addressed as part of the LCRAS public process.

Modeling Program

The calculations required by LCRAS were performed by a multipage spreadsheet for calendar year 1995. A description of this spreadsheet can be found in the introduction pages to Appendix I. Reclamation will investigate the potential application of the River Basin Modeling System, a specialized form of hydrologic modeling, to perform the calculations required by LCRAS and archive the required data. This system of modeling is currently being applied to the Colorado River Simulation System and the 24-Month Study, which are used for Colorado River reservoir operations and water supply studies.

The calculations required for this 1996 report were performed by an updated version of the multipage spreadsheets used in 1995. A description of this spreadsheet can be found in the introductory pages of Appendix I. Reclamation assigned this portion of the program to a relatively low priority in 1996 to assure the timely completion of this report.

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. Beginning with this report, Reclamation will tabulate the residuals for the reaches of the water balance for this and previous applications of LCRAS. This tabulation is shown on table 8 below.

Table 8. — 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%

ET_0 Values from the AZMET and CIMIS Stations

The ET_0 values from the AZMET and CIMIS stations are the basis of ET calculations for crops and phreatophytes, and evaporation from open water surfaces. Reclamation has noticed that the CIMIS station in the Palo Verde valley consistently shows lower annual ET_0 values than the AZMET stations across the river. Three possible causes are under investigation by staff from Reclamation and the CIMIS and AZMET networks: 1) the difference in the method used by each network to calculate net solar radiation (the only difference in the ET_0 calculations used by each network), 2) siting effects, and 3) actual micro-climatic differences that may exist on opposite sides of the river. The ET_0 values produced by each AZMET station and the Palo Verde CIMIS station and accompanying precipitation values are shown on figure 2, which follows.

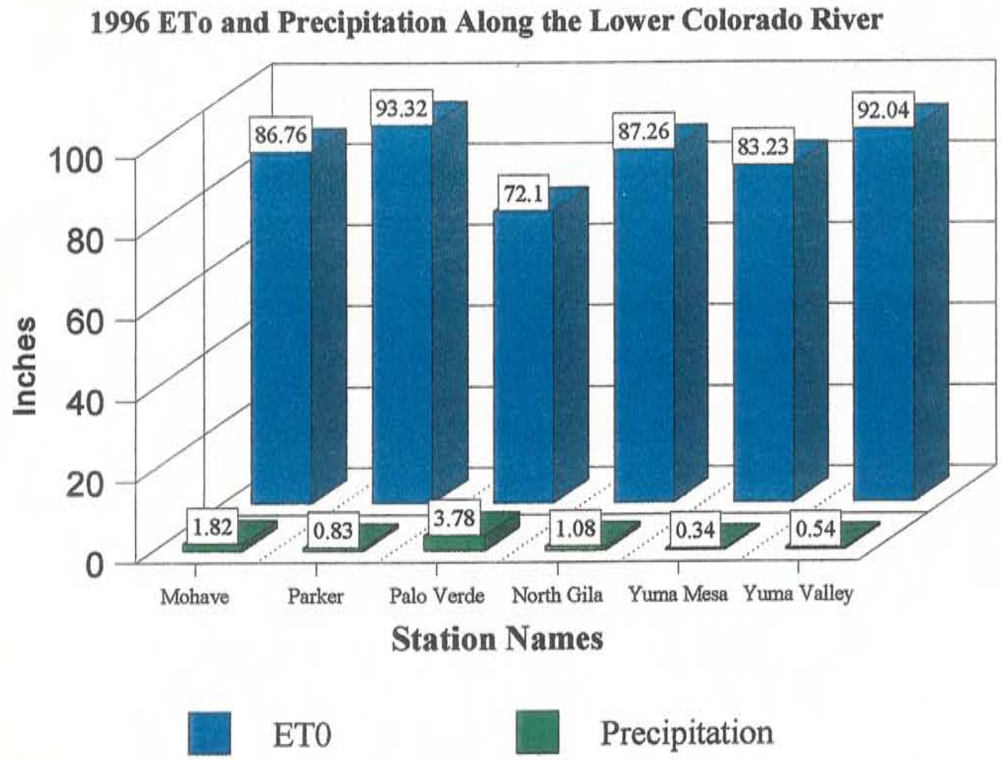


Figure 2 — ET_0 and Precipitation Values from AZMET and CIMIS Stations.

Paul Brown of the AZMET network has collected and processed data from the AZMET station at the University of Arizona turf experimentation farm to quantify the differences in solar radiation values produced by the CIMIS and AZMET methods of calculation. Preliminary results for the past year indicate that the two calculation methods yield ET_0 values that differ from each other by about 8 to 10 percent. Further study is underway.

Chapter 4

Conclusion and Future Activities

The goal of the LCRAS program is to improve Decree Accounting, using the technologies developed by LCRAS. 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 interested in 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 1997 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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Lower Colorado River Accounting System

Attachments - Calendar Year 1996

Attachment 1

Colorado River History and Legal Framework Att-1

Attachment 2

Measured and Unmeasured Flows for Each Reach Att-4

Attachment 3

Calculation of Domestic Consumptive Use for LCRAS - Calendar Year 1996 .... Att-6

Attachment 4

Monthly storage values for Lakes Mohave and Havasu, and Senator Wash Reservoir Att-13

Attachment 5

Results in Tabular Form Att-14

Results in Graphic Form Att-30

Attachment 6

Remote Sensing and GIS Procedures .... Att - 37

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 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 the 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—Committed 1.5 million acre-feet of the 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 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	9,972,100	9,421,500
Change in storage Lake Mohave !	-51,600	9,422,500
Davis Dam to Parker Dam Reach		
Colorado River below Davis Dam	9,931,500	9,423,000
Colorado River Aqueduct $	1,230,353	9,424,150
Bill Williams River below Alamo Dam	19,278	9,426,000
Central Arizona Project Canal $	1,196,059	9,426,650
Change in storage Lake Havasu !	1,100	9,427,500
Parker Dam to Imperial Dam Reach		
Colorado River below Parker Dam	7,300,500	9,427,520
Change in storage Senator Wash !	5,450	
Colorado River above Imperial Dam	6,106,432	9,429,490
Imperial Dam to Mexico Reach		
Diversion to Mittry Lake	9,859	9,522,400
All-American Canal	5,018,900	9,523,000
All-American Canal below Pilot Knob	3,485,600	9,527,500
Gila Gravity Main Canal **	846,813	9,522,500
Wellton-Mohawk Canal **	371,484	9,522,700
Colorado River below Imperial Dam	230,860	9,429,500
Gila River near Dome	9,406	9,520,500
Colorado River at NIB #	1,386,962	9,522,000
Eleven Mile wasteway #	573	9,525,000
Cooper wasteway #	1,362	9,531,850
Twenty-one Mile wasteway #	388	9,533,000
Main drain + 242 wells #	102,878	9,534,000
West Main Canal wasteway #	5,403	9,534,300
East Main Canal wasteway #	7,758	9,534,500

$ Provided by user, not U.S. Geological Survey
! U.S. Geological Survey - December 1995 minus December 1996
** 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[1]	4,000
Groundwater discharge	
Davis Dam to Topock	0
Topock to Parker Dam	880
Piute Valley	2,300
Sacramento Valley	10,000
Chemehuevi Valley	260
Bill Williams River subarea[1]	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
Imperial Dam to Mexico reach	
Groundwater Discharge	
Gila River	1,000
Unmeasured runoff, Yuma area	2,000

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

Attachment 3
Calculation of Domestic Consumptive Use for LCRAS - Calendar Year 1996

Summary

This document's purpose is to provide background and rationale for the methods and factors used to calculate domestic consumptive use for the Lower Colorado River Accounting System (LCRAS), as applied to calendar year 1996. Domestic consumptive use is calculated by one of four methods. An explanation of the development of these methods, their assumptions, and the basis of the assumptions is presented in the following paragraphs.

Domestic consumptive use is calculated as follows:

1. As a measured diversion less a measured return, where measured diversions and returns are available;

2. As a measured diversion less the sum of a measured and an unmeasured return, where measured diversions and returns are available and studies have been performed which quantify an unmeasured return flow;

3. As a measured diversion multiplied by a domestic consumptive use factor of 0.6, where a measured diversion is available and no measured returns or other data or information is available;

4. As the product of an annual per-capita consumptive use factor (0.14 acre-feet per-capita per year) and an estimate of population (the 1990 census if no other information is available) if landscape irrigation is not a significant portion of the domestic water use. If landscape irrigation is a significant portion of the domestic water use, a per-capita use rate of 0.3 acre-feet per capita per year will be used, or the evapotranspiration of the plants which make up the landscape will be made and added to the domestic use calculated as the population times a domestic use factor of 0.14 acre-feet per capita per year.

Domestic Use Factor

The domestic consumptive use factor of 0.6 was derived by examining the relationship between the measured diversion and consumptive use of municipalities along the lower Colorado River with measured diversions and measured returns. There are only four such cities: Boulder City, Nevada[1]; Laughlin, Nevada (Big Bend Water District); Needles[2], California; and Yuma, Arizona. Table 1 shows the volume of water diverted from and returned to the Colorado River, and the ratio of consumptive use (diversion less return flow) to diversion for each of these cities. Values are in annual acre-feet from 1995 Decree Accounting unless otherwise noted. The use from the Robert B. Griffith Water Project (Las Vegas Valley, Henderson, and Boulder City, Nevada, combined) was added to Table 1 as a check value.

Figure 1 is a bar graph showing the domestic consumptive use factors, from Table 1, for each of the cities and the Robert B. Griffith Water Project. As can be seen from examining this figure, 0.6 appears to be a useable domestic consumptive use factor that falls near the average of the information available. This, or a similar value, will be used until additional information becomes available.

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1 Boulder City, Nevada, does not return water to the Colorado River, but does return water to a treatment plant where the unused portion of the diverted water can be measured. Consumptive use for Boulder City, as used here, is intended to demonstrate the portion of a diverted volume of water that is consumed by domestic use. Boulder City's accountable consumptive use is equal to its diversion until such time as the city actually returns water to the Colorado River.

2 Needles, California, is credited with both a measured and unmeasured return flow. This information was developed in studies performed by the Colorado River Board of California.

City	Diversion	Wastewater or Return Flow	Domestic Consumptive use	Domestic Consumptive Use Factor[3]
Boulder City, NV[4]	5,430	1,368	4,062	0.75
Boulder City, NV (Household Use Only[5])	3,133	1,280	1,853	0.59
Laughlin, NV[6]	5,313	946	4,367	0.82
Needles, CA (w/ Measured Return)	3,119	459	2,660	0.85
Needles, CA (w/ Measured & Unmeasured Return)	3,119	1,707	1,412	0.45
Yuma, AZ	25,645	10,743	14,902	0.58
Robert B. Griffith Water Project, NV	315,631	136,588	179,043	0.57
			Average	**0.66**

Table 1

[3] Domestic Consumptive Use / Diversion for Domestic Purposes

[4] Average 1988 through 1992 values from Boulder City municipal records. Diversion does not include water delivered to municipal parks and golf course use. Boulder City is also known for extensive domestic landscape irrigation.

[5] 1988 to 1992 average January value multiplied by 12 to simulate an annual value without domestic lawn and shrub watering (few people water their lawn and shrubs in January). The delivery for municipal landscape watering has also been removed.

[6] Includes irrigation of alfalfa as part of the waste water treatment and extensive visitor water use from hotels and casinos.

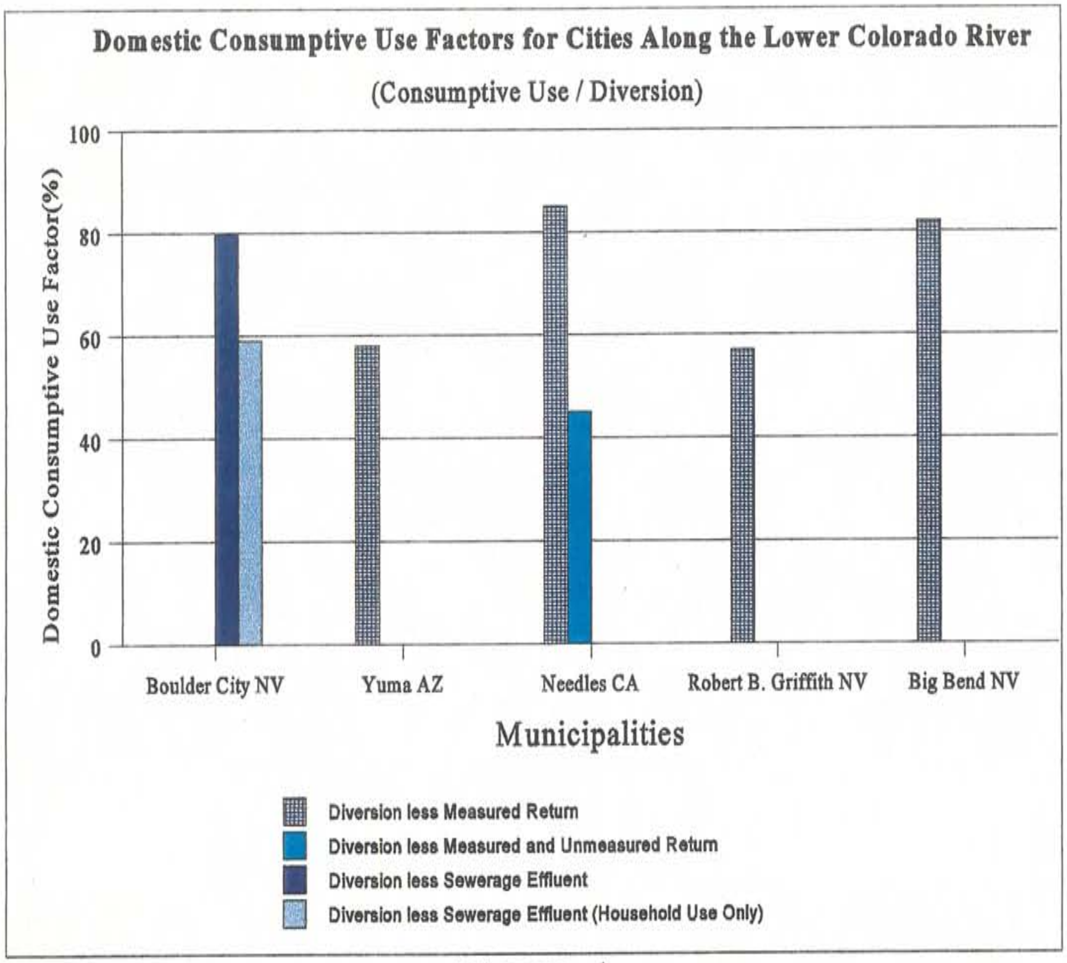


Figure 1

Per-Capita Consumptive Use Factor

The per-capita consumptive use factor used by LCRAS for calendar year 1996 is derived from an analysis of Boulder City, Nevada. Boulder City is the only municipality along the lower Colorado River that derives all of its water from a municipal diversion of Colorado River water (there are no private wells), and all the domestic water is returned to a sewerage system (there are no septic tanks). Boulder City also does not have a large transient population or large visitor population.

Reclamation compiled records of the City's diversions (delivered to households and businesses), wastewater (arriving at the City-owned and operated wastewater treatment plant), and irrigation water used on the City-owned golf course and parks, from measurements taken by the City from June 1988 through December

December 1992. June 1988 through December 1992 was the most complete and readily available data when this study was performed (summer of 1994).

All of the domestic water used within the City is delivered through a municipal-owned and operated delivery system. All of the wastewater generated within the City is collected through a municipal-owned and operated sewer system. Given this structure, accurate measurements of water delivered and wastewater generated can be made for the entire community in order to calculate the City's per-capita consumptive use factor and wastewater generation rate.

Below is a detailed compilation of water deliveries and wastewater quantities for the City from June 1988 through December 1992. It also includes calculations for monthly and annual per-capita consumptive use within the City for this same time period.

Based on these measurements and calculations, the actual consumptive use in Boulder City, Nevada, ranged from a high of 0.37 to a low of 0.29 acre-feet per person per year, with the average being 0.32 acre-feet per person per year. These values do not include the water used by the City for the municipal parks and golf course. They do, however, include individual landscape use (lawns and other outside-the-house uses, assumed to be large in the City when compared with small municipalities along the lower Colorado River).

An estimate was also made of the per-capita consumptive use of water in the City that minimized the influence of domestic landscape use. This was done by examining the per-capita consumptive use of water in the City during the month of January (landscape water use is much reduced in January), and extrapolating this use for an entire year. The result of this analysis yields a per-capita consumptive use factor of 0.14 acre-feet per capita per year. This factor will be used for domestic users where landscape irrigation is not a significant portion of the domestic water use until additional information becomes available. The data used in this analysis is shown below:

Population of Boulder City

Year	Population
1988	12,130
1989	12,740
1990	12,760
1991	12,950
1992	12,810

Diversions in Acre-Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1988	N/a	N/a	N/a	N/a	N/a	824.4	993.2	897.7	821.6	651.6	377.5	299.9	N/a
1989	268.5	295.2	480.6	639.0	720.9	823.1	921.0	831.1	759.6	677.4	585.3	520.8	7522.7
1990	322.6	259.6	471.4	474.8	582.5	767.0	868.2	821.0	671.2	544.8	415.2	325.0	6523.4
1991	268.9	299.2	302.6	486.1	643.9	775.3	881.4	791.2	678.6	580.4	606.5	288.2	6602.2
1992	274.7	253.2	203.8	453.0	699.4	819.8	879.6	872.5	787.5	609.8	399.3	288.5	6541.2
89-92AV	283.7	276.8	364.6	513.2	661.7	796.3	887.6	829.0	724.2	603.1	501.6	355.6	6797.4

Wastewater in Acre-Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1988	N/a	N/a	N/a	N/a	N/a	104.3	110.5	102.2	100.4	100.4	95.8	97.3	N/a
1989	97.6	88.1	104.7	113.3	119.4	120.0	125.8	122.5	114.2	114.5	103.4	104.0	1327.4
1990	105.9	93.9	113.3	118.5	116.9	124.3	126.8	119.4	119.1	113.9	114.5	118.2	1384.5
1991	112.9	107.1	110.8	109.0	115.1	126.8	134.7	129.2	120.9	115.1	115.1	113.9	1410.6
1992	110.5	105.9	113.3	110.2	117.2	114.2	116.6	116.9	117.2	111.1	107.3	108.5	1348.9
89-92AV	106.7	98.7	110.5	112.7	117.2	121.3	126.0	122.0	117.9	113.6	110.1	111.1	1367.8

Water used for Municipal Landscape Irrigation (Golf Course and Parks) in Acre-Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1988	15.0	47.9	87.5	78.6	175.6	224.4	267.6	192.4	173.7	153.8	61.7	35.9	1514.0
1989	18.7	43.0	81.9	147.6	148.5	178.9	241.5	186.3	166.7	144.2	83.8	39.6	1480.8
1990	32.5	25.5	69.7	118.2	173.1	208.7	201.6	165.7	138.7	131.4	73.4	37.8	1376.2
1991	25.2	45.1	31.3	112.0	135.3	183.5	244.0	153.1	182.9	107.1	45.1	34.1	1298.8
1992	14.1	21.2	34.7	87.8	177.1	195.5	210.5	200.4	172.5	112.9	55.6	31.0	1313.3
89-92AV	22.6	33.7	54.4	116.4	158.5	191.7	224.4	176.4	165.2	123.9	64.5	35.6	1367.3

Total Domestic Consumptive Use (Diversion - Wastewater - Municipal Landscape Irrigation), in Acre-Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1988	N/a	N/a	N/a	N/a	N/a	495.7	615.0	603.1	547.5	397.4	220.1	166.7	N/a
1989	152.2	164.2	294.0	378.1	453.0	524.2	553.7	522.4	478.8	418.6	398.1	377.2	4714.4
1990	184.1	140.3	288.5	238.2	292.5	434.0	539.9	535.9	413.4	299.5	227.4	169.1	3762.7
1991	130.7	147.0	160.5	265.2	393.5	465.0	502.7	508.9	374.7	358.2	446.2	140.3	3892.8
1992	150.1	126.1	55.9	255.0	405.1	510.1	552.4	555.2	497.8	385.8	236.4	149.0	3878.9
89-92AV	154.3	144.4	199.7	284.1	386.0	483.3	537.2	530.6	441.2	365.5	327.0	208.9	4062.2

Per-Capita Month Total Domestic Consumptive Use, in Acre-Feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	N/a	N/a	N/a	N/a	N/a	0.0409	0.0507	0.0497	0.0451	0.0328	0.0181	0.0137
1989	0.0119	0.0129	0.0231	0.0297	0.0356	0.0411	0.0435	0.0410	0.0376	0.0329	0.0312	0.0296
1990	0.0144	0.0110	0.0226	0.0187	0.0229	0.0340	0.0423	0.0420	0.0324	0.0235	0.0178	0.0133
1991	0.0101	0.0114	0.0124	0.0205	0.0304	0.0359	0.0388	0.0393	0.0289	0.0277	0.0345	0.0108
1992	0.0117	0.0098	0.0044	0.0199	0.0316	0.0398	0.0431	0.0433	0.0389	0.0301	0.0185	0.0116
89-92AV	0.0120	0.0113	0.0156	0.0222	0.0301	0.0377	0.0419	0.0414	0.0344	0.0285	0.0255	0.0163

Per-Capita Year Total Domestic Consumptive Use, in Acre-Feet

Year	Annual Total
1988	N/A
1989	0.3701
1990	0.2949
1991	0.3006
1992	0.3028
89-92AV	0.3171

To estimate household (in-house) use (total domestic consumptive use less domestic landscape irrigation), assume January reflects household use only (few people watering their lawn and shrubs in January, and note how per-capita use is much larger in the summer months from the above). Subtract municipal landscape watering and wastewater from the average January diversion. Assume this represents household use for every month of the year. Averages are over the period 1989-1992.

Average January Diversion:	283.7 Acre-Feet
Less Average January Municipal Landscape Use:	22.6 Acre-Feet
Less Average January Waste Water:	106.7 Acre-Feet
Equals Average January Household Consumptive Use:	154.4 Acre-Feet

Average Annual Household Consumptive Use:	1,852.8 Acre-Feet (154.4 x 12)
Average Annual Diversion for Household Consumptive use:	3,133.2 ((283.7-22.6)x12)
Average Annual Consumptive Use Factor for Household Use:	0.59 (1,852.8/3,133.2)
Average Annual Per-Capita Household Consumptive Use Factor:	0.14 Acre-Feet/Capita/ Year (1,852.8/12,810)

Attachment 4
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	1,631,800	1,666,000	1,632,500	1,707,000	1,734,400	1,685,700	1,649,500	1,646,300	1,578,400	1,497,400	1,526,900	1,577,800	
Mohave	BOM	1,629,400	1,631,800	1,666,000	1,632,500	1,707,000	1,734,400	1,685,700	1,649,500	1,646,300	1,578,400	1,497,400	1,526,900	
(acre-feet)	Change	2,400	34,200	-33,500	74,500	27,400	-48,700	-36,200	-3,200	-67,900	-81,000	29,500	50,900	-51,600
Lake	EOM	568,500	569,800	527,000	580,800	609,800	594,200	581,400	594,700	596,700	580,200	563,900	555,200	
Havasu	BOM	554,100	568,500	569,800	527,000	580,800	609,800	594,200	581,400	594,700	596,700	580,200	563,900	
(acre-feet)	Change	14,400	1,300	-42,800	53,800	29,000	-15,600	-12,800	13,300	2,000	-16,500	-16,300	-8,700	1,100
Senator	EOM	7,761	6,381	6,567	6,636	7,975	8,810	5,021	9,016	5,831	3,059	2,565	7,740	
Wash	BOM	2,290	7,761	6,381	6,567	6,636	7,975	8,810	5,021	9,016	5,831	3,059	2,565	
(acre-feet)	Change	5,471	-1,380	186	69	1,339	835	-3,789	3,995	-3,185	-2,772	-494	5,175	5,450

Attachment 5
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 (pht=6,059+115) + Cottonwood Cove (domestic consumptive use=149).	6,174	149	249	Lake Mead National Recreation Area, diversion from Lake Mohave (Cottonwood). Reported as a diversion.
Southern California Edison (domestic consumptive use).		13,149	13,149	Southern Nevada Water Authority (Southern California Edison), pumped from Sec 24 T32S R66E. Diversion = consumptive use.
Big Bend Water District (domestic consumptive use).		4,339	4,339	Big Bend Water District Diversion Sec 12 T32S R66E. Reported as a consumptive use.
Sportsman's Park (Domestic consumptive use).	0	0	0	Sportsman's Park. Reported as a diversion.
Boy Scouts (Domestic consumptive use).		6	10	Boy Scouts of America. Reported as a diversion.
Fort Mojave Indian Reservation, NV. (Pht=10,510; Domestic consumptive use [Avi]=61).	10,510	61	100	Fort Mohave Indian Reservation (Avi) Water Pumped for Domestic Use
State of Nevada Includes all crop, phreatophyte, and domestic use not identified with a known diverter.	12,759	0		Not reported.
Uses above Hoover Dam (from 1996 Decree Accounting).		231,400	231,400	Uses above Hoover Dam.
			746	Unmeasured return flow credit to Nevada.
Nevada Total	29,443	249,104	248,501	Nevada Total

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
California				
Fort Mojave Indian Reservation, CA.	5,691	17,487	30,189	Fort Mohave Indian Reservation, pumped from river and wells. Reported as a diversion.
Needles (Includes Havasu Water Company, CA; domestic consumptive use).		1,469	1,471	City of Needles, 4 wells NW SW Sec 29 T9N R23E SBM. Reported as a consumptive use.
Colorado River Aqueduct (export).		1,224,190	1,227,279	Metropolitan Water District, diversion from Lake Havasu. Reported as a consumptive use.
Parker Dam/Gov't. Camp (domestic consumptive use).		241	290	Parker Dam and Government Camp, diversion at Parker Dam. Reported as a diversion.
Colorado River Indian Reservation, CA (pht=40,770; crop=780) + North Lyn-De Farm, CA (portion not within Colorado River Indian Reservation boundary: pht=0; crop=195) + South Lyn-De Farm, CA (pht=2; crop=1,999) + Bernal Farm, CA (pht=1,377; crop=1,029) + Clark Farm, CA (pht=368; crop=0). **Note:** Some uncertainty exists concerning the southerly Colorado River Indian Reservation boundary in CA.	42,517	4,003	7,320	Colorado River Indian Reservation, pumped from 11 pumps and wells, 4 pumps from river. **Note:** 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. Reported as a diversion.
Chemehuevi Indian Reservation, CA. (Pht=53; crop=0; domestic use=509).	53	509	848	Chemehuevi Indian Reservation, Diversions from Pumps.
BLM-Black Meadow (Domestic consumptive use).		91	151	BLM Permittees.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Havasu National Wildlife Refuge, CA.	6,634	0		Not reported.
Park Moabi, CA.	298	0		Not reported.
BLM Permittees.		262	442	BLM Permittees.
Palo Verde Irrigation District, CA (pht=8,045; crop=349,165) + Palo Verde Irrigation District, AZ (pht=493; crop=651) + Blythe (city, domestic use=1,180) + East Blythe (domestic use=212) + Ripley (domestic use=53) + Palo Verde (domestic use=46).	8,538	351,307	493,572	Palo Verde Irrigation District, diversion from Palo Verde Dam. Reported as a consumptive use.
Cibola National Wildlife Refuge, CA.	39,546			Not reported.
Imperial National Wildlife Refuge, CA.	21,555			Not reported.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Winterhaven (Domestic consumptive use).		82	269	City of Winterhaven, 1 well, SE SE NE Sec 27 T16S R22E SBM=136 AF & Town of Winterhaven, 1 well, 6S-22E 27DAA=133 AF Reported as diversions.
Fort Yuma Indian Reservation and Picacho State Recreation Area, CA.	0	0		Not reported.
Picacho State Recreation Area, CA.	5,121	0		Not reported.
Picacho Development Corp., CA (Domestic consumptive use).		66	110	Picacho Development Corp. Reported as a diversion.
All-American Canal below Pilot Knob (Final estimate of export at gauge number 09527500).		3,535,286	3,491,082	Imperial Irrigation District, diversion at Imperial Dam (3,159,609) + Coachella Valley Water District, diversion at Imperial Dam (331,473). 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).		50	84	Southern Cal Gas. Reported as a diversion.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Imperial National Wildlife Refuge and Yuma Proving Ground, CA.	52	0		Not reported.
Yuma Proving Ground, CA.	9,348	0		Not reported.
Fort Yuma Indian Reservation and Yuma Proving Ground, CA .	955	90		Not reported.
Fort Yuma Indian Reservation, Indian Unit, CA (pht=558; crop=21,035) + Fort Yuma Indian Reservation, Bard Unit, CA (pht=945; crop=26,812) + Bard (domestic consumptive use = 215 acre-feet) + Fort Yuma Indian Reservation, CA (pht=14,307; crop=4,731).	15,810	52,793	50,076	Yuma Projects, Reservation Division Indian Unit, diversion at Imperial Dam (32,521 CU) + Yuma Projects, Reservation Division Bard Unit, diversion at Imperial Dam (55,726 CU) - Returns from Yuma Project, Reservation Division returns Sum Yuma Projects, Reservation Division use (41,731) + Ralf Land, 1 well, Sec 35 T15S R23E DDC=385 acre-feet + Living Earth Farm, 1 well, Sec 02 T16S R23E BBC=284 acre-feet + Berrymen, 1 well (C-16S-23E) 9CCA=33 acre-feet + Valdez, Mike, 1 well, Sec 22 T16S R23E BDD=578 acre-feet + Power, Pete, 1 well, Sec 14 T16S R23E CCB=2,040 acre-feet + Unknown, I.D., 1 well, 16S-22E 29DAD=240 acre-feet. Indian and Bard units reported as consumptive use. Wells are reported as diversions.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS				**Decree Accounting**
State Of California. Crop and phreatophyte consumptive uses not within known diverter boundaries.	57,535	14,822	19,470	Ida Cal, 3 wells, 11N/22W -31BAB=403 acre-feet, 11N/21E -36ADD=876 acre-feet, 11N/21E - 36CDA=598 acre-feet. (These wells irrigate lands north of Fort Mohave Irrigation District in CA). Lye, C.L., 1S/24E -16Gb=30 acre-feet. Harp, P. (R. Harp), (C-8-23) 13AAD=600 acre-feet. Horizon Farms, 9 wells, (C-8-22) 6CDA=2,727 acre-feet, (C-8-22) 7BAB=1,032 acre-feet, (C-10-22)7ADB=500 acre-feet, (C-10-22)6DCB=500 acre-feet), Barett (C-8-22) 6BBD=600 acre-feet), (C-8-22)6BCD=2,244 acre-feet, (C-10-22)6CBB=250 acre-feet, (C-8-23) 1DCC=1,087 acre-feet, (C-8-23) 12CDB=826 acre-feet). Living Earth Farm, (C-8-23) 2ADC=28 acre-feet). Ed Weavers Farms, 4 wells (C-8-22) 6BCD=0 acre-feet, (C-8-22) 6CBA=1,296 acre-feet, (C-8-22) 1BBA=264 acre-feet, (C-8-23) 1BAD=69 acre-feet). Valdez, Mike, 2 wells, Sec T16S R23E 30ACC= 657 acre-feet, Sec T16S R23E 30ADD=627 acre-feet. Power, O.L., (C-8-23) 11DCA=1,118 acre-feet; Harp, Robert, (C-8-23) 12DAC=180 acre-feet; Dees, Alex, (C-8-23) 1DAC=2,118 acre-feet; Wilson Farms, (C-8-23) 12BBA=59 acre-feet; Land, K. H., (C-8-23) 2DDA=780 acre-feet. The following wells have not been located, but are presumed to be within the State of CA polygons: Wetmore, Kenneth (1 well=0 acre-feet). Williams, Jerry (1 well=1 acre-feet). Lindeman, William H. and Hazel D., Carney, Jerome D., and Phillips, Dorothy L. (3 wells=0 acre-feet).
			96,487	Unmeasured return flow credit to California.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Arizona				
Lake Mead National Recreation Area, AZ (pht=6,059 [Hov-Dwv]+405 [Dav-Pkr]) + Katherine Landing and Willow Beach (Domestic consumptive use=211).	6,464	211	352	Lake Mead National Recreation Area, AZ, Diversions from Lake Mohave, (Katherine, Willow Beach). Reported as a diversion.
Lower Colorado Region Dams Project (Domestic consumptive use).		33	55	Lower Colorado Region Dams Project (Davis Dam), Diversion at Davis Dam. Reported as a diversion.
Bullhead City (Domestic consumptive use).		4,411	7,352	Bullhead City, Pumped from wells. Reported as a diversion.
Mohave County Parks (Domestic consumptive use).		64	105	Diversion at Davis Dam, Mohave Co. Parks. Reported as a diversion.
MVIDD Domestic (includes Bermuda City and other small domestic consumptive uses).		4,902		Not reported. Note: Check for pumpers.
Mohave Valley Irrigation and Drainage District, AZ (includes no domestic use).	37,826	25,926	45,793	Mohave Valley Irrigation and Drainage District, Pumped from wells. Reported as a diversion. **Note:** Includes 8,326 acre-feet of municipal and industrial use in 1996.
Fort Mojave Indian Reservation, AZ.	36,190	41,061	68,035	Fort Mohave Indian Reservation, 12 pumps and wells in flood plain. Reported as diversions.
Golden Shores (Domestic consumptive use).		325	542	Golden Shores Water Conservation District, pumped from wells. Reported as a diversion.
Topock (Domestic consumptive use).		126		Not reported.
Havasu Water Company, AZ (Domestic consumptive use).		273	455	Havasu Water Co. of AZ (Citizens Utilities). Reported as a diversion.
Mohave Water Conservation District (Domestic consumptive use).		476	793	Mohave Water Conservation District; pumped from wells. Reported as a diversion.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Brook Water (Domestic consumptive use).		387	388	Brook Water, (was Consolidated Water Utilities), pumped from river. Reported as a consumptive use.
Havasu National Wildlife Refuge, AZ. **Note:** Topock Marsh evaporation is estimated to be about 12,000 acre-feet. This evaporation was assigned to system loss for this 1996 demonstration. Should evapotranspiration from Topock Marsh be included in estimates of consumptive use for the Havasu National Wildlife Refuge in Arizona?	55,169	738	28,841	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 (Domestic consumptive use).		8,679	14,466	Lake Havasu City, pumped from wells. Reported as diversions.
Bill Williams National Wildlife Refuge (Lake Havasu).	736	0		Not reported.
Central Arizona Project Canal (export).		1,193,045	1,196,059	Central Arizona Project; pumped from Lake Havasu. Reported as a diversion.
Town of Parker (Domestic consumptive use).		1,144	1,143	Town of Parker; pumped from river, 1 well-NW NW NW Sec 7 T9N R19W G&SRM. Reported as a consumptive use.
Lake Havasu State Park, AZ. **Note:** May have missed a golf course.	4,115	0		Not reported.
Poston (Domestic consumptive use).		67		Not reported.
Colorado River Indian Reservation, AZ.	161,854	361,341	476,338	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).		257	428	Ehrenburg Improvement Association, 1 pump SW Sec 3 T3N R22W G&SRM. Reported as a diversion.
Cibola (Domestic consumptive use).		26		Not reported.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Ehrenberg Farm, AZ.	0	2,632	5,047	Jack Rayner (2 pumps; (B-04-22) 34 DCC(CDD)=4,791 acre-feet and (B-04-22)34 DCC(DCD)=256 acre-feet). Reported as a diversion.
Arkelian Farms, AZ. **Note**: Are there more Arkelian Farms pumps that are not reported?	3,226	2,440	2,208	George Arkelian (2 pumps; (B-03-22)16 DBD(DAD)=0 acre-feet and (B-03-22)16 DBD(DAD)=2,208 acre-feet). Reported as a diversion.
Bureau of Land Management permittees (Domestic consumptive use; 51 AF:Dav-Pkr, 465 AF Pkr-Imp).		516	860	Bureau of Land Management permittees. Reported as a diversion.
Hillcrest Water Company (Domestic consumptive use).		13	22	Hillcrest Water Co. Reported as a diversion.
Yuma Proving Ground (Pht=426,Domestic consumptive use=826).	426	826	1,381	Yuma Proving Ground, diversion at Imperial Dam, wells X,Y,M. Reported as a diversion.
Fort Yuma Indian Reservation, Mittry Lake State Wildlife Area and Yuma Proving Ground, AZ.	1,002	0		Not reported.
Fort Yuma Indian Reservation, AZ.	4,434	223	2,750	Dulin, A, 2 wells (C-8-22) 9CCC=1,147 acre-feet and (C-8-22) 7DAC=232 acre-feet + Glen Curtis Cit, 2 wells, (C-8-22) 18CAD=0 acre-feet, (C-8-22) 18DDD=200 acre-feet + Glen Curtis Cit, (C-8-22) 7CCD=211 acre-feet + Yowelman, R., Sec 17 T08S R22WCBC= 960 acre-feet. Reported as a diversion.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Fort Yuma Indian Reservation,AZ/Homesteads	0	1,355		Not Reported
Martinez Lake (Domestic consumptive use.)		1		Not reported.
Cibola Valley Irrigation and Drainage District, AZ. **Note:** Part is on CA side of river and probably reduces Palo Verde Irrigation District return flow.	6,032	13,993	29,223	Cibola Valley Irrigation District, 3 pumps Sections 20, 21, and 26T1N R23W. Reported as a diversion.
Cibola National Wildlife Refuge, AZ.	20,778	5,937	14,467	Cibola National Wildlife Refuge, 5 pumps, Secrion 2 T1S R24W, Section 31 T1S, R23W. Reported as a diversion.
Imperial National Wildlife Refuge, AZ.	35,923	0	10,000	Imperial National Wildlife Refuge, 2 wells, Sec 13 T5S R22W G&SRM. Reported as a diversion.
Mittry Lake State Wildlife Area, AZ.	11,267	0	360	Pumper L. Pratt Sec 14 T7S R22W ABC.
Sturges Gila Monster Ranch, AZ.	54	8,429	6,529	Sturges, diversions at Imperial Dam (Warren Act). Reported as a consumptive use.
City of Yuma (Domestic consumptive use).		18,502	18,500	City of Yuma, diversion at Imperial Dam (All-American Canal), diversion at Imperial Dam (Gila). Reported as a consumptive use.
Marine Corps Air Station (Domestic consumptive use). **Note:** Located within Yuma Mesa Irrigation and Drainage District, AZ polygon.		1,375	2,292	Marine Corps Air Station (Yuma), diversion at Imperial Dam. Reported as a diversion.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
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. An agricultural diverter immediately to the north of Unit B Irrigation and Drainage District. Included in the State of Arizona total.			1,131	University of Arizona, diversion at Imperial Dam (Warren Act). Reported as a diversion.
Yuma Union High School (Domestic consumptive use).		117	195	Yuma Union High School, diversion at Imperial Dam. Reported as a diversion..
Unidentified in LCRAS. Apparently an agricultural user included in another user's total. Need actual location and user boundary.			50	Camille, Alec, Jr., diversion at Imperial Dam (Warren Act). Reported as a diversion.
Desert Lawn Memorial (Domestic consumptive use).		61	102	Desert Lawn Memorial, diversion at Imperial Dam. Reported as a diversion.
North Gila Valley Irrigation District, AZ.	940	20,254	20,646	North Gila Valley Irrigation District, diversion at Imperial Dam. Reported as a consumptive use.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Yuma Irrigation District, AZ.	372	36,234	52,694	Yuma Irrigation District, diversion at Imperial Dam. Pumped from private wells=52,073 acre-feet. Cameron Bros (2 wells Sec 24 T08S R22W CCB=295 acre-feet, Sec 24 T08S R22W CAD=161 acre-feet) Judd T. Ott (1 well Sec 30 T08S R22W BAB=165 acre-feet) Yuma Irrigation District reported as a consumptive use, wells reported as diversions.
Yuma Mesa Irrigation and Drainage District, AZ. (Pht=0 acre-feet, Crop=74,269 acre-feet) The portion of the underflow to Mexico that is presumed to be from the application of water on the Yuma Mesa is about 52,700 acre-feet (85% of 62,000 acre-feet). The water use on 4,985 acres of land in Arizona downgradient of the district. Water applied in this area does not return to the Colorado River above the Northerly International Boundary (Pht = 0 acre-feet, Crop= 17,911 acre-feet). Hillander "C" Irrigation District, AZ (Pht=0 acre-feet, Crop=3,515 acre-feet). The Prison (Domestic consumptive=12 acre-feet).	0	148,407	203,787	Yuma Mesa Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use. 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.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (annual acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS				**Decree Accounting**
Yuma County Water Users Association, AZ., Pht=45 acre-feet, Crop=161,448 acre-feet + 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 is about 19,600 acre-feet (the total underflow to Mexico across the Limitrophe Section is about 20,000 acre-feet, about 400 acre-feet is presumed to be from irrigation on the West Cocopah Indian Reservation) + State of Arizona - Limitrophe Section (pht=5,832 acre-feet; crop=2,790 acre-feet) + The water use of the cities of Somerton (720 acre-feet), Gadsden (24 acre-feet), and San Luis (1,500 acre-feet).	5,877	186,082	240,019	Yuma County Water Users Association, diversion at Imperial Dam and pumped from wells=231,122 acre-feet) + Burrell (1 well, Sec 33 T08S R24W BAB=300 acre-feet) + Farmland Management (3 wells, Sec 19 T09S R24W BAD=248 acre-feet, Sec19 T09S R24W BDD=673 acre-feet, Sec19 T09S R24W BDA=359 acre-feet) + Waymon Farms (1 Well, Sec 31 T09S R24W AAA=1,059 acre-feet) + Waymon Farms, (C-9-24) 31BBB=1,790 acre-feet + J.W. Cumings, (C-10-25) 1BBA=1134 acre-feet + State of AZ Limitrophe Section J.W. Cumings (C-10-25), 14ADB=560 acre-feet + C & J Cummings, (C-10-25) 26BAB=480 acre-feet + J. Barkley, (C-10-25) 35CBA=480 acre-feet; + Brown, Rodger S., (C-11-25) 2BBA=412 acre-feet + Earl Huges, (C-11-25) 3DAC=1,402 acre-feet. 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. YCWUA reported as a consumptive use, well use reported as diversion.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Unit B Irrigation and Drainage District, AZ. (Pht=0 acre-feet, Crop=10,441 acre-feet). The portion of the underflow to Mexico that is presumed to be from the application of water on Unit B is about 9,300 acre-feet (15% of 62,000 acre-feet).	0	19,741	25,231	Unit "B" Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use. Includes a portion of the underflow to Mexico across the Southerly International Boundary.
West Cocopah Indian Reservation, AZ. 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 is about 2 percent of the total underflow, 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 about 20,000 acre-feet.	7,051	8,083	3,932	Cocopah Indian Reservation, diversion at Imperial Dam. Pumped from wells (includes return flows)=1,352 acre-feet. Reported as a consumptive use. **Note:** Diversions from canal, 9 wells reported by U.S. Geological Survey in sections 25, 26, and 36, and wells reported by Yuma Area Office, Bureau of Reclamation (locations unknown) + W. Brand-D. Donnely (1 well, (C-9-25) 35ABA=630 acre-feet) + P. Sibley, (C-10-25) 2CDA=1,950 acre-feet . Wells reported as diversions.
Yuma Area Office, Bureau of Reclamation (Domestic consumptive use).		775	1,450	Yuma Area Office, diversion from Mode and Well No.8. Reported as a consumptive use.
Yucca Power Plant (Domestic consumptive use). **Note:** Reported well location plots within the North Cocopah Indian Reservation.		728	728	Yucca Power Plant. Reported as a diversion.

Table A1.--LCRAS and Decree Accounting consumptive use by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
North Cocopah Indian Reservation, AZ; pht=849 acre-feet, crop = 889 acre-feet + Cocopah Bend RV (Domestic consumptive use=204 acre-feet). Located within North Cocopah Indian Reservation.	849	1,093	2,098	Huerta Packing, 2 wells; 16S/22E-30CDA=905 acre-feet and 16S/21E-25ADD=853 acre-feet + Cocopah Bend RV, 1 well, Sec 30 T16S R22E BDB=340 acre-feet. Reported as diversions.
East Cocopah Indian Reservation, AZ. A small trailer court should be addressed as a domestic use.	0	0		Not reported.
Yuma County (Domestic consumptive use).		4,794		Not reported.
State of Arizona Note: Includes crop, phreatophyte, and domestic uses not associated with any identified diverter boundary.	38,101	11,546	10,749	Hall, Ansil (Sec 36 T16S R21E BCB=432 acre-feet) + Texas Hill Farm (Sec 28 T16S R22E CDA=130 acre-feet) + Curry Family LTD (Sec 29 T16S R22E DAC=276 acre-feet) + R.E. & P. Power (Sec 29 T16S R22E BCC=2,850 acre-feet) + Ogram, George, Sec 24 T08S R23W DCC=454 acre-feet + Peach, Sec 22 T08S R23W DCC=328 acre-feet + AZ prod, Sec 23 T08S R23W CDA=0 acre-feet + Ott, Judd T., (C-8-22) 19CCA=577 acre-feet + Glen Curtis Cit (2 wells (C-8-22) 24BDD=1,980 acre-feet (C-8-22) 24BDD=3,722 acre-feet) + Murphy Broadcasting, Inc=0 (less than 1 acre-foot). Reported as diversions.

Table A1.—LCRAS and Decree Accounting consumptive uses by diverter (acre-feet)

Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
LCRAS			**Decree Accounting**	
Arizona Subtotal (Below Hoover Dam, less Wellton-Mohawk Irrigation and Drainage District).	438,686	2,137,685	2,497,656	Arizona Subtotal (Below Hoover Dam, less Wellton-Mohawk Irrigation and Drainage District).
			57,368	Pumped from South Gila Wells (drainage pump outlet channels): Returns.
Arizona uses above Hoover Dam (from 1996 Decree Accounting).		188	188	Arizona uses above Hoover Dam.
Wellton-Mohawk Irrigation and Drainage District (from 1996 Decree Accounting Report).		274,421	274,421	Wellton-Mohawk Irrigation and Drainage District.
			161,955	Unmeasured return flow credit to Arizona.
Arizona Total.	438,686	2,412,294	2,552,942	Arizona Total.
Total Lower Basin Use.	681,782	7,864,383	8,027,609	Total Lower Basin Use.

Notes:
pht = Consumptive use by phreatophytes
crop = Consumptive use by crops
Decree Accounting values include some unquantified amount of phreatophyte use

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)

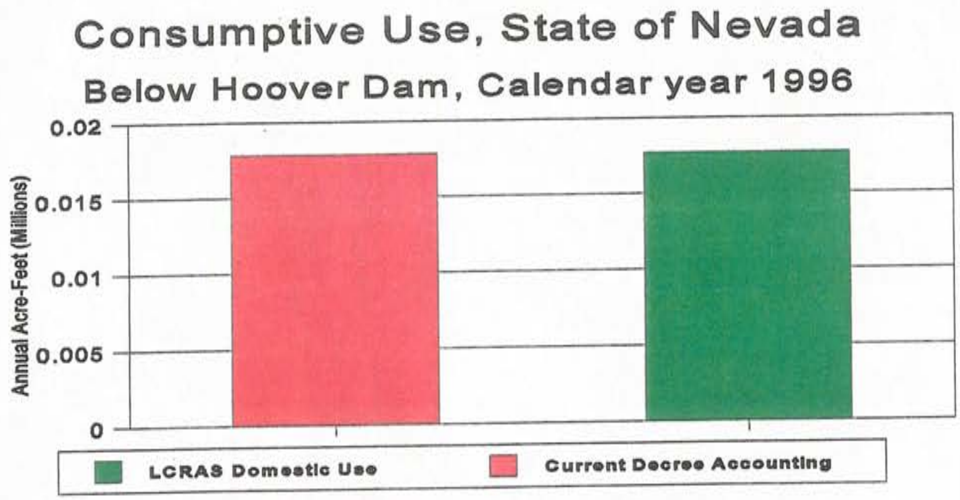
Cibola Valley Irrigation and Drainage District (AZ)

The following bar charts show the consumptive use reported by the 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:

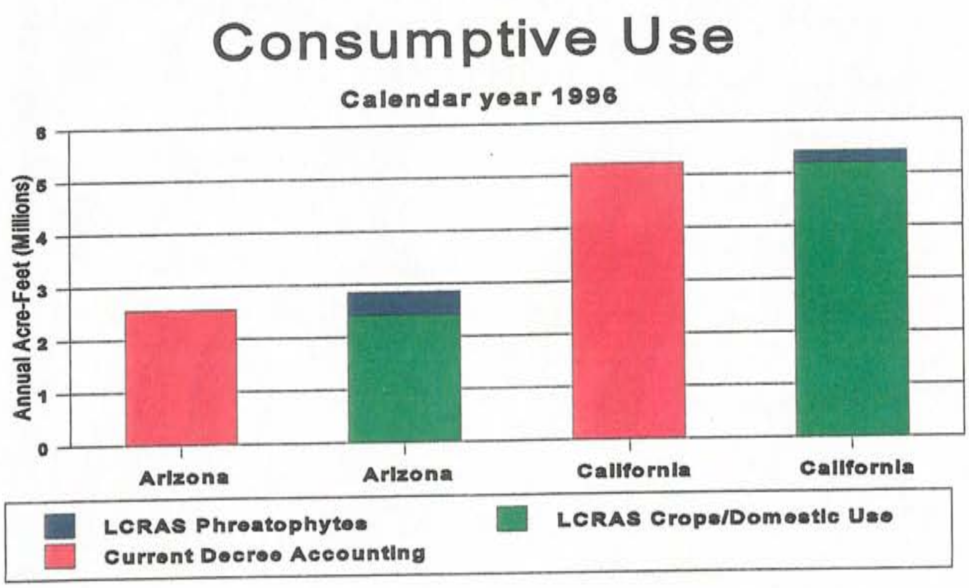
- Importance of determining the amount of phreatophyte use that should be reported as part of a diverters' consumptive use.

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

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

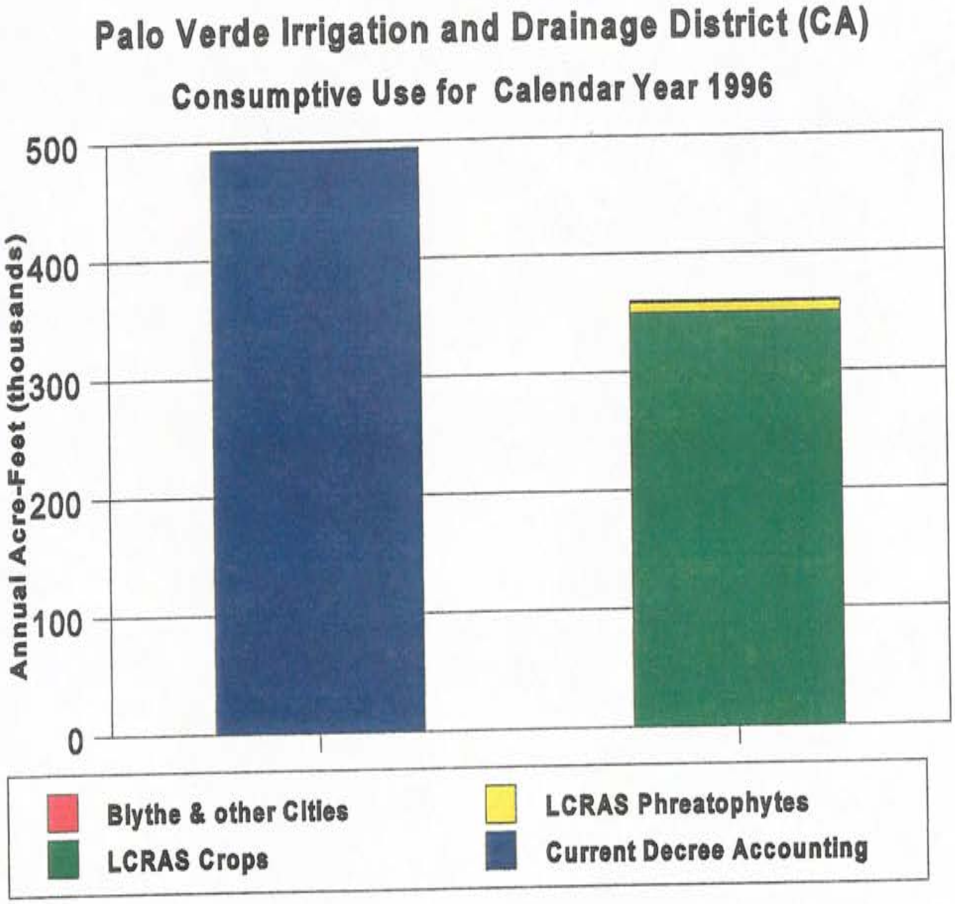


Phreatophyte consumptive use is not shown for Nevada because consumptive use in Nevada is domestic use only. Phreatophyte consumptive use in Nevada is unlikely to be the result of anthropogenic activity.

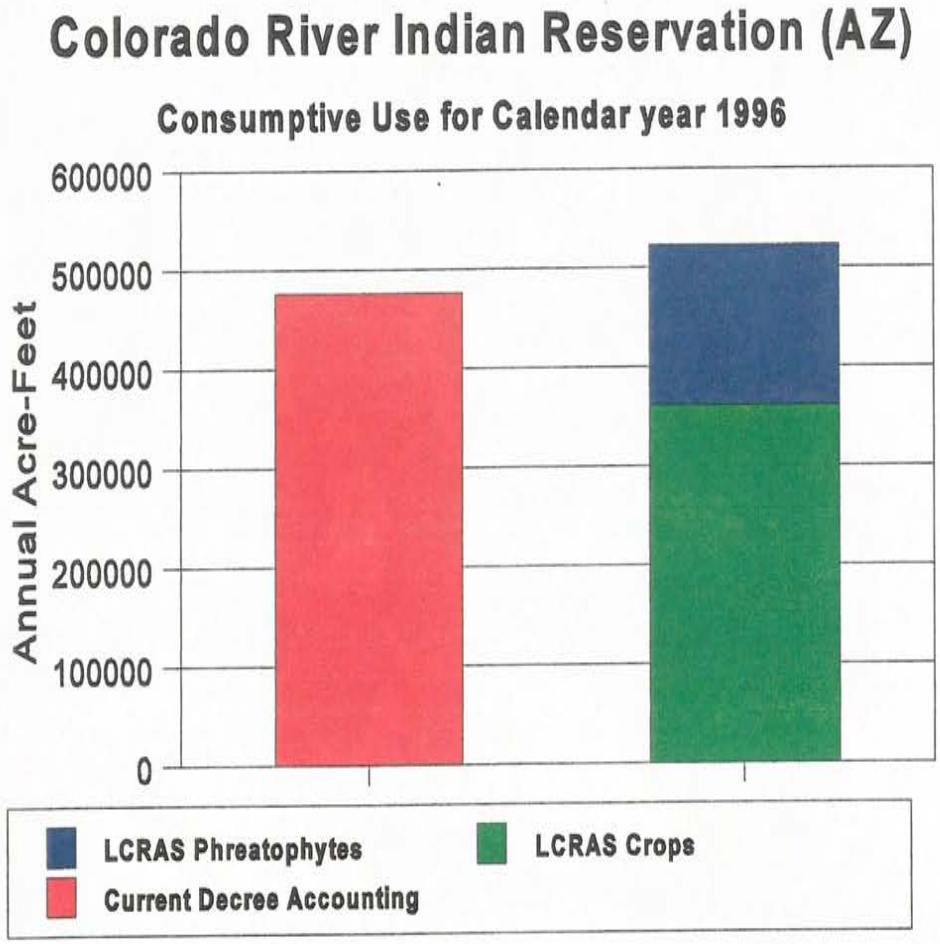


The bar chart for the State of Nevada shows the minor impact LCRAS has on consumptive use calculations in Nevada. LCRAS has a minor impact because there was no irrigation in Nevada in 1996.

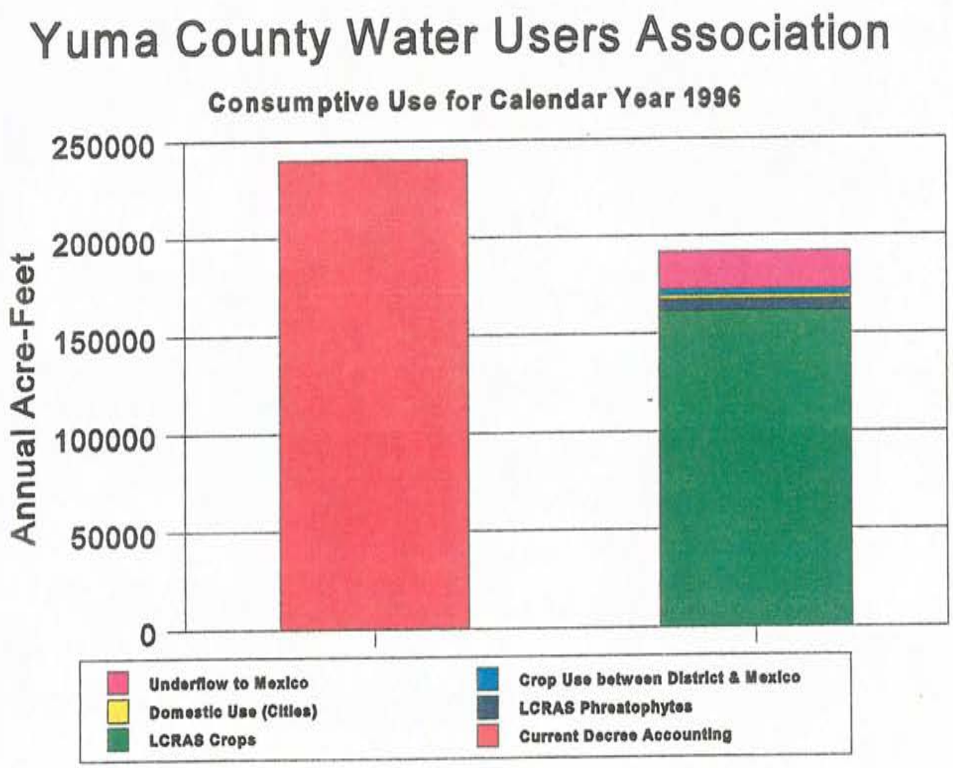
The bar chart for the States of California and Arizona shows a good comparison between the total consumptive uses of crops and phreatophytes produced by LCRAS and the total consumptive uses reported by the Decree Accounting Report (with Decree Accounting estimates of unmeasured return flows to the States included). It also shows the small amount of water use by phreatophytes when compared to crops on a State-wide basis.



The bar chart for the Palo Verde Irrigation and Drainage District shows the sum of consumptive uses from crops, phreatophytes, and domestic uses to be less than the measured diversion less measured return flow calculation used by the Decree Accounting Report. This result appears to be from two potential sources: 1) that the measured return flows tend to underestimate the actual return flows from the district, and 2) that the CIMIS station at PVID may underestimate ET_0. There is most likely some combination of both of these factors operating at PVID.



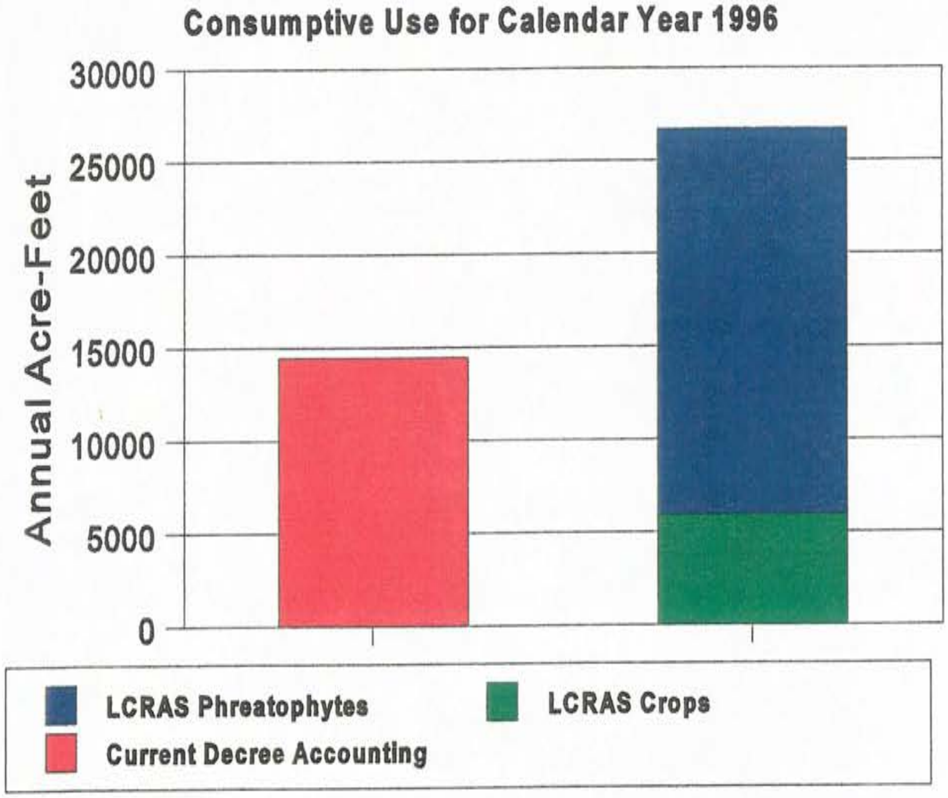
The bar chart for the Colorado River Indian Reservation (AZ) shows the sum of consumptive uses from crops and phreatophytes to be close to the measured diversion less measured return flow calculation used by the Decree Accounting Report. This appears to imply that the measured returns do a reasonable job of estimating the actual return flows from the district, and that the Parker AZMET station does a reasonable job of estimating ET_0.



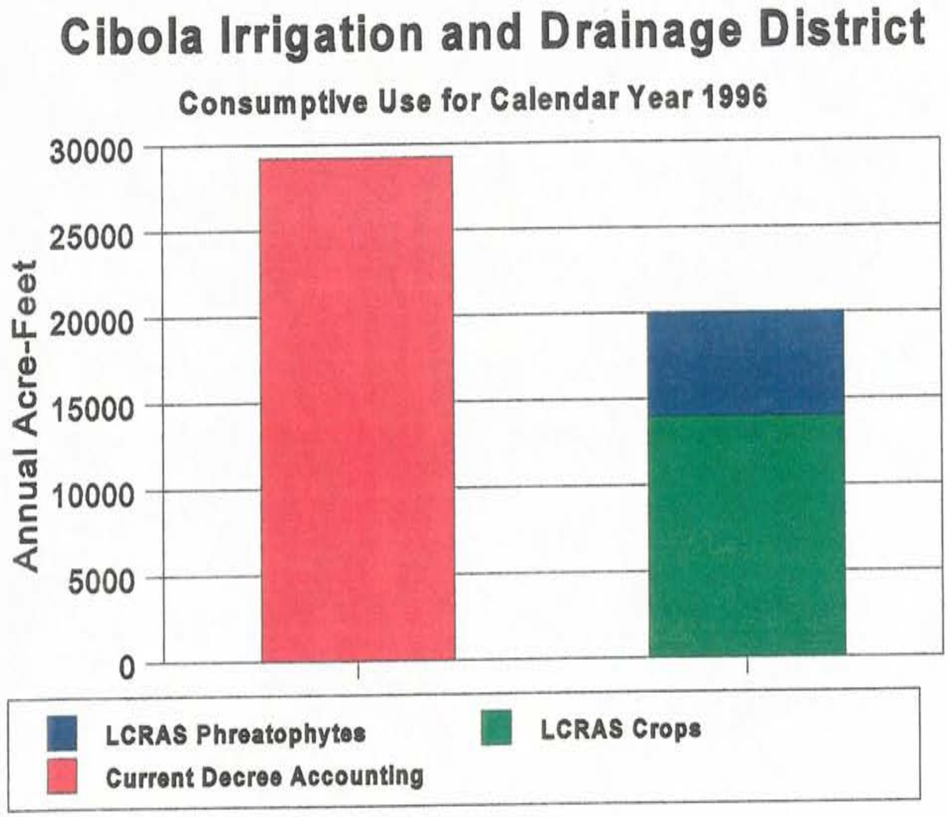
The bar chart for the Yuma County Water Users Association compares the Decree Accounting Report value of consumptive use to the crop and phreatophyte consumptive use within the district boundaries developed by LCRAS plus an estimate of the underflow to Mexico that results from applied but unconsumed water plus domestic uses plus crop and phreatophyte use between the Mexican border and the district 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.

Cibola National Wildlife Refuge (AZ)



The bar chart for the Cibola National Wildlife Refuge shows the consumptive use reported by the Decree Accounting Report (a diversion with no return flow) and the crop and phreatophyte consumptive use produced by LCRAS. 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.



In some cases, such as the Cibola Irrigation and Drainage District, the crop (as well as the sum of crop and phreatophyte) consumptive use developed by LCRAS is less than the consumptive use reported by the Decree Accounting Report. In the case of the Cibola Irrigation and Drainage District, much of this difference can be attributed to the fact that the Decree Accounting Report only reports the water diverted by Cibola Irrigation and Drainage District; there are no return flows reported.

Attachment 6

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, classify phreatophytes, classify open water surface, and 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.

Digital Database

Field Border Database - Refer to pg. 13 in this report for an explanation of how this database was created. Refer to Table 6-A for metadata on this database. Five field border databases cover the project area (Fig. 6-1). The aerial 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 6-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 insure 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 is being completed in

1998 using Fall 1997 Indian Remote Sensing (IRS) orthorectified 5 meter panchromatic imagery.

TABLE 6-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

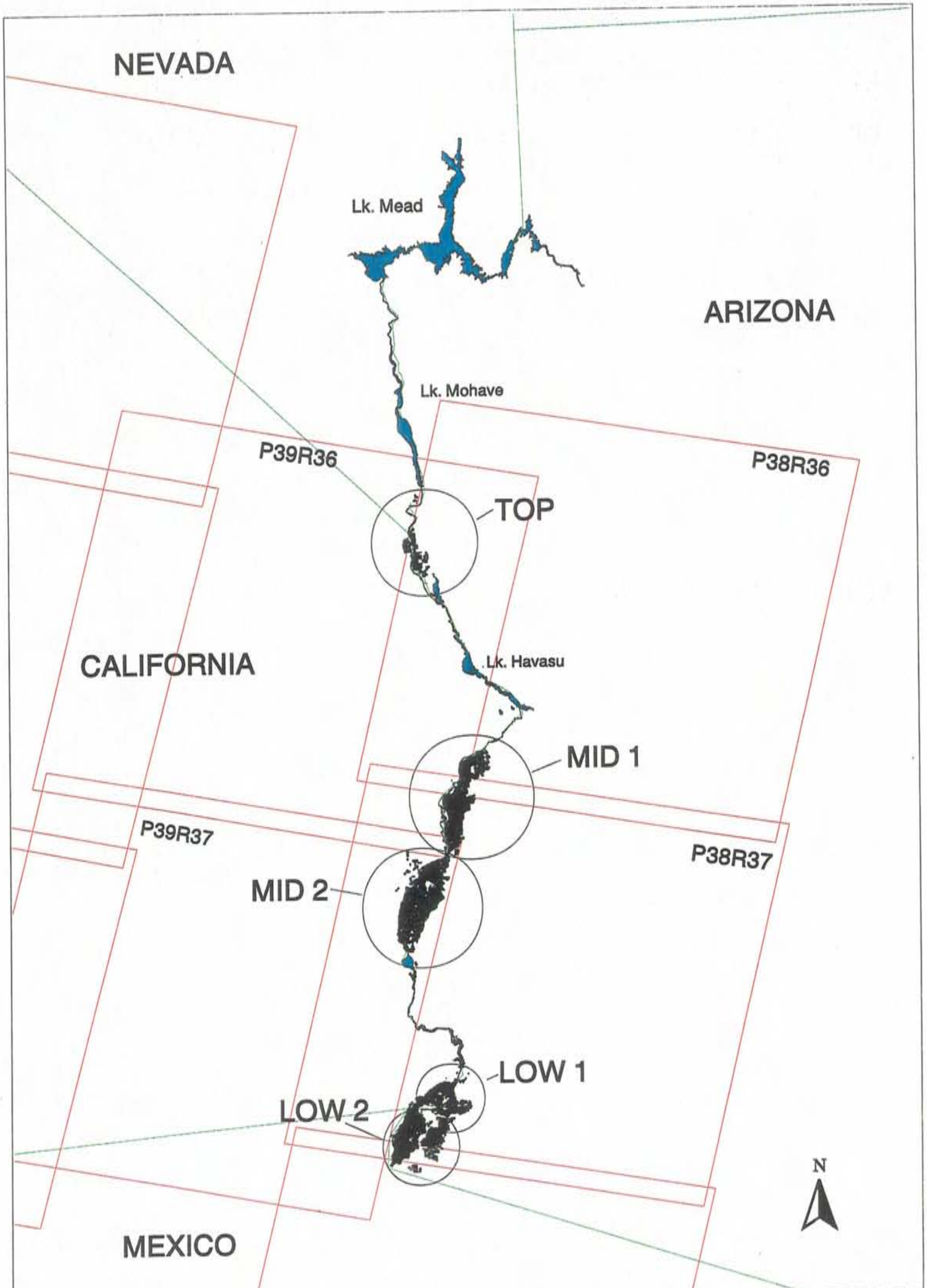


Fig. 6.1 : Image processing areas for agriculture and Landsat scene boundaries.

TABLE 6-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 two-week period. This period is chosen based on the Landsat satellite fly-over date.

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 per 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 accounted for. Approximately 16 percent of the fields in the project area are sampled. Ground reference fields were originally chosen by processing area 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 SPOT or 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 written for this project. Table 6-C lists ground reference attributes that are collected. Table 6-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 6-C

Ground Reference Attributes

Attribute	Comments
Date	MM/DD/YR
7.5' USGS 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, prebloom, bloom, senescent, harvested, seeded, windrowed, 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, northwest, northeast, west, uniform (leveled), pivot
Furrow moisture	Dry/Semimoist, saturated, ponding
Bed moisture	Dry/Semimoist, saturated, ponding
Photo	Roll/Frame # if photo taken for reference
Map Change	Yes/No - indicating field border update from field observation
Comments	Such as minor weeds, currently being irrigated/harvested, grazed, etc.

Spectral Classification - Figures 6.2, 6.3, and 6.4 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 20 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 insure 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 6-D

1996 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**

1996 Crop List

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		

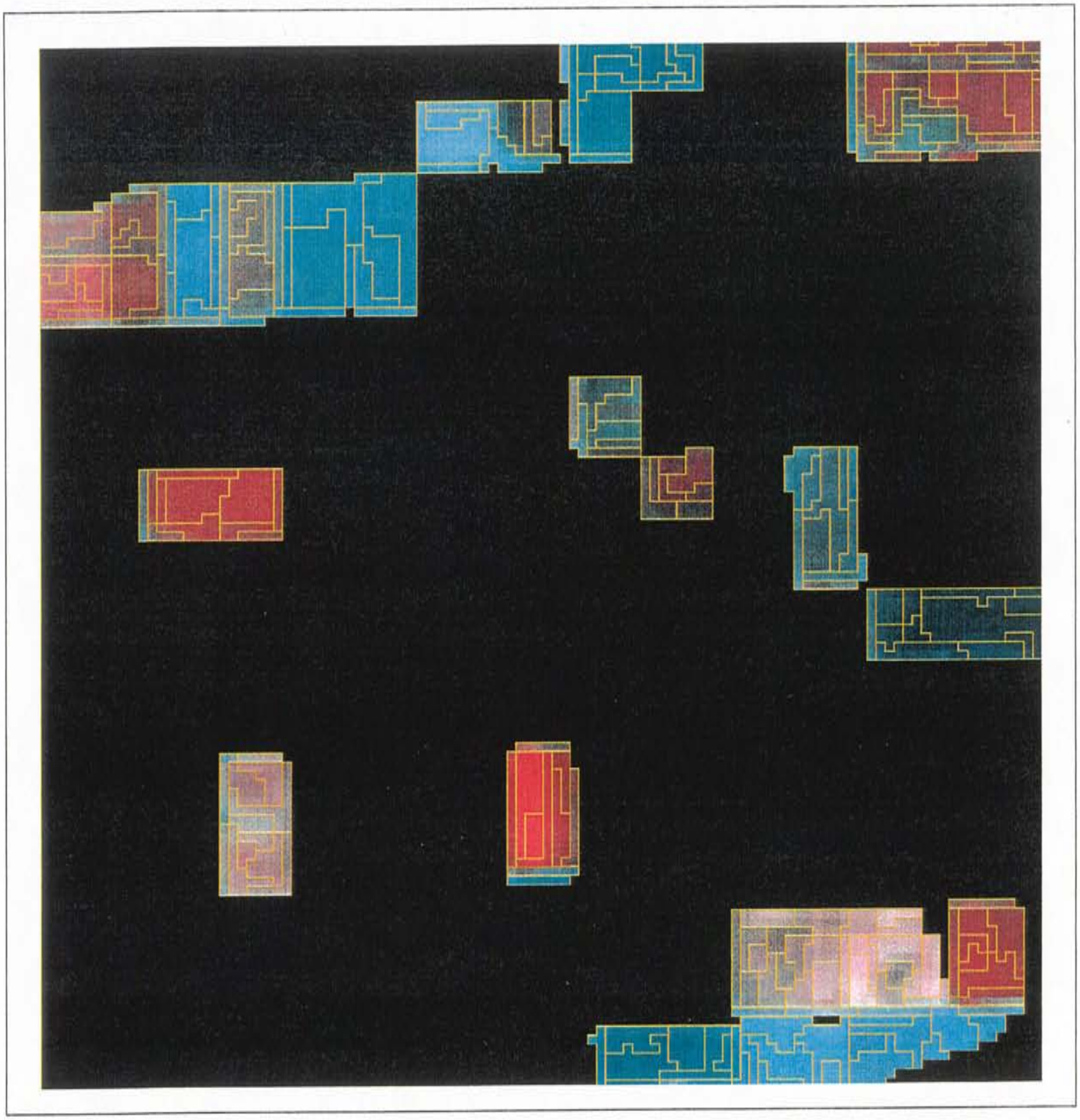


Fig. 6.5 : Ground reference fields - masked and partitioned into spectral regions for signature generation. Yellow lines denote spectral regions plotted on Landsat bands 4,3,2.

This process typically produces over 4000 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 20 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 6-E, 6-F, 6-G, and 6-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 6-E

MARCH 1996 ACCURACY ASSESSMENT - BY FIELD

GROUND REFERENCE FIELDS

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda	Citrus	Tomatoes	Sudan	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**	**157**		8				3						3			**171**	91.81%
Cotton	**2**		**1**			1	1										**3**	33.33%
Small Grain	**4**	3		**163**		6						12	2	1			**187**	87.17%
Corn	**5**																**0**	#DIV/0!
Lettuce	**6**			4		**3**					1		1				**9**	33.33%
Melons	**7**						**5**							1			**6**	83.33%
Bermuda Grass	**8**	1						**10**									**11**	90.91%
Citrus	**9**								**69**								**69**	100.00%
Tomatoes	**10**																**0**	#DIV/0!
Sudan Grass	**11**																**0**	#DIV/0!
Other Vegs.	**12**			1		3						**7**					**11**	63.64%
Crucifers	**13**												**2**				**2**	100.00%
Fallow	**14**	**9**	**13**	**11**	**8**	**16**	**12**	**2**			**1**	**4**	**3**	**145**			**224**	64.73%
Dates	**15**														**11**		**11**	100.00%
Safflower	**16**																**0**	#DIV/0!
TOTALS		**170**	**14**	**187**	**8**	**29**	**18**	**15**	**69**	**0**	**2**	**23**	**8**	**150**	**11**	**0**	**704**	Total Samples
%correct by crop		92%	7%	87%	0%	10%	28%	67%	100%	#DIV/0!	0%	30%	25%	97%	100%	#DIV/0!	**573**	Total Correct
																	81%	**% correct**
total w/ fallow correction		161	1	176	0	13	6	13	69	0	1	19	5	229	11	0	704	
%correct w/ fallow correction		98%	100%	93%	#DIV/0!	23%	83%	77%	100%	#DIV/0!	0%	37%	40%	98%	100%	#DIV/0!	**93%**	
total berm OR alf correct		158						13										
%correct w/ b/a correction		93%						87%									**82%**	
% correct w/ b-a & fallow correcti		98%						100%									**93%**	

MARCH 1996 ACCURACY ASSESSMENT - BY ACREAGE

GROUND REFERENCE FIELDS

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda	Citrus	Tomatoes	Sudan	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**	**5340.31**		278.21				76.33						88.18			**5783.03**	92.34%
Cotton	**2**		**28.20**			39.08	21.53										**88.81**	31.75%
Small Grain	**4**	36.74		**4264.92**		106.44						190.74	22.82	10.03			**4631.69**	92.08%
Corn	**5**																**0.00**	#DIV/0!
Lettuce	**6**			72.07		**108.22**					92.85		37.69				**310.83**	34.82%
Melons	**7**						**150.56**							35.62			**186.18**	80.87%
Bermuda Grass	**8**	**30.99**						**281.70**									**312.69**	90.09%
Citrus	**9**								**1044.76**								**1044.76**	100.00%
Tomatoes	**10**																**0.00**	#DIV/0!
Sudan Grass	**11**																**0.00**	#DIV/0!
Other Vegs.	**12**			26.20		76.38						**265.52**					**368.10**	72.13%
Crucifers	**13**												**31.30**				**31.30**	100.00%
Fallow	**14**	**258.18**	**355.12**	**291.51**	**218.88**	**379.28**	**283.99**	**106.94**			**54.78**	**43.49**	**53.83**	**4801.36**			**6847.36**	70.12%
Dates	**15**														**67.48**		**67.48**	100.00%
Safflower	**16**																**0.00**	#DIV/0!
TOTALS		**5666.22**	**383.32**	**4932.91**	**218.88**	**709.40**	**456.08**	**464.97**	**1044.76**	**0.00**	**147.63**	**499.75**	**145.64**	**4935.19**	**67.48**	**0.00**	**19672.23**	Total Samples
%correct by crop		94%	7%	86%	0%	15%	33%	61%	100%	#DIV/0!	0%	53%	21%	97%	100%	#DIV/0!	**16384.33**	Total Correct
																	83%	**% correct**
total w/ fallow correction		5408.04	28.2	4641.4	0	330.12	172.09	358.03	1044.76	0	92.85	456.26	91.81	6981.19	67.48	0	19672.23	
%correct w/ fallow correction		99%	100%	92%	#DIV/0!	33%	87%	79%	100%	#DIV/0!	0%	58%	34%	98%	100%	#DIV/0!	**94%**	
total berm OR alf correct		5,371.30						358.03									**5729.33**	
%correct w/ b/a correction		95%						77%									**84%**	
% correct w/ b/a/f correction		99%						100%									**94%**	

*w/ = with *b/a = bermuda and alfalfa *b/a/f = bermuda, alfalfa, and fallow *$DIV/0! = 0 value

TABLE 6-F

MAY 1996 ACCURACY ASSESSMENT - BY FIELD

GROUND REFERENCE FIELDS

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda	Citrus	Tomatoe	Sudan	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	161	0	1	1	0	1	3	0	0	2	2	0	3	0	0	174	92.53%
Cotton	2	1	101	1	0	0	1	0	0	0	2	0	0	3	0	1	110	91.82%
Small Grain	4	2	0	143	2	0	1	1	0	0	1	2	0	0	0	2	154	92.86%
Corn	5	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	10	100.00%
Lettuce	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	#DIV/0!
Melons	7	0	1	2	0	0	17	0	0	0	0	0	0	0	0	0	20	85.00%
Bermuda Grass	8	8	0	0	0	0	0	7	0	0	3	0	0	1	0	0	19	36.84%
Citrus	9	0	0	0	0	0	0	0	49	0	0	0	0	0	0	0	49	100.00%
Tomatoes	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	#DIV/0!
Sudan Grass	11	4	0	0	0	0	0	1	0	0	23	0	0	0	0	0	28	82.14%
Other Vegs.	12	0	0	1	0	0	0	0	0	0	0	7	0	2	0	0	10	70.00%
Crucifers	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	#DIV/0!
Fallow	14	1	5	1	0	0	0	0	0	0	1	2	0	18	0	0	28	64.29%
Dates	15	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	10	100.00%
Safflower	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	100.00%
TOTALS		177	107	149	13	0	20	12	49	0	32	13	0	27	10	5	614	Total Samples
%correct by crop		91%	94%	96%	77%	#DIV/0!	85%	58%	100%	#DIV/0!	72%	54%	#DIV/0!	67%	100%	40%	548	Total Correct
																	89%	% correct
total w/ fallow correction		176	102	148	13	0	20	12	49	0	31	11	0	37	10	5	614	
%correct w/ fallow correction		91%	99%	97%	77%	#DIV/0!	85%	58%	100%	#DIV/0!	74%	64%	#DIV/0!	80%	100%	40%	91%	
total berm OR alf correct		169						10										
%correct w/ b/a correction		95%						83%									91%	
% correct w/ b/a/f correction		96%						83%									93%	

MAY 1996 ACCURACY ASSESSMENT - BY ACREAGE

GROUND REFERENCE FIELDS

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda	Citrus	Tomatoe	Sudan G	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	5535	0	74	74	0	32	43	0	0	82	44	0	28	0	0	5911.53	93.63%
Cotton	2	36	3237	6	0	0	110	0	0	0	59	0	0	111	0	19	3578.17	90.46%
Small Grain	4	51	0	3754	36	0	0	38	0	0	14	111	0	0	0	52	4056.48	92.53%
Corn	5	0	0	0	157	0	0	0	0	0	0	0	0	0	0	0	156.86	100.00%
Lettuce	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	#DIV/0!
Melons	7	0	12	54	0	0	555	0	0	0	0	0	0	0	0	0	620.38	89.46%
Bermuda Grass	8	154	0	0	0	0	0	283	0	0	74	0	0	0	0	0	511.64	55.39%
Citrus	9	0	0	0	0	0	0	0	834	0	0	0	0	0	0	0	834.31	100.00%
Tomatoes	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	#DIV/0!
Sudan Grass	11	55	0	0	0	0	0	10	0	0	970	0	0	0	0	0	1034.64	93.72%
Other Vegs.	12	0	0	13	0	0	0	0	0	0	0	212	0	23	0	0	248.27	85.31%
Crucifers	13	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	11.69	0.00%
Fallow	14	46	74	37	0	0	0	0	0	0	52	37	0	261	0	0	505.60	51.53%
Dates	15	0	0	0	0	0	0	0	0	0	0	0	0	0	89	0	88.53	100.00%
Safflower	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	28	27.83	100.00%
TOTALS		5876.56	3322.01	3937.96	266.69	0.00	697.08	373.73	834.31	0.00	1251.32	403.58	0.00	434.39	88.53	99.77	17585.93	Total Samples
%correct by crop		94%	97%	95%	59%	#DIV/0!	80%	76%	100%	#DIV/0!	77%	52%	#DIV/0!	60%	100%	28%	15913.46	Total Correct
																	90%	% correct
total w/ fallow correction		5830.61	3248.32	3901.29	266.69	0	697.08	373.73	834.31	0	1199.12	367.04	0	679.44	88.53	99.77	17585.93	
%correct w/ fallow correction		95%	100%	96%	59%	#DIV/0!	80%	76%	100%	#DIV/0!	81%	58%	#DIV/0!	80%	100%	28%	92%	
total berm OR alf correct		5,688.90						326.06									6014.96	
%correct w/ b/a correction		97%						87%									92%	
% correct w/ b/a/f correction		98%						87%									93%	

*w/ = with *b/a = bermuda and alfalfa *b/a/f = bermuda, alfalfa, and fallow *$DIV/0! = 0 value

TABLE 6-G

AUGUST 1996 ACCURACY ASSESSMENT - BY FIELD

GROUND REFERENCE FIELDS

MAP LABEL		Alfalfa 1	Cotton 2	Small Grain 4	Corn 5	Lettuce 6	Melons 7	Bermuda 8	Citrus 9	Tomatoes 10	Sudan 11	Other Vegs. 12	Crucifers 13	Fallow 14	Dates 15	Safflower 16	TOTALS	
Alfalfa	1	152	10					5			7			1			175	86.86%
Cotton	2	10	107		1						3	3		1			125	85.60%
Small Grain	4	2		1							1						4	25.00%
Corn	5																0	#DIV/0!
Lettuce	6																0	#DIV/0!
Melons	7																0	#DIV/0!
Bermuda Grass	8	8	1					8									17	47.06%
Citrus	9								49		2						51	96.08%
Tomatoes	10																0	#DIV/0!
Sudan Grass	11	2						1			18						21	85.71%
Other Vegs.	12											1		2			3	33.33%
Crucifers	13																0	#DIV/0!
Fallow	14	2	1				1				3	2		237	1		247	95.95%
Dates	15														10		10	100.00%
Safflower	16															1	1	100.00%
TOTALS		176	119	1	1	0	1	14	49	0	34	6	0	241	11	1	654	Total samples
%correct by crop		86%	90%	100%	0%	#DIV/0!	0%	57%	100%	#DIV/0!	53%	17%	#DIV/0!	98%	91%	100%	584	Total correct
																	89%	% correct
total w/ fallow correction		174	118	1	1	0	0	14	49	0	31	4	0	251	10	1	654	
%correct w/ fallow correction		87%	91%	100%	0%	#DIV/0!	#DIV/0!	57%	100%	#DIV/0!	58%	25%	#DIV/0!	98%	100%	100%	91%	
total berm OR alf correct		160						13										
%correct w/ b/a correction		91%						93%									91%	
% correct w/ b/a/f correction		92%						93%									93%	

AUGUST 1996 ACCURACY ASSESSMENT - BY ACREAGE

GROUND REFERENCE FIELDS

MAP LABEL		Alfalfa 1	Cotton 2	Small Grain 4	Corn 5	Lettuce 6	Melons 7	Bermuda 8	Citrus 9	Tomatoes 10	Sudan 11	Other Vegs. 12	Crucifers 13	Fallow 14	Dates 15	Safflower 16	TOTALS	
Alfalfa	1	5286.83	270.45					171.60			199.94			27.25			5956.07	88.76%
Cotton	2	286.90	3728.63		46.97						138.73	17.76		6.75			4225.74	88.24%
Small Grain	4	73.83		123.87							13.56						211.26	58.63%
Corn	5																0.00	#DIV/0!
Lettuce	6																0.00	#DIV/0!
Melons	7																0.00	#DIV/0!
Bermuda Grass	8	126.17	58.93					196.13			44.41						425.64	46.08%
Citrus	9								720.68								720.68	100.00%
Tomatoes	10																0.00	#DIV/0!
Sudan Grass	11	46.32						7.34			940.91						994.57	94.60%
Other Vegs.	12											14.57		10.66			25.23	57.75%
Crucifers	13																0.00	#DIV/0!
Fallow	14	47.25	18.28				40.50				140.48	22.12		5626.13			5894.76	95.44%
Dates	15														95.19		95.19	100.00%
Safflower	16															23.16	23.16	#DIV/0!
TOTALS		5867.30	4076.29	123.87	46.97	0.00	40.50	375.07	720.68	0.00	1478.03	54.45	0.00	5670.79	95.19	23.16	18572.3	Total samples
%correct by crop		90%	91%	100%	0%	#DIV/0!	0%	52%	100%	#DIV/0!	64%	27%	#DIV/0!	99%	100%	100%	16756.1	Total correct
																	90%	% correct
total w/ fallow correction		5820.05	4058.01	123.87	46.97	0	0	375.07	720.68	0	1337.55	32.33	0	5939.42	95.19	23.16	18572.3	
%correct w/ fallow correction		91%	92%	100%	0%	#DIV/0!	#DIV/0!	52%	100%	#DIV/0!	70%	45%	#DIV/0!	99%	100%	100%	92%	d/t w/ fallow correction
total berm OR alf correct		5,413.00						367.73										
%correct w/ b/a correction		92%						98%									92%	d/t w b/a correction
% correct w/ b/a/f correction		93%						98%									93%	d/t w b/a/f correction

* w/ = with * b/a = bermuda and alfalfa * b/a/f = bermuda, alfalfa, and fallow *$DIV/0! = 0 value

TABLE 6-H

DECEMBER 1996 ACCURACY ASSESSMENT - BY FIELD

GROUND REFERENCE FIELDS

MAP LABEL		Alfalfa 1	Cotton 2	Small Grain 4	Corn 5	Lettuce 6	Melons 7	Bermuda 8	Citrus 9	Tomatoes 10	Sudan 11	Other Vegs 12	Crucifers 13	Fallow 14	Dates 15	Safflower 16	TOTALS	
Alfalfa	1	179				7		2				2	1	6			197	90.86%
Cotton	2	2	7											1			10	70.00%
Small Grain	4											1					1	0.00%
Corn	5																0	#DIV/0!
Lettuce	6	6				101	1					2	10	6			126	80.16%
Melons	7																0	#DIV/0!
Bermuda Grass	8	4						14									18	77.78%
Citrus	9								49								49	100.00%
Tomatoes	10																0	#DIV/0!
Sudan Grass	11	1									1						2	50.00%
Other Vegs.	12											2					2	100.00%
Crucifers	13					4						1	15	3			23	65.22%
Fallow	14	15	1	1		9		2			2		2	177			209	84.69%
Dates	15														12		12	100.00%
Safflower	16																0	#DIV/0!
TOTALS		207	8	1	0	121	1	18	49	0	3	8	28	193	12	0	649	Total Samples
%correct by crop		86%	88%	0%	#DIV/0!	83%	0%	78%	100%	#DIV/0!	33%	25%	54%	92%	100%	#DIV/0!	557	Total Correct
																	86%	**% correct**
total w/ fallow correction		192	7	0	0	112	1	16	49	0	1	8	26	225	12	0	649	
%correct w/ fallow correction		93%	100%	#DIV/0!	#DIV/0!	90%	0%	88%	100%	#DIV/0!	100%	25%	58%	93%	100%	#DIV/0!	91%	
total berm OR alf correct		183						16										
%correct w/ b/a correction		88%						89%									87%	
% correct w/ b/a/f correction		95%						100%									92%	

DECEMBER 1996 ACCURACY ASSESSMENT - BY ACREAGE

GROUND REFERENCE FIELDS

MAP LABEL		Alfalfa 1	Cotton 2	Small Grain 4	Corn 5	Lettuce 6	Melons 7	Bermuda Gra 8	Citrus 9	Tomatoe 10	Sudan G 11	Other Vegs 12	Crucifers 13	Fallow 14	Dates 15	Safflower 16	TOTALS	
Alfalfa	1	6872.90				133.15		67.20				8.24	15.99	406.96			7504.44	91.58%
Cotton	2	28.77	223.66											20.5			272.93	81.95%
Small Grain	4											20.39					20.39	0.00%
Corn	5																0.00	#DIV/0!
Lettuce	6	43.07				1872.23	39.43					36.47	188.73	101.49			2281.42	82.06%
Melons	7																0.00	#DIV/0!
Bermuda Grass	8	121.47						437.18									558.65	78.26%
Citrus	9								1456.45								1456.45	100.00%
Tomatoes	10																0.00	#DIV/0!
Sudan Grass	11	32.91									73.7						106.61	69.13%
Other Vegs.	12											62.97					62.97	100.00%
Crucifers	13					96.76						22.25	221.42	59.61			400.04	55.35%
Fallow	14	429.62	72.29	10.47		283.05		38.51			160.66		19.02	6753.21			7766.83	86.95%
Dates	15														66.73		66.73	100.00%
Safflower	16																0.00	#DIV/0!
TOTALS		7528.74	295.95	10.47	0.00	2385.19	39.43	542.89	1456.45	0.00	234.36	150.32	445.16	7341.77	66.73	0.00	20497.46	Total Samples
%correct by crop		91%	76%	0%	#DIV/0!	78%	0%	81%	100%	#DIV/0!	31%	42%	50%	92%	100%	#DIV/0!	18040.45	Total Correct
																	88%	**% correct**
total w/ fallow correction		7099.12	223.66	0	0	2102.14	39.43	504.38	1456.45	0	73.7	150.32	426.14	8355.39	66.73	0	20497.46	
%correct w/ fallow correction		97%	100%	#DIV/0!	#DIV/0!	89%	0%	87%	100%	#DIV/0!	100%	42%	52%	93%	100%	#DIV/0!	93%	
total berm OR alf correct		6,994.37						504.38									7498.75	
%correct w/ b/a correction		93%						93%									89%	
% correct w/ b/a/f correction		99%						100%									94%	

*w/ = with *b/a = bermuda and alfalfa *b/a/f = bermuda, alfalfa, and fallow *$DIV/0! = 0 value

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. The Other Vegetable class is confused with Small Grain in the March classification date. Sudan grass tends to be confused with Alfalfa and Cotton in the May and August classification dates, and Crucifers are confused with Lettuce in the December classification date. Note that based on this statistical sample, this error represents less than 8 percent of the total crop acreage in the project area.

It is very important to understand error in the classification as a function of the intended use of the data. Error must also be considered with respect to water consumption calculations. Error between particular crop classes may be negligible with respect to water consumption calculations when taking into account both acreage and evapotranspiration coefficients for particular crop types. 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 1000 unique combinations in the 1996 database) and assigns acreage of crop type(s) for each field. Figure 6.6 is a graphic example of how this program functions. In Figure 6.6, 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. Theses data were updated in 1996 and are currently being updated for 1997. Phreatophytes will be updated on an annual basis. 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, 1994 and May, 1995) and focuses remapping efforts in areas of spectral change.

ANNUAL CROP SUMMARY

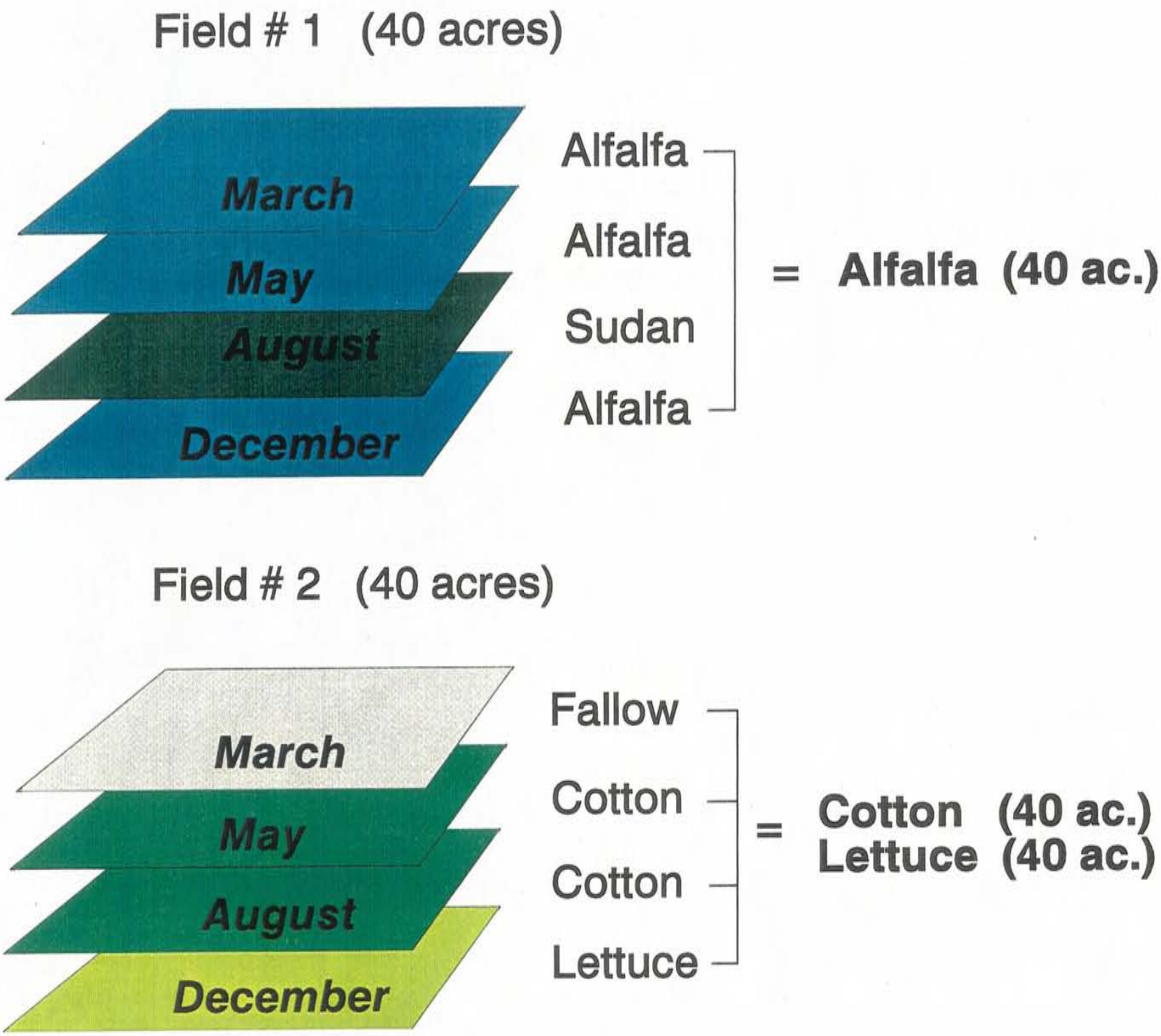


Fig. 6.6 : Graphic example of logic for annual crop summary.

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.

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 on an annual basis using change detection methodologies. Landsat imagery is used for image-to-image comparison to identify spectral change from year to year. The first update used a May 1996 to May 1994 image comparison. Phreatophytes will be updated again 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 the phreatophytes. Accuracy assessment for phreatophytes will include fuzzy set logic to adequately address complexities associated with natural vegetation communities (Gopal, et. al., 1994). Further data will be available in the 1997 report.

LCRAS Crop Classification Flow Diagram

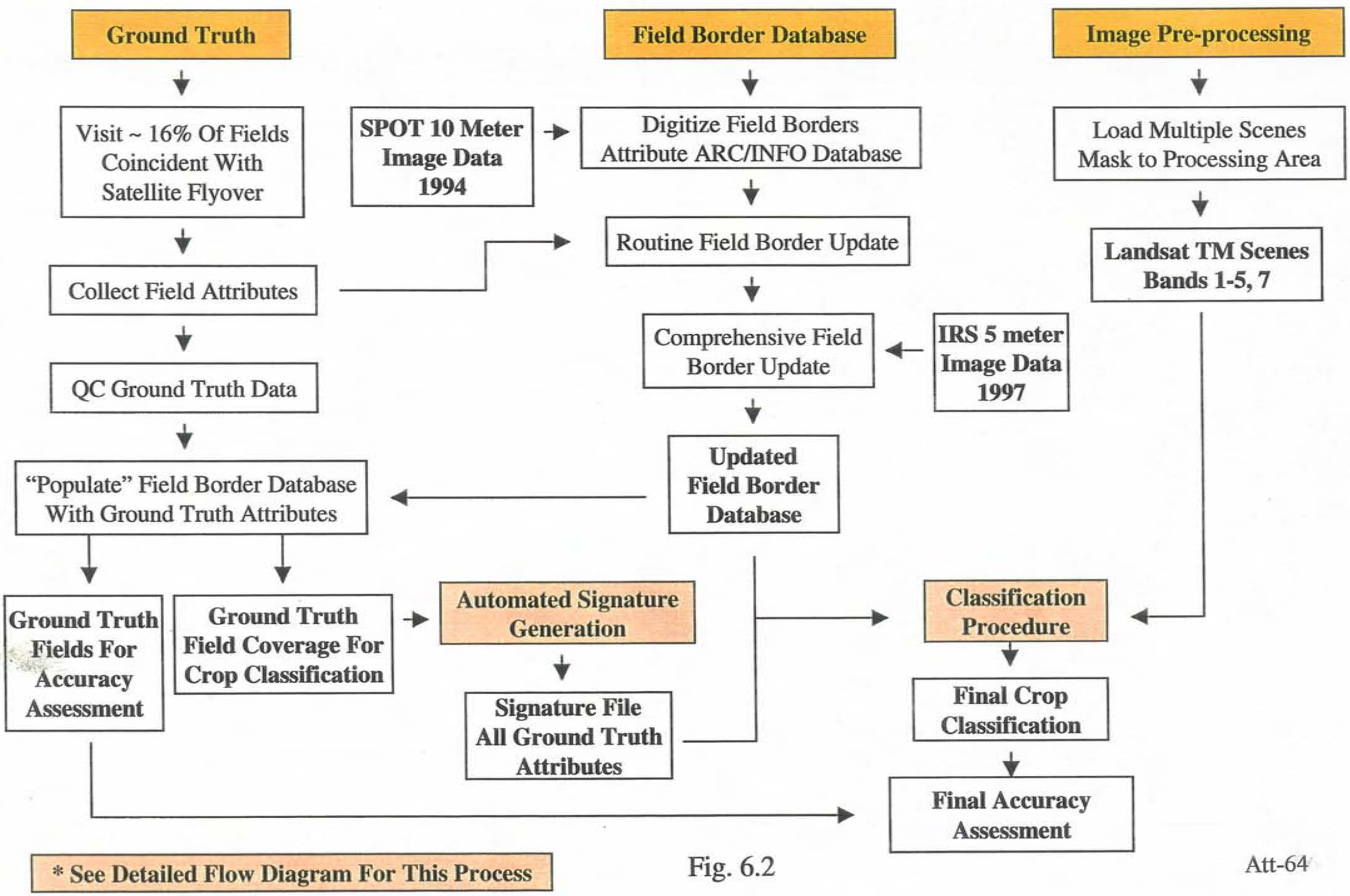


Fig. 6.2

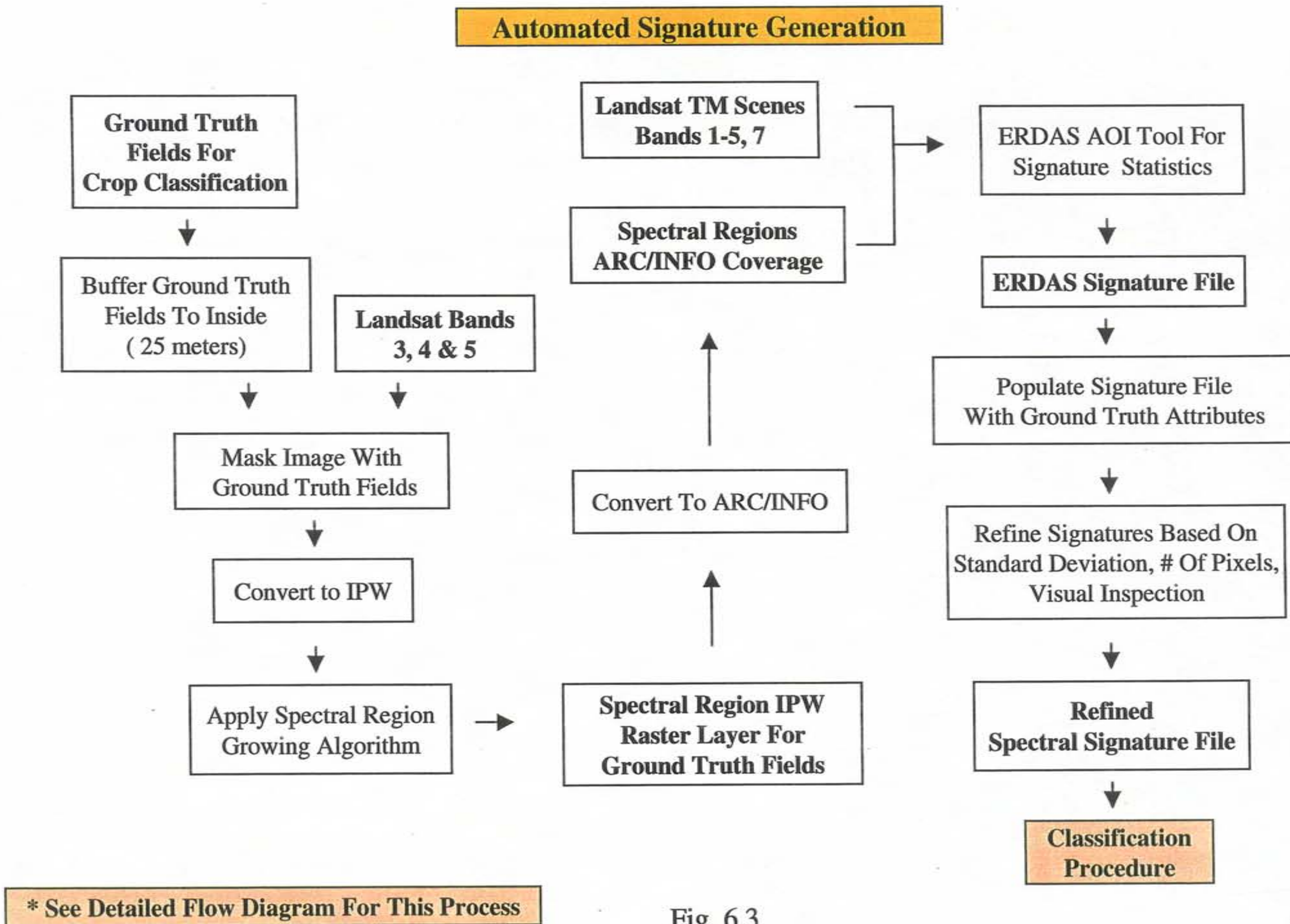
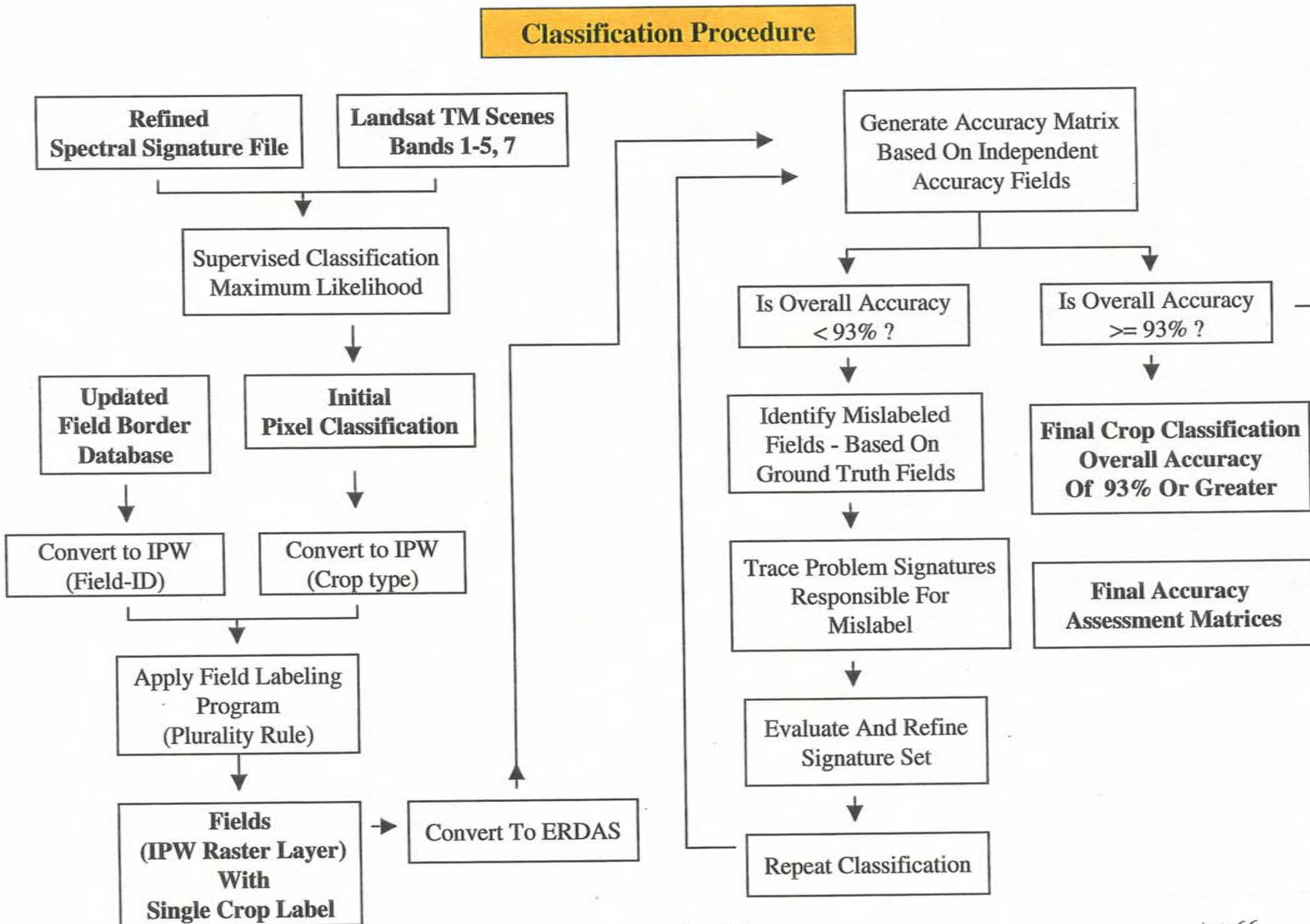

Automated Signature Generation
Ground Truth Fields For Crop Classification
Buffer Ground Truth Fields To Inside (25 meters)
Landsat Bands 3, 4 & 5
Mask Image With Ground Truth Fields
Convert to IPW
Apply Spectral Region Growing Algorithm
Spectral Region IPW Raster Layer For Ground Truth Fields
Convert To ARC/INFO
Spectral Regions ARC/INFO Coverage
Landsat TM Scenes Bands 1-5, 7
ERDAS AOI Tool For Signature Statistics
ERDAS Signature File
Populate Signature File With Ground Truth Attributes
Refine Signatures Based On Standard Deviation, # Of Pixels, Visual Inspection
Refined Spectral Signature File
Classification Procedure
* See Detailed Flow Diagram For This Process

Fig. 6.3



Classification Procedure
Refined Spectral Signature File
Landsat TM Scenes Bands 1-5, 7
Supervised Classification Maximum Likelihood
Updated Field Border Database
Initial Pixel Classification
Convert to IPW (Field-ID)
Convert to IPW (Crop type)
Apply Field Labeling Program (Plurality Rule)
Fields (IPW Raster Layer) With Single Crop Label
Convert To ERDAS
Generate Accuracy Matrix Based On Independent Accuracy Fields
Is Overall Accuracy < 93% ?
Is Overall Accuracy >= 93% ?
Identify Mislabeled Fields - Based On Ground Truth Fields
Final Crop Classification Overall Accuracy Of 93% Or Greater
Trace Problem Signatures Responsible For Mislabel
Final Accuracy Assessment Matrices
Evaluate And Refine Signature Set
Repeat Classification

Fig. 6.4

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