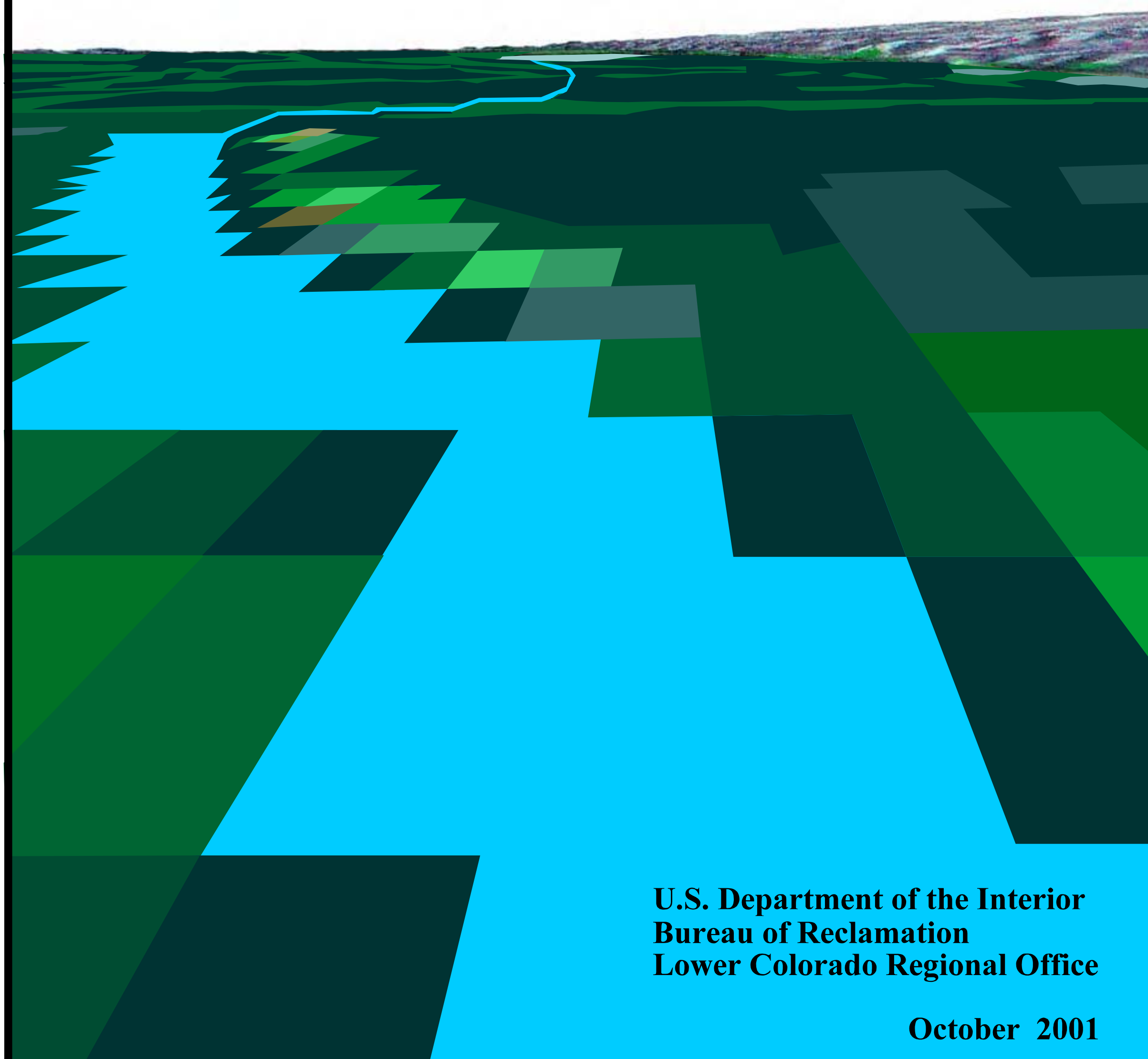
Lower Colorado River Accounting System
Demonstration of Technology

Calendar Year 2000



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

October 2001

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

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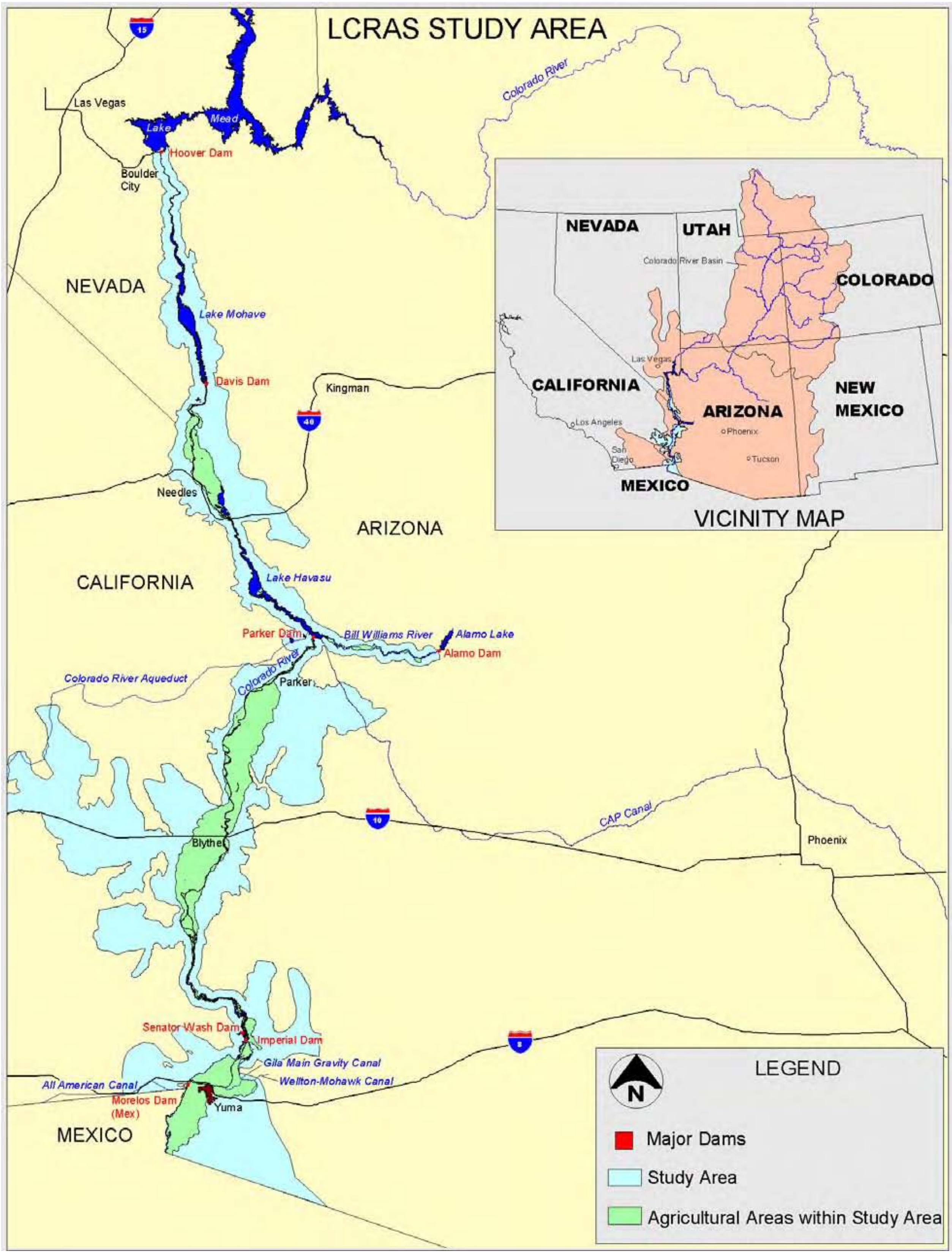
LCRAS STUDY AREA
Colorado River
Las Vegas
Lake Mead
Hoover Dam
Boulder City
NEVADA
Lake Mohave
Davis Dam
Kingman
Needles
ARIZONA
CALIFORNIA
Lake Havasu
Parker Dam
Bill Williams River
Alamo Lake
Alamo Dam
Colorado River Aqueduct
Colorado River
Parker
CAP Canal
Blythe
Phoenix
Senator Wash Dam
Imperial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

Executive Summary

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

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

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

This report documents the application of LCRAS to calendar year 2000 and the changes made to the LCRAS method since Bureau of Reclamation 1999 was issued.

The LCRAS Method

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

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

ET is estimated using

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

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

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

The amount, if any, of the phreatophyte water use within a diverter's boundary that should be included in a diverter's total consumptive use is an open question, not addressed by this report.

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

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

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

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

4) occasionally for unique cases, using a method submitted by the diverter.

The derivation of the domestic use factors mentioned above can be found in attachment 7. The final estimate of domestic consumptive use is made by adding a proportion of the residual to the initial estimate. The residual can be either a positive or a negative number; therefore, the final estimate of domestic consumptive use can be either slightly larger or smaller than the initial estimate.

Results

LCRAS calculates crop consumptive use and phreatophyte water use for each irrigator and wildlife refuge, and domestic consumptive use for domestic diverters along the mainstream of the lower Colorado River from Hoover Dam to Mexico. A description and qualitative assessment of the results for the major components of LCRAS follows.

Image Classification Results

The image classification results are excellent using Landsat 5 and Landsat 7 image data to discriminate crop groups. Reliable results are obtained using single-date image classification processes. Post-classification accuracy assessment shows that, overall, the crop groups can be mapped with an average accuracy of greater than 90 percent for each image classification date (four dates in calendar year 2000).

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

The initial phreatophyte coverage used in Bureau of Reclamation, 1997 was developed in 1994. Discrimination between phreatophyte groups, while not as well defined as crop groups, was successful with post-classification accuracy assessment of the original 1994 phreatophyte coverage resulting in an overall accuracy of 87 percent. The phreatophyte coverage is updated each year using remote-sensing-based change detection methodologies. Major changes identified by the remote-sensing-based change detection methodologies, usually from fire or development, are field verified.

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

Water Balance Results

Water balance closure is evaluated by comparing the value of the residual to the presumed measurement error of the mainstream inflow to each reach. If the value of the residual is about equal to or less than the presumed measurement error of the mainstream flow entering the reach, distributing the residual is considered optional. Reclamation has chosen to distribute the residual in all reaches for calendar year 2000.

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

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

Table ES-1 — Water balance summary (not adjusted for residual)

(Units: annual acre-feet unless otherwise noted)

Water balance inflows, outflows, and water uses	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})	10,692,000	10,716,200	7,895,700	6,527,141	10,692,000
Flow at the downstream boundary (Q_{ds})	10,716,200	7,895,700	6,527,141	2,119,441	2,119,441
Residual (Q_{res})	-178,133	-265,510	226,712	102,702	-114,229
Residual as a percentage of flow at the upstream boundary (Q_{us})	-1.67%	-2.48%	2.87%	1.57%	-1.07%
Difference between flow at the upstream and downstream boundaries (Q_{dif})	-24,200	2,820,500	1,368,559	4,407,700	8,572,559
Measured Tributary inflow (Trm)	0	13,327	0	6,577	19,904
Unmeasured Tributary inflow (Trum)	6,480	36,290	33,750	3,000	79,520
Exported flow (Q_{ex})	0	2,724,172	0	3,858,331	6,582,503
Evaporation (E)	138,549	116,580	62,882	6,209	324,220
Domestic consumptive use (CU_d)	728	35,825	4,270	30,701	71,524
Crop evapotranspiration (ET_{crop})	0	78,169	756,406	350,719	1,185,294
Phreatophyte evapotranspiration (ET_{pht})	936	179,881	351,036	68,615	600,468
Change in reservoir storage (ΔS_r)	20,200	1,000	1,003	0	22,203
Change in aquifer storage (ΔS_a)	0	0	0	0	0

Consumptive Use Results

Table ES-2 compares state totals of crop and domestic consumptive use, and phreatophyte water use calculated by LCRAS with consumptive use as reported in the decree accounting report for calendar year 2000.

Table ES-2.— LCRAS Crop and Domestic Consumptive Use, and Phreatophyte Water Use, and Consumptive Use from the Decree Accounting Report

(Units: annual acre-feet)

LCRAS			Decree Accounting Report	
Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
Nevada				
Uses above Hoover Dam (from decree accounting report)		299,687	299,687	Uses above Hoover Dam
Uses below Hoover Dam	20,538	19,070	22,297	Uses below Hoover Dam
			2,128	Unmeasured return flow credit
Nevada Total	20,538	318,757	319,856	Nevada Total
California				
			5,185,466	Sum of individual diverters
			100,530	Unmeasured return flow credit
California Total	171,993	5,230,253	5,084,936	California Total
Arizona				
Subtotal (below Hoover Dam, less Wellton-Mohawk IDD)	409,470	2,284,651	2,596,387	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (decree accounting report)		132	132	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (decree accounting report)		275,747	275,747	Wellton-Mohawk IDD
			69,525	Pumped from South Gila wells (drainage pump outlet channels [DPOCs]).
			169,244	Unmeasured return flow credit
Arizona Total	409,470	2,560,530	2,633,497	Arizona Total
Lower Colorado River Basin Total				
Total Lower Basin Use	602,001	8,109,540	8,038,289	Total Lower Basin Use

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

Table ES-3.— Final distributed and adjusted water balance values

(Units: annual acre-feet unless otherwise noted)

Water balance inflows, outflows, and water uses	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})	10,884,165	10,730,415	7,654,309	6,501,857	10,884,165
Flow at the downstream boundary (Q_{ds})	10,730,415	7,654,309	6,501,857	2,179,734	2,179,734
Residual (Q_{res})	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	153,750	3,076,106	1,152,452	4,322,123	8,704,431
Measured Tributary inflow (Trm)	0	13,337	0	6,574	19,911
Unmeasured Tributary inflow (Trum)	6,489	36,643	33,193	2,993	79,318
Exported flow (Q_{ex})	0	2,715,324	0	3,872,049	6,587,373
Evaporation (E)	138,440	116,479	62,936	6,210	324,065
Domestic consumptive use (CU_d)	728	35,823	4,270	30,704	71,525
Crop consumptive use (CU_{crop})	0	78,123	764,181	353,208	1,195,512
Phreatophyte water use (CU_{pht})	936	179,640	352,711	68,710	601,997
Change in reservoir storage (ΔS_r)	20,192	995	1,003	0	22,190
Change in aquifer storage (ΔS_a)	-57	-298	544	809	998

Continued Development of LCRAS

The methods used in LCRAS are expected to continually evolve as new information and techniques become available and potential improvements are identified through reviews and experience. An outstanding question that must be resolved is the appropriate crediting of phreatophyte water use, if any, to diverter consumptive use.

Conclusions

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

LCRAS is a water accounting method that

1) Uses the best technology available,

2) Provides a suite of tools which can be used, and which have been developed specifically, to fulfill the Supreme Court Decree mandate to account for the consumptive use of Colorado River water, and

3) Provides a consistent set of methods which can be used to determine the consumptive use of Colorado River water for all diverters along the lower Colorado River from Hoover Dam to Mexico.

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

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

1. Reclamation will use the current decree accounting report methods to develop the official decree accounting report until LCRAS is implemented.

2. Reclamation will calculate consumptive use using the LCRAS method in parallel with the decree accounting report for calendar years 2001 and 2002 and will continue to compare the results of the two methods.

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Chapter 1

Introduction

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

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

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

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

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

This report documents the processes and data used to apply the LCRAS method to determine consumptive use along the lower Colorado River from Hoover Dam to Mexico for calendar year 2000. The following terms and definitions will be used in this report;

Water use - the consumption of Colorado River water by plants, for domestic purposes, water exported from the system, evaporation, and any other activity that removes water from the system,

Consumptive use - water use considered to be part of the apportionments of Colorado River water confirmed by the US Supreme Court to be available to Arizona, California, and Nevada.

The LCRAS Method

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

Crop consumptive use within an irrigation district or Indian reservation is initially estimated as crop evapotranspiration (ET) plus an estimate of evaporation from major distribution canals (adding this canal evaporation estimate is new for calendar year 2000). Phreatophyte water use is initially estimated as ET. The final estimate of crop consumptive use and phreatophyte water use is made by adding a proportion of the residual to the ET. The residual can be either a positive or a negative number; therefore, the final estimates of crop consumptive use and phreatophyte water use can be slightly larger or slightly smaller than the ET.

ET is estimated using

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

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

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

Evaporation from major distribution canals within an irrigation district or Indian reservation is estimated using,

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

2) coefficients relating evaporation to reference ET (similar to an ET coefficient), and

3) the acreage of open water in the major distribution canals that are within an irrigation district or Indian reservation (developed by digitizing canal areas using 5-meter panchromatic satellite imagery).

The initial estimate of domestic consumptive use is generally made by

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

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

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

4) occasionally, for unique cases, domestic consumptive uses are initially estimated through a method submitted by the diverter.

The derivation of the domestic use factors mentioned above can be found in attachment 7. The final estimate of domestic consumptive use is made by adding a portion of the residual to the initial estimate. The residual can be either a positive or a negative number; therefore, the final estimate of domestic consumptive use can be either slightly larger or smaller than the initial estimate.

Comparison of LCRAS with Decree Accounting Reports

Attachment 3 presents a comparison between consumptive-use values compiled for the decree accounting report and those calculated by LCRAS for all diverters. A description of the conceptual differences in the way consumptive use is compiled for the decree accounting report and calculated by LCRAS can be found in Bureau of Reclamation 1997 and Bureau of Reclamation 1998.

Chapter 2

LCRAS in Calendar Year 2000

Reclamation's activities for calendar year 2000 began with scheduled ground reference data collection to record crop groups and field conditions. Reclamation purchased satellite imagery for times concurrent to ground reference data collection and processed it using standard image classification methods, incorporating improvements to procedures developed as the LCRAS processes have matured. Reclamation also finalized the delineation of district boundaries that would be used for calendar year 2000.

Reclamation acquired standardized reference ET values calculated using the Standardized Reference Evapotranspiration Equation (standardized equation) recommended by the Task Committee on Standardization of Reference Evapotranspiration empaneled by the American Society of Civil Engineers, Evapotranspiration in Irrigation and Hydrology Committee. Reclamation then developed area-specific reference ET values for the Yuma Area, and the Palo Verde and Parker Valleys by averaging the standardized reference ET values calculated from data collected by the CIMIS and AZMET stations sited in those areas. Reclamation compiled domestic uses, flows at major dams, diversion and delivery points, and changes in reservoir storage at Lakes Mohave and Havasu, and Senator Wash Reservoir for calendar year 2000.

Reclamation identified and quantified the area of open water exposed to evaporation by major distribution canals within irrigation districts and Indian reservations. Using reference ET and evaporation coefficients used for calculating the evaporation of open water areas of the mainstream, Reclamation calculated the evaporation from major distribution canals within irrigation districts and Indian reservations. Evaporation from these distribution canals represents an evaporation of water that was diverted from the mainstream which does not return to the mainstream, and is therefore a consumptive use. Beginning for calendar year 2000, this evaporation is added to the ET of crops to develop the Crop ET term for the reach water budget.

Analysis of calendar year 2000 data was performed as the data became available throughout the year. The acreage of each crop group grown, each phreatophyte group in the flood plain, and the number of acres of open water exposed to evaporation by major distribution canals within irrigation districts and Indian reservations, and the number of acres of open water exposed to evaporation by reservoirs and in the mainstream channel of the river between Hoover Dam and Mexico were developed from image classification, field survey data, and GIS processes. Reclamation combined this information with the final diverter boundaries and calculated the acreage of each crop and phreatophyte group within the boundary of each irrigator, wildlife refuge, or other reservation of land along the river.

Reclamation finalized the form of the water balance that would be used for calendar year 2000, then calculated and proportionally distributed the residual to each water balance inflow, outflow, and water use producing final values of crop and domestic consumptive use, final values of phreatophyte water use, and final values of water exported from the system.

The paragraphs below describe each of these activities and provide an assessment of their success and relative importance to the overall success of LCRAS for calendar year 2000.

Remote Sensing and Geographic Information Systems

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

The flood plain boundary (shown in exhibits 2 through 8) used for calendar year 2000 is the same as the flood plain boundary developed for Bureau of Reclamation 1999. The flood plain boundary is used to identify phreatophyte areas that should be included in the image classification process. The cropped areas included in this analysis are located within the flood plain boundary along the mainstream of the lower Colorado River from Hoover Dam to Mexico and upon the Palo Verde and Yuma Mesas. These areas are used to calculate the ET for each diverter and evaporation for each reach. The domestic diverter boundaries are not part of this GIS coverage. They, and their service areas, will be incorporated in the future.

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

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

Satellite Image Processing

Remote sensing analysis is performed on multispectral image data to classify and map crop and phreatophyte groups, and verify delineated open water areas along the mainstream of the lower Colorado River from Hoover Dam to Mexico. Crop, phreatophyte, and open-water delineation processes have been developed for multispectral image data acquired by Thematic Mapper (TM) sensors mounted onboard the Landsat 5 and Landsat 7 satellites, as well as 5-meter panchromatic imagery acquired by the Indian Remote Sensing IRS 1-C or 1-D sensors. These sensors detect and record reflected and emitted energy from the Earth's surface in seven bands within the electromagnetic spectrum. At any given instant, it focuses on only one small area of the Earth's surface, which corresponds to a single picture element or pixel. A pixel is the smallest unit composing a satellite image. The pixel size or spatial resolution of the Landsat TM data used for image analysis is resampled to 30 meters. TM image data were acquired for analysis during calendar year 2000 on the dates shown in table 1 below. Path and row designations in table 1 refer to image locations based on the World Reference System[2]. Figure 4.1 in attachment 4, "Remote Sensing and GIS Procedures," displays the image locations as defined by path and row upon a backdrop of the lower Colorado River from Lake Mead to Mexico.

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

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

Path 38, rows 36 and 37	February 2, 2000		
Path 38, rows 36 and 37	April 26, 2000	Path 39, row 36	May 3, 2000
Path 38, rows 36 and 37	July 15, 2000	Path 39, row 36	July 6, 2000
Path 38, rows 36 and 37	November 28, 2000		

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

Ground Reference Data Collection

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

Ground reference data are collected for approximately 1,900 of the 13,800 irrigated fields in the study area. This represents about 15 percent of the total irrigated area. From 65 to 70 percent of the ground reference data are used in image classification, and the remaining 30 to 35 percent are used to assess the accuracy of the crop and phreatophyte classifications. Selections of ground reference sites are based on the distribution of crop groups in each major irrigated area along the mainstream of the lower Colorado River from Hoover Dam to Mexico. Irrigated fields are selected randomly from a GIS database of the irrigated fields. Additional fields are added to the random sample where necessary to ensure all major crop groups are represented to provide a statistically valid data set for image classification procedures.

Ground reference data are collected and satellite imagery is purchased four times a year. Ground reference data are collected at times which coincide with the acquisition of the satellite imagery. The variability in planting and harvesting times for each crop group is a critical factor in the selection of optimum image dates.

Table 2 presents the crop groups sampled. Groups such as Small Vegetables, Small Grains, and Crucifers are general group names that consist of a variety of specific crops. A complete listing of the crop groups and the individual crops within each group can be found in table 4.4 in attachment 4 entitled, "2000 Crop Group and Name List." ET calculations are performed daily and these daily calculations, daily ET coefficients, and all other data that enter into the calculation are available for review in Part 1 of Appendix 1.

Table 2 — Crop Groups

Crop Groups			
Alfalfa - Perennial	Lettuce - Late	Citrus - Declining	Orchards
Alfalfa - Annual	Melons - Spring	Tomatoes	
Alfalfa - Seed	Melons - Fall	Sudan	Root Vegetables
Cotton	Bermuda Grass	Legume and Solanum Vegetables	
Small Grain	Bermuda Grass with Rye Grass	Crucifers	Sugar Beets
Field Grain	Citrus - Young	Dates	
Lettuce - Early	Citrus - Mature	Safflower	Fallow

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

Table 3 — Phreatophyte Groups

Group Name	Description
Marsh	40% cattail, bulrush, and phragmites
Barren	Less than 10% vegetation
Sc_low	11% to 60% salt cedar and less than 25% arrowweed
Sc_high	61% to100% salt cedar and less than 25% arrowweed
Sc/ms	11% to 60% salt cedar, 11% to 60% mesquite, and less than 25% arrowweed
Sc/aw	Less than 75% salt cedar and 25% or more arrowweed
Sc/ms/aw	15% to 45% salt cedar, 15% to 45% mesquite, and 20% to 40% arrowweed
Ms-low	11% to 60% screwbean and honey mesquite, and less than 25% arrowweed
Ms-high	61% to 100% screwbean and honey mesquite, and less than 25% arrowweed
Ms/aw	21% to 60% mesquite, 31% to 60% arrowweed, and less than 20% salt cedar
Aw	51% to 100% arrowweed and less than 10% any trees
Cw	61% to 100% cottonwood and willow
Low veg	Greater than 10% and less than 30% any phreatophyte vegetation

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

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

Delineation of Cropped Areas

A relational database (GIS coverage) has been developed that delineates the field borders in all irrigated areas along the mainstream of the lower Colorado River from Hoover Dam to Mexico. All the ground reference data collected for image classification are linked to this field-border database. These borders were originally derived from 10-meter Systemme Pour l'Observation de la Terre (SPOT) image data acquired in June and August of 1992. All field borders were digitized on screen using the SPOT data as a backdrop. Changes in field borders, noted during the acquisition of ground reference data throughout the year, have served as a data source for updates to the field-border database since 1995.

This process continued for calendar year 2000. Reclamation is now using 5-meter Indian Remote Sensing satellite imagery on an annual basis to update field borders in areas where ground reference data show significant changes in field border locations. Field borders will continue to be routinely updated using these two practices.

All areas along the mainstream of the lower Colorado River from Hoover Dam to Mexico that are known by Reclamation to divert or pump water are included in this analysis and shown in exhibits 1 through 8. Exhibit 9 is an example of digitized field borders, exhibit 10 shows an overview of the diverter boundaries, and exhibit 11 shows the Bill Williams River area.

Excellent results are obtained for crop groups listed in table 2 using a single-date image classification process several times per year. Post-classification accuracy assessment shows that, overall, the crop groups can be mapped with an average accuracy of greater than 90 percent for each image classification date (four dates in calendar year 2000).

Delineation of Phreatophyte Areas

Phreatophyte areas are updated by delineating areas of spectral change using image-to-image comparisons (change detection methods) of Landsat TM imagery. Areas of spectral change are field-checked to confirm that the spectral change is actually due to land-cover change. Areas of land-cover change are remapped and used to update the phreatophyte database. Image dates of May 1999 and May 2000 were used to perform the update for this report.

Delineation of Open Water

Open Water of the Mainstream

Vegetation and open water layers developed by the Bureau of Reclamation Environmental Group, and outside contractors were used to generate an open water layer for calendar year 2000. Improved backwater area delineations were incorporated into this data. TM imagery acquired for July 2000 was overlaid with the open water data to ensure that no significant changes in open water area occurred during the calendar year. The Image interpretation showed no significant changes in water surface in calendar year 2000.

Open Water in Major Delivery Canals

Beginning this year, the calculation of ET for irrigation districts and Indian reservations includes evaporation from major canals within the district or reservation. Bank to bank canal area (in acres) was identified by screen digitizing using 5 meter panchromatic data from the Indian Remote Sensing IRS 1-C or 1-D sensor using Arc-Info GIS software. The result is an Arc/Info polygon coverage from which the acreage of open water within each canal was calculated.

Water Balance

The water balance for calendar year 2000 uses the same equation used in Bureau of Reclamation 1999. The water balance equation is shown below:

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

Where:

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

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

[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.

Data are gathered from Reclamation records and reports, and reports provided to Reclamation by others. The following sections discuss the sources of data and calculations made with the data.

Flow Data

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

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

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

Underflow To Mexico

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

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

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[4] The Geological Survey provided flow information in *U.S. Supreme Court Decree Stations of the Lower Colorado River, Diversions and Return Flows Data for Calendar Year 2000*.

and near the Limitrophe section. The irrigators and their estimated contributions to the underflow across the Limitrophe section can be found in the worksheet at the end of attachment 3 entitled, "Distribution of Underflow to Mexico To Water Users Below The Northerly International Boundary With Mexico."

The initial estimate of underflow to Mexico is 20,000 acre-feet across the Limitrophe section and 62,443 acre-feet across SIB for a total of 82,443 acre-feet. After distribution of the residual in the Imperial Dam to Mexico reach, the final estimate of underflow to Mexico increased to 24,070 acre-feet across the Limitrophe section and 74,984 acre-feet across SIB, for a total of 99,054 acre-feet, a change of about 20%. Of this total, all of the 24,070 acre-feet estimated to cross the Limitrophe section and about 83% of the 74,984 acre-feet estimated to cross SIB (or 62,237 acre-feet) is added to the crop and domestic consumptive use of irrigators in the Yuma, Arizona area who's operations contribute to the underflow to Mexico.

Export Flow (Q_{ex})

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

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

In calendar year 2000, 1,808 acre-feet of the water pumped by the Drainage Pump Outlet Channels (DPOC's) near Yuma, Arizona, was measured as discharged into the Main Outlet Drain (MOD) or Main Outlet Drain Extension (MODE). This water was bypassed to the Santa Clara Slough and not returned to the Colorado River. The water balance considers the water pumped by the DPOC's and discharged to the MODE/MOD to be exported from the Colorado River system.

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

Table 4 — Changes in export values after residual distribution

(Units: annual acre-feet unless otherwise noted)

Export	Initial Estimate	Final Estimate	Change in Acre-Feet	Change in Percent
MWD	1,300,014	1,295,792	-4,222	-0.32%
CAP	1,424,158	1,419,532	-4,626	-0.32%
Wellton-Mohawk	403,495	404,930	1,435	0.36%
IID & Coachella	3,453,028	3,465,305	12,277	0.36%

The sum of the final estimates of export flows (excluding the discharge into the MOD/MODE from the DPOC's) accounts for about 84 percent of the consumptive use from crop, domestic, and export water uses along the lower Colorado River from Hoover Dam to Mexico.

Measured Tributary Inflow Data (T_{rm})

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

Not all of the flow measured below Alamo Dam reaches the Colorado River at Lake Havasu because of depletion from irrigated agriculture, large established stands of phreatophytes, and evaporation between Alamo Dam and Lake Havasu. The inflow to the Colorado River at Lake Havasu from the Bill Williams River is derived by subtracting estimates of the depletion between Alamo Dam and Lake Havasu[5] from

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

the sum of the flow below Alamo Dam and estimates of unmeasured inflow to the Bill Williams River.

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

The sum of the measured tributary inflow to the lower Colorado River below Hoover Dam was 19,904 acre-feet in calendar year 2000, or about two tenths of one percent of the flow below Hoover Dam. After distribution of the residuals from the water balance in each reach, the final value of measured tributary inflow increased to 19,911 acre-feet, a change of less than one tenth of one percent. Measured tributary inflow values can be found in attachment 2.

Unmeasured Tributary Inflow Data (T_{rum})

Unmeasured tributary inflow values are taken directly from Owen-Joyce, Sandra J., 1987, with the exception of the unmeasured groundwater inflow from Sacramento Wash. The value for inflow from Sacramento Wash is taken from an investigation by the Arizona Department of Water Resources. The flow values presented by Owen-Joyce, Sandra J., 1987 are primarily a compilation of existing studies, based upon mean annual precipitation, available at the time of publication. The sum of the initial estimate of unmeasured tributary flows used in this report is 79,520 acre-feet.

After distribution of the residuals from the water balance in each reach, the final value of unmeasured tributary inflow decreased to 79,318 acre-feet, a change of about one half of one percent. Initial estimates of unmeasured tributary flow values can be found in attachment 2.

Evapotranspiration

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

ET calculations require the following:

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

Reference ET

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

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

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

Reclamation develops area-specific reference ET values for the Yuma Area, and the Parker and Palo Verde Valleys, by averaging reference ET values calculated using the standardized equation and data collected by the CIMIS and AZMET stations sited within these areas. Reference ET values for the Mohave Valley are calculated using the standardized equation and data provided by the Mohave AZMET station.

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

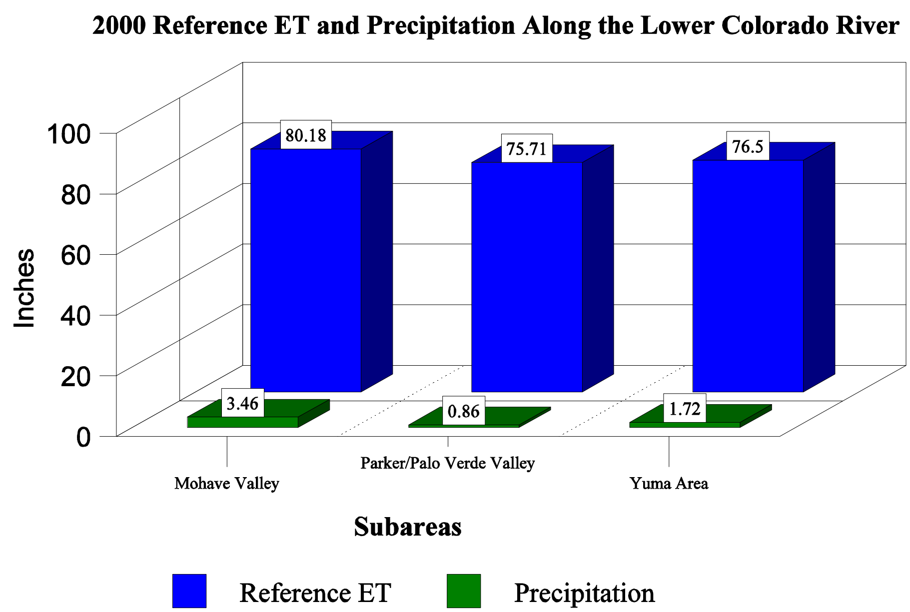


Figure 1. — Reference ET and Precipitation Values by Subarea Along the Lower Colorado River.

ET Coefficients for Crop and Phreatophyte Groups

The crop groups used in this report are the same as those used in Bureau of Reclamation 2000a for calendar year 1999[7]. A table showing the crop groups can be found in attachments 4 and 6. The rationale used to develop crop groups for use by the LCRAS program can be found in Jensen, 1998.

Number of Acres Covered by Each Crop and Phreatophyte Group

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

Effective Precipitation

LCRAS calculates effective precipitation as the product of recorded precipitation and an effective precipitation coefficient. Precipitation is recorded by precipitation gauges at CIMIS and AZMET stations sited along the lower Colorado River as well as precipitation gages operated by the National Weather Service (NWS). Precipitation measured at the AZMET, CIMIS and NWS stations located within the Yuma area, Parker and Palo Verde area, and Mohave Valley were averaged to provide a single daily precipitation value for each area. The effective precipitation coefficients used for this report are documented in Jensen, Marvin E., 1993.

The equation used to calculate effective precipitation is:

Effective Precipitation = Daily Precipitation × Monthly Effective Precipitation Coefficient

The depth of precipitation that fell over the lower Colorado River Valley in calendar year 2000 ranged from 0.21 inches, measured by the Palo Verde CIMIS station, to 1.31 inches measured by the Ehrenberg 2E NWS station.

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

Crop ET (ET_{crop})

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

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

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

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

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

Where:

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

$\sum_n$ = Summation for n time (monthly)

ET_0 = Daily Reference ET (inches)

K_{cotton} = Daily ET coefficient specific to cotton (dimensionless)

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

Effective PPT = Effective precipitation (inches)

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

New for calendar year 2000, the evaporation from major delivery canals within irrigation districts and Indian reservations or between the point of diversion and the point of delivery to irrigation districts and Indian reservations is added to the ET_{crop} shown above. These canal evaporation calculations are discussed in the subsection entitled, “Evaporation from Major Delivery Canals within Irrigation Districts and Indian Reservations ” below under the section entitled, “Evaporation (E) ”.

The sum of the ET_{crop} compiled for calendar year 2000 from Hoover Dam to Mexico is 1,185,294 acre-feet. After distribution of the residuals from the water balance in each reach, the final calculation of crop consumptive use increased to 1,195,512 acre-feet, a change of about one percent. Crop consumptive use accounts for about 14 percent of the consumptive use from crop, domestic, and export water uses along the lower Colorado River from Hoover Dam to Mexico.

The water use by crops, and other purposes, in the Imperial Irrigation District (IID), the Coachella Valley Water District (CVWD), and the Wellton-Mohawk Irrigation and Drainage District (WMIDD) is not included here. Water use in IID and CVWD is included in the export at station 1117 on the All-American Canal, and water use in WMIDD is included in the export to WMIDD at station 792.87 on the Gila Gravity Main Canal. See the section above entitled “Export Flow (Q_{ex})” for more details.

Phreatophyte ET (ET_{pht})

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

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

Remote sensing processes, including analysis of aerial photography, were used to develop the original acreage values for each phreatophyte group used to calculate ET_{pht} in the 1995 LCRAS report. There are 14 phreatophyte groups. These groups are listed in table 3 in the section "Ground Reference Data Collection" in chapter 2 of this report.

Beginning for calendar year 1996 and continuing for calendar year 2000, phreatophyte acreage values have been updated using remote-sensing-based change detection methodologies. When major changes are identified, usually from fire or development, they are field verified.

The sum of the ET_{pht} calculated for calendar year 2000 from Hoover Dam to Mexico is 600,468 acre-feet. After distribution of the residuals from the water balance in each reach, the final calculation of phreatophyte water use increased to 601,997 acre-feet, a change of less than one percent. Phreatophyte water use accounts for about 7 percent of the combined use and loss from crops, domestic uses, exports, evaporation, and phreatophytes along the lower Colorado River from Hoover Dam to Mexico.

Evaporation (E)

Evaporation from the Mainstream

LCRAS calculates evaporation from the open water of Lakes Mohave and Havasu, Senator Wash, and the open water of the Colorado River and adjacent backwaters (such as Topock Marsh and Mittry Lake) from Hoover Dam to Mexico. These estimates of water consumed by evaporation from the mainstream are not considered part of the lower Basin States apportionments of Colorado River water.

Monthly open-water evaporation rates are calculated as follows,

1. take the product of a monthly summation of average daily reference ET (inches) and,

2. a monthly evaporation coefficient (dimensionless),

3. from the product in 2, subtract precipitation recorded at precipitation gages nearest the area of open water for each month of the year (inches),

4. divide the result in 3, by 12 inches per foot to yield units of feet.

The monthly evaporation rate is multiplied by the open-water area in acres to yield the monthly open-water evaporation in acre-feet.

Open-water area is developed by analyzing images acquired July 15, 2000, for the Hoover Dam to Davis

Dam reach and images acquired July 6, 2000, for the Davis Dam to Parker Dam, Parker Dam to Imperial Dam, and Imperial Dam to Mexico reaches. More details are available in the section on remote sensing.

The initial estimate of evaporation from Hoover Dam to Mexico for calendar year 2000 is 324,220 acre-feet. After distribution of the residuals from the water balance in each reach, the final calculation of evaporation decreased to 324,065 acre-feet, a change of less than one tenth of one percent. Evaporation accounts for less than 4 percent of the combined water use and loss from crops, domestic uses, exports, phreatophytes, and evaporation along lower Colorado River from Hoover Dam to Mexico.

Evaporation from Major Delivery Canals within Irrigation Districts and Indian Reservations

Evaporation from major delivery canals within irrigation districts and Indian reservations, or between irrigation districts and Indian reservations and their point(s) of diversion from the mainstream is added to the crop evapotranspiration as a portion of the incidental losses associated with the delivery of water. This evaporation is calculated using the same basic technique discussed above for evaporation from the mainstream except that the open-water area used in this calculation is the open-water area in the canal assigned to each irrigation district or Indian reservation. The open-water area in major delivery canals was digitized using a 5-meter panchromatic image acquired on October 20, 1999 by the Indian Remote Sensing IRS 1-C or 1-D sensors.

Major delivery canals were categorized into two groups, those which provide water to a single irrigation district or Indian reservation (single user canals), and those which provide water to two or more irrigation districts or Indian reservations (shared canals). An example of a single user canal is the Colorado River Indian Reservation Main Canal and an example of a shared canal is the All American Canal.

Evaporation from a single user canal is added to the crop ET of the irrigation district or Indian reservation which receives water from the canal. Evaporation from a shared canal is proportioned among the irrigation districts or Indian reservations which receive water from the canal in proportion to the quantity of water delivered and the linear distance of canal through which water flows to reach each district or reservation. The amount of canal evaporation assigned to an irrigation district or Indian reservation which receives water from a shared canal is added to the crop ET calculated for that irrigation district or Indian reservation.

The proportion of the evaporation from a shared canal assigned to each irrigation district or Indian reservation which receives water from the canal begins by calculating the proportionate use of the canal as follows,

1. calculate a single diversion point distance from the canal head works for each irrigation district or Indian reservation by calculating the average distance of each point of diversion from the canal head works and weighing these distances by the diversion through each point of diversion (these values have units of miles),

2. multiply the value in 1, above, by the total diversion of each irrigation district or Indian reservation (these values have units of acre-foot miles),

3. divide the acre-foot mile values for each irrigation district and Indian reservation by the sum of acre-foot mile values for all irrigation districts and Indian reservations which receive water from the canal (these values are the proportionate use of the canal which can be expressed as fractions or percentages).

The proportionate use of the canal, from the calculations described above, is used to proportion the open-water area of the shared canal among the irrigation districts and Indian reservations which received water from the canal. The open-water area assigned to each irrigation district or Indian reservation is calculated as the proportionate use of the shared canal times the total open-water area of the canal.

Once the proportionate share of the open-water area of the shared canal has been assigned to each irrigation district or Indian reservation, the evaporation assigned to each irrigation district or Indian reservation is calculated on Sheet H of the water balance tables (see appendix I), using the technique discussed above for evaporation from the mainstream substituting the open-water area assigned to each irrigation district and Indian reservation.

Evaporation added to crop ET from major delivery canals within and between points of diversion and irrigation districts and Indian reservations totals about 11,150 acre-feet, less than two tenths of one percent of the combined water use from crops and exports along the lower Colorado River from Hoover Dam to Mexico.

Domestic Consumptive Use (CU_d)

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

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

Domestic consumptive use is initially estimated by

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

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

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

4) occasionally, for unique cases, using a method submitted by the diverter.

The derivation of the domestic consumptive use factors discussed above can be found in attachment 7.

The initial estimate of domestic consumptive use from Hoover Dam to Mexico for calendar year 2000 is 71,524 acre-feet. After distribution of the residuals from the water balance in each reach, the final estimate of domestic consumptive use increased by one acre-foot to 71,525 acre-feet. Domestic consumptive use accounts for less than one percent of the consumptive use (crop, domestic, and export) along the lower Colorado River from Hoover Dam to Mexico.

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

Change in Reservoir Storage (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 is no reservoir in a reach, the change in reservoir storage value is zero.

Reservoir storage values are reported monthly by Reclamation in Reservoir Elevations and Contents tables provided by the Lower Colorado Dams Facilities Office. The change in reservoir storage values used in this report are the difference between storage calculated on the first day of each month. The initial estimate of change in storage from Hoover Dam to Mexico in calendar year 2000 was 22,203 acre-feet. After distribution of the residuals from the water balance in each reach, the change in storage from Hoover Dam to Mexico decreased to 22,190 acre-feet, a change of less than one tenth of one percent.

Change in Aquifer Storage (ΔS_a)

A initial value of zero is used for all reaches of the river. Currently, no network of wells exists that would give consistent and current water-level data throughout the study area. Non-zero values for the standard error of estimate (5,000 acre-feet for the Hoover Dam to Davis Dam reach and 10,000 acre-feet for the remaining reaches) are derived from judgement and provide for some of the residual from the water balance in each reach to be distributed to change in aquifer storage. The sum of the portions of the residual distributed to change in aquifer storage from Hoover Dam to Mexico is small (998 acre-feet).

Residual (Q_{res})

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

The residual values for each reach, along with the inflows, outflows, and water uses of the water balance, are displayed in table 5.

Table 5 — Water balance summary (not adjusted for residual)

(Units: annual acre-feet)

Water balance inflows, outflows, and water uses	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})	10,692,000	10,716,200	7,895,700	6,527,141	10,692,000
Flow at the downstream boundary (Q_{ds})	10,716,200	7,895,700	6,527,141	2,119,441	2,119,441
Residual	-178,133	-265,510	226,712	102,702	-114,229
Residual as a percentage of the flow at the upstream boundary (Q_{us})	-1.67%	-2.48%	2.87%	1.57%	-1.07%
Difference between flow at the upstream and downstream boundaries (Q_{dif})	-24,200	2,820,500	1,368,559	4,407,700	8,572,559
Measured Tributary inflow (Trm)	0	13,327	0	6,577	19,904
Unmeasured Tributary inflow (Trum)	6,480	36,290	33,750	3,000	79,520
Exported flow (Q_{ex})	0	2,724,172	0	3,858,331	6,582,503
Evaporation (E)	138,549	116,580	62,882	6,209	324,220
Domestic consumptive use (CU_d)	728	35,825	4,270	30,701	71,524
Crop evapotranspiration (ET_{crop})	0	78,169	756,406	350,719	1,185,294
Phreatophyte evapotranspiration (ET_{pht})	936	179,881	351,036	68,615	600,468
Change in reservoir storage (ΔS_r)	20,200	1,000	1,003	0	22,203
Change in aquifer storage (ΔS_a)	0	0	0	0	0

The residuals in calendar year 2000 vary from less than 2% to almost 3% of the presumed standard error of estimate of the flow at the upstream boundary in all reaches. The overall residual from hoover Dam to Mexico is barely over 1%. Reclamation considers these results to be acceptable for a large river system such as the lower Colorado River. The standard error of estimate values used for the upstream flows for each reach are 1.4 percent for Hoover Dam, 2.2 percent for Davis and Parker Dams, 1.5 percent for Imperial Dam, and 1.4 percent for the flow to Mexico.

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

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

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

The standard error of estimate and variance values used in this report are based upon values recommended in Lane, W. L., 1998. Minor adjustments are made to some of the recommended values based upon judgment. The standard error of estimate and variance values used for calendar year 2000 can be found on Sheet A of the water-balance tables in appendix I.

Interaction between Reaches

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

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

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

[8] Q_{dif} is the difference between the flow entering a reach at the upstream boundary and the flow exiting a reach at the downstream boundary (Q_{us} - Q_{ds}).

Table 6 shows the calculations described above applied to calendar year 2000 values, and the adjusted flows below Hoover, Davis, and Parker Dams, at Imperial Dam, and to Mexico.

Table 6 — Adjustments to the flow below Hoover, Davis and Parker Dams, at Imperial Dam, and to Mexico

(units: annual acre-feet unless otherwise noted)

Description	Hoover Dam	Davis Dam	Parker Dam	Imperial Dam	Flow to Mexico [9]	Average
Gaged flow	10,692,000	10,716,200	7,895,700	6,527,141	2,119,441	
Amount of residual from the water balance of each reach below each dam apportioned to Q_{dif}.	-177,950	-255,606	216,108	85,578	N/A	
Temporary adjustments to flows (start with zero at most upstream dam and add cumulatively to most downstream flow)	0	-177,950	-433,556	-217,448	-131,870	-192,165
Temporary adjusted flows (gaged flow + temporary adjustment)	10,692,000	10,538,250	7,462,144	6,309,693	1,987,571	
Final adjusted flows (temporary adjusted flow - average of temporary adjustments)	10,884,165	10,730,415	7,654,309	6,501,857	2,179,734	
Final adjustments (final adjusted flow - gaged flow)	192,165	14,215	-241,391	-25,284	60,293	
Final adjustments to gaged flows in percent	1.80%	0.13%	-3.06%	-0.39%	2.84%	

By solving this boundary problem, a table of adjusted values for the whole water balance can be created which yields a residual of zero for all reaches of the lower Colorado River below Hoover Dam.

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

The final results of the water balance are shown on table 7.

Table 7 — Final distributed and adjusted water balance values

(Units: annual acre-feet)

Water balance inflows, outflows, and water uses	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})	10,884,165	10,730,415	7,654,309	6,501,857	10,884,165
Flow at the downstream boundary (Q_{ds})	10,730,415	7,654,309	6,501,857	2,179,734	2,179,734
Residual (Q_{res})	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	153,750	3,076,106	1,152,452	4,322,123	8,704,431
Measured tributary inflow (Trm)	0	13,337	0	6,574	19,911
Unmeasured tributary inflow (Trum)	6,489	36,643	33,193	2,993	79,318
Exported flow (Q_{ex})	0	2,715,324	0	3,872,049	6,587,373
Evaporation (E)	138,440	116,479	62,936	6,210	324,065
Domestic consumptive use (CU_d)	728	35,823	4,270	30,704	71,525
Crop consumptive use (CU_{crop})	0	78,123	764,181	353,208	1,195,512
Phreatophyte water use (CU_{pht})	936	179,640	352,711	68,710	601,997
Change in reservoir storage (ΔS_r)	20,192	995	1,003	0	22,190
Change in aquifer storage (ΔS_a)	-57	-298	544	809	998

Sample Calculation

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

The calculation for crop consumptive use has four major steps.

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

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

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

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

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

Calculate Crop ET for Each Diverter Within the Reach

Crop ET for a reach is the sum of the crop ET for all of the diverters within a reach. The crop ET of a diverter is the sum of the ET of each crop grown and, new for calendar year 2000, an estimate of the evaporation from major delivery canals within the diverter's boundary or between the diverter's boundary and the point of diversion. ET for a single crop is calculated as the reference ET less the effective precipitation, multiplied by the ET coefficient for the crop and the number of acres of the crop grown. The evaporation from major delivery canals is calculated as the reference ET less the total precipitation (all precipitation is considered effective at reducing open water evaporation), multiplied by an evaporation coefficient times the number of acres of water surface in the major delivery canals.

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

The paragraphs below provide an example of crop ET calculations for a single crop (alfalfa), and the evaporation from major delivery canals within a single diverter boundary (CRIR).

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

This example of an ET calculation begins with the area-specific reference ET for the Parker/Palo Verde Valleys for February 20, 2000. The area-specific reference ET for the Parker/Palo Verde Valleys is used to calculate ET for CRIR. February 20th has been chosen to provide an example with a value of effective precipitation that is greater than zero to demonstrate the use of this parameter. The area-specific reference ET is the average of the ET values calculated for each of the CIMIS and AZMET station sites within the Parker and Palo Verde Valleys, shown in table 8 below.

Table 8 — Reference ET values for February 20, 2000

AZMET/CIMIS Station Name	Reference ET (Millimeters) for February 20, 2000 (Standardized Equation)
Parker AZMET station site	2.00
Palo Verde CIMIS station site	2.20
Blythe NE CIMIS station site	2.00
Ripley CIMIS station site	1.90

The area-specific reference ET calculation for February 20th is show below:

$$\text{Area-Specific Reference ET} = (2.00+2.20+2.00+1.90) \div 4 \div 25.4 \text{ inches/millimeter}$$
$$= 0.08 \text{ inches (rounded)}$$

This sample calculation proceeds using alfalfa - perennial as the sample crop group, referred to hereafter simply as alfalfa. Note the following values for February 20th:

Area-Specific reference ET	=	0.08 (listed on Sheet D, inches)
ET Coefficient for alfalfa	=	1.104 (listed on page 2 of 2, Sheet E, dimensionless)
Precipitation	=	0.01 (listed on Sheet B, inches)

The daily ET rate for alfalfa is calculated by multiplying the area-specific daily reference ET times the daily ET coefficient for alfalfa, and subtracting effective precipitation. Effective precipitation is the portion of the precipitation that contributes to the ET requirement of the crop. Effective precipitation is calculated as the average precipitation reported by stations sited within the Parker and Palo Verde Valleys times a coefficient which varies by the month of the year (0.4 for February, from Sheet C). The Daily ET rate calculation for alfalfa is shown below:

The daily ET rate[11] for alfalfa on February 20th is calculated as shown below:

Daily ET $Rate_{alfalfa}$ = Reference ET (0.08 inches from Sheet D) * ET coefficient for alfalfa (1.104 from Sheet E, page 2 of 2), - effective precipitation (0.004 inches, rounded to 0.00 on Sheet C)

= 0.084 inches (round to 0.08 as shown on Sheet E)

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

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

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

The example continues with the calculation of ET (in acre-feet) for alfalfa for the month of February. The ET for alfalfa in February is the product of the ET rate for alfalfa for the month of February (3.27 inches, from the Parker/Palo Verde ET-rate Table, Sheet E, page 1 of 2) and the acreage of alfalfa on CRIR listed for February 2000 (49,283 acres, from the Parker Dam to Imperial Dam Water-Balance Table, Sheet O, page 3 of 5 in appendix I, Part 2, rounded to the nearest acre).

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

$ET_{alfalfa}$ for February = 3.27 (inches) * 49,283 (acres) ÷ 12 (inches/foot)

= 13,429 acre-feet (rounded to nearest acre-foot, Sheet O, Page 1 of 5).

The process is repeated for each crop group and the results for each crop group are summed.

Evaporation from major delivery canals is calculated much like crop ET, except that the calculations are done on a monthly instead of daily basis and the total precipitation is considered effective in reducing evaporation (no calculation for effective precipitation is required). The calculations for major delivery canal evaporation at CRIR can be found in appendix I on Sheet H, page 2 of 2 of the Parker Dam to Imperial Dam Water Balance Table under the section heading, "Open-Water Evaporation Within District and Shared Canal Evaporation (3)," and the results of the evaporation calculations for major delivery canals can also be found on the diverter ET sheets (Sheet O, page 1 of 5 for CRIR, AZ) in the water balance tables on the line entitled, "On-District Open-Water Evap. (from Sheet H)."

A sample calculation of evaporation from major delivery canals within CRIR for the month of February, 2000 is presented below (all values can be found on Sheet H).

Canal Evaporation for February = [〈Reference ET (inches) * Evaporation Coefficient (dimensionless)〉- Precipitation (inches)] * Open Water Surface Area In Canals (acres) ÷ 12 Inches/Foot

Canal Evaporation for February = [(3.32 inches *0.57) - 0.14 inches] * 279 acres ÷ 12 inches/foot = 41 acre-feet (rounded to nearest acre-foot)

The annual crop ET for CRIR is calculated by summing the monthly ET for each crop group and, new for calendar year 2000, adding the evaporation from major delivery canals within CRIR. The Crop ET for the reach used in the water balance is the sum of the crop ET for each crop, for each month, for each diverter.

Calculate the Residual for the Reach

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

The water balance between Parker and Imperial Dams is performed on annual values and consists of many parts. Each part used for calendar year 2000 is described in the following paragraphs.

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

The mainstream inflow to the Parker Dam to Imperial Dam reach (Q_{us})is the flow below Parker Dam (7,895,700 acre-feet), as shown on Sheet A, page 1 of 2, of the Parker Dam to Imperial Dam Water-Balance Table. The unmeasured tributary inflow between Parker and Imperial Dams (33,750 acre-feet) is shown on Sheet C of the Parker Dam to Imperial Dam Water-Balance Table. The unmeasured tributary inflow value was provided by the Geological Survey (page 46 of Owen-Joyce, Sandra J., and Raymond, Lee H., 1996). Measured tributary inflow between Parker and Imperial Dams is zero (as shown on Sheet C).

The flow at the downstream boundary of the Parker Dam to Imperial Dam reach is the flow at Imperial Dam (6,527,141 acre-feet, shown on Sheet A), which is the sum of four flows as shown on Sheet H of the Parker Dam to Imperial Dam Water-Balance Table. These flows are Station 60 on the All-American Canal (5,268,800 acre-feet), Station 30 on the Gila Gravity Main Canal (834,627 acre-feet), the inflow to Mittry Lake (10,444 acre-feet), and the Colorado River Sluiceway (413,270 acre-feet).

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

Evaporation

This evaporation calculation represents the evaporation from the open water areas of the mainstream, including lakes. This evaporation calculation does not include evaporation from major delivery canals.

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

Evaporation = [[February sum of daily reference ET (3.32 inches) * February evaporation coefficient (0.57)] - precipitation (0.14 inches)] * area of open water (4,000 acres) ÷ 12 (inches/foot)

= 584 acre-feet

The evaporation, reference ET, evaporation coefficient, precipitation, area of open water, and total evaporation for February (1,900 acre-feet) can be found on Sheet H (pages 1 and 2) of the Parker Dam to Imperial Dam Water-Balance Table.

Domestic Consumptive Use

The initial estimate of domestic consumptive use between Parker and Imperial Dams is the sum of several users, as shown on Sheet E of the Parker Dam to Imperial Dam Water-Balance Table. The methods described in the above section entitled “Domestic Use (CU_d)” are used to develop these values. For example, Poston, with a population of approximately 389 (2000 census) is initially estimated to use 54 acre-feet annually (389 * 0.14). Monthly values are calculated as the product of the annual per-capita use rate divided by 12 and the population, unless a monthly distribution of water use is provided through diversion records or other information is available. The initial estimate of consumptive use in February for Poston is therefore 4.5 acre-feet [389 people * (0.14 ÷ 12)].

Change in Reservoir Storage

Senator Wash is the only reservoir between Parker and Imperial Dams. Change in reservoir storage is calculated on Sheet D of the Parker Dam to Imperial Dam Water-Balance Table as the difference in water held in Senator Wash between the beginning and end of each month. The January beginning-of-month storage (as measured midnight December 31, 1999) is 5,097 acre-feet and end-of-month storage (measured midnight January 31, 2000) is 3,203 acre-feet. The difference is a loss of 1,894 acre-feet. The annual change in reservoir storage is the difference between the January beginning-of-month storage and the December end-of-month storage (1,003 acre-foot gain in calendar year 2000).

The Residual

The residual is calculated on Sheet A, page 1 of 2, of the Parker Dam to Imperial Dam Water-Balance Table. This result for calendar year 2000 is 226,712 acre-feet, or about 2.87 percent of the flow below Parker Dam. The residual calculation is shown below (see the above section entitled “Water Balance” for definitions of terms),

$$\begin{aligned}\text{Residual} &= Q_{dif}\,(1{,}368{,}559) + Q_{Trum}\,(33{,}750) - S_r\,(1{,}003) - CU_d\,(4{,}270) - ET_{crop}\,(756{,}406) - \\ &\quad ET_{pht}\,(351{,}036) - E\,(62{,}882) \\ &= 226{,}712 \text{ acre-feet}\end{aligned}$$

Calculate Crop Consumptive Use for the Reach

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

$$\text{Crop CU}_{\text{Reach}} = \text{Crop ET}_{\text{Reach}} + [\,(\text{VAR}_{\text{Crop ET}} \div \text{TVAR}) \times Q_{\text{res}}\,]$$

Where:

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

The crop ET in the Parker Dam to Imperial Dam reach is 756,406 acre-feet, and the SEE is presumed to be 5 percent, yielding a variance of 1,430,352,400 acre-feet squared. The TVAR of the reach is 41,709,996,588 acre-feet squared, and the residual is 226,712 acre-feet. All the values in the above paragraph can be found on Sheet A of the Parker Dam to Imperial Dam Water-Balance Table.

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

$$\text{Crop CU}_{\text{Reach}} = 756{,}406 + [(1{,}430{,}352{,}400 \div 41{,}709{,}996{,}588) \times (226{,}712)]$$

$$\text{Crop CU}_{\text{Reach}} = 764{,}181 \text{ acre-feet}$$

Calculate the Crop Consumptive Use for Each Diverter

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

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

Where:

Crop CU_{CRIR} = Crop consumptive use for CRIR,

Crop ET_{CRIR} = Crop ET for CRIR,

Crop ET_{Reach} = Crop ET between Parker and Imperial Dams,

Crop CU_{Reach} = Crop consumptive use between Parker and Imperial Dams.

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

$$\text{Crop } CU_{CRIR} = 333{,}708 \text{ acre-feet} \div 756{,}406 \text{ acre-feet} * 764{,}181 \text{ acre-feet}$$

$$\text{Crop } CU_{CRIR} = 337{,}138 \text{ acre-feet}$$ [12]

Results

The results of LCRAS for Calendar Year 2000 are presented in the tables and charts found on the following pages and in attachment 3. Table 9 presents a summary of the water use values calculated using LCRAS and the consumptive use values reported in the decree accounting report.

Some of the differences in reported consumptive uses between LCRAS and the decree accounting report shown in table 9 can be attributed to,

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

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

2. the consumptive use reported by the decree accounting report for each diverter does not include the unmeasured return flow calculated for each diverter which is currently treated as a total for the whole basin; and

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

Table 9 — LCRAS Crop and Domestic Consumptive Use, and Phreatophyte Water Use, and Consumptive Use from the Decree Accounting Report

(Units: annual acre-feet)

LCRAS			**Decree Accounting Report**	
Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
Nevada				
Uses above Hoover Dam (from 2000 decree accounting report)		299,687	299,687	Uses above Hoover Dam
Uses below Hoover Dam	20,538	19,070	22,297	Uses below Hoover Dam
			2,128	Unmeasured return flow credit
Nevada Total	20,538	318,757	319,856	Nevada Total
California				
			5,185,466	Sum of individual diverters
			100,530	Unmeasured return flow credit
California Total	171,993	5,230,253	5,084,936	California Total
Arizona				
Subtotal (Below Hoover Dam, less Wellton-Mohawk IDD)	409,470	2,284,651	2,596,387	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (from the 2000 decree accounting report)		132	132	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (from 2000 decree accounting report)		275,747	275,747	Wellton-Mohawk IDD
			69,525	Pumped from South Gila wells (DPOCs): returns
			169,244	Unmeasured return flow credit
Arizona Total	409,470	2,560,530	2,633,497	Arizona Total
Lower Colorado River Basin Total				
Total Use	602,001	8,109,540	8,038,289	Total Use

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

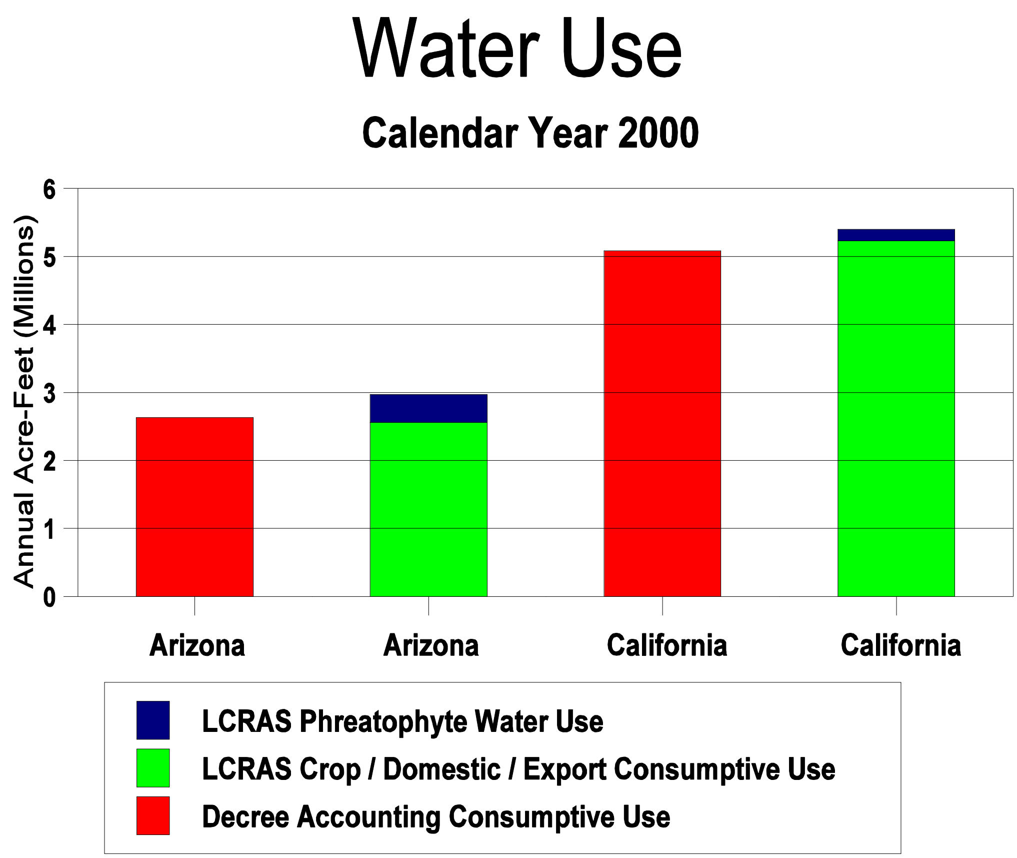


Figure 2. — State water use totals for Arizona and California (calendar year 2000).

LOWER COLORADO RIVER ACCOUNTING SYSTEM MAP INDEX

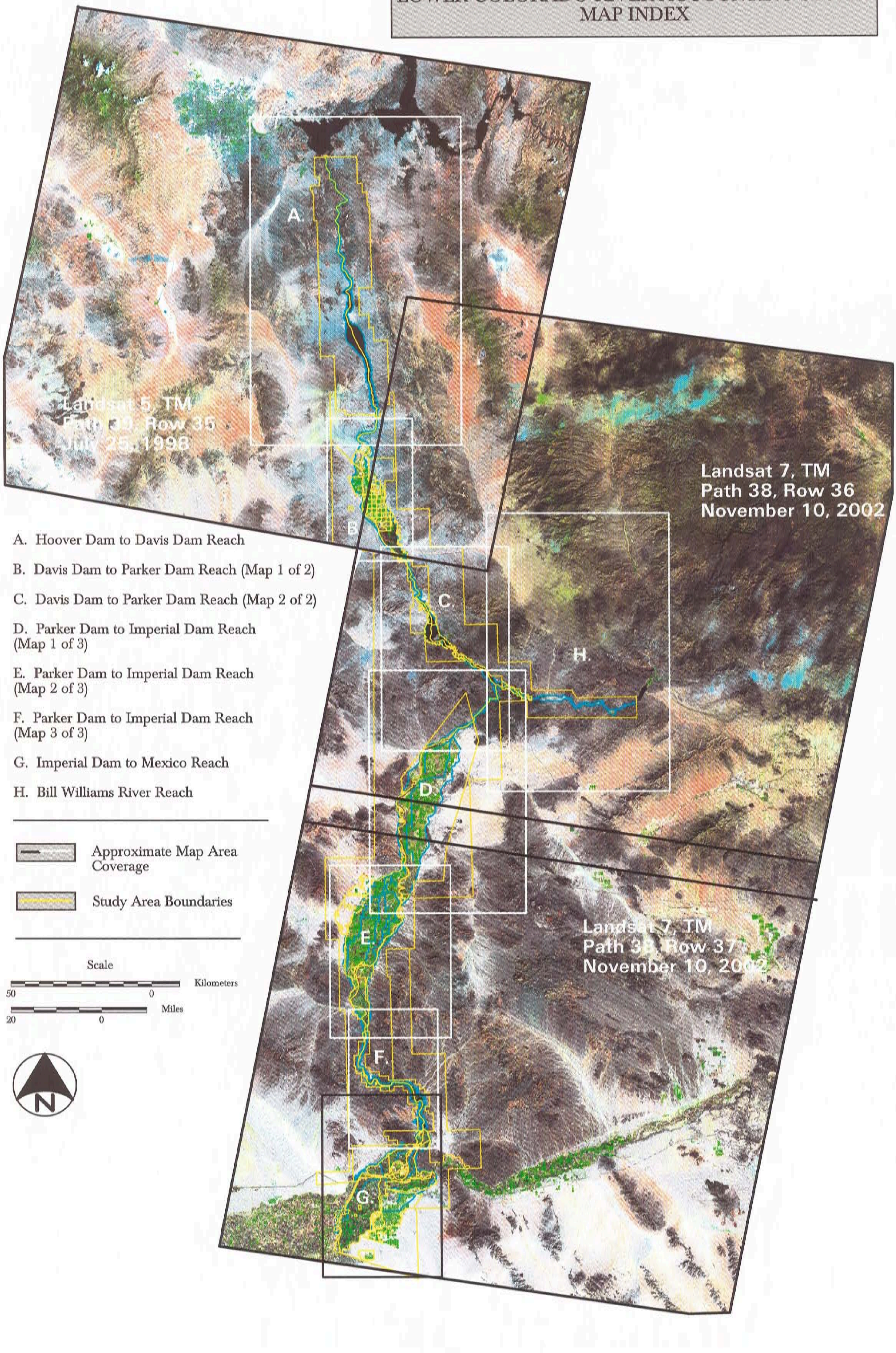
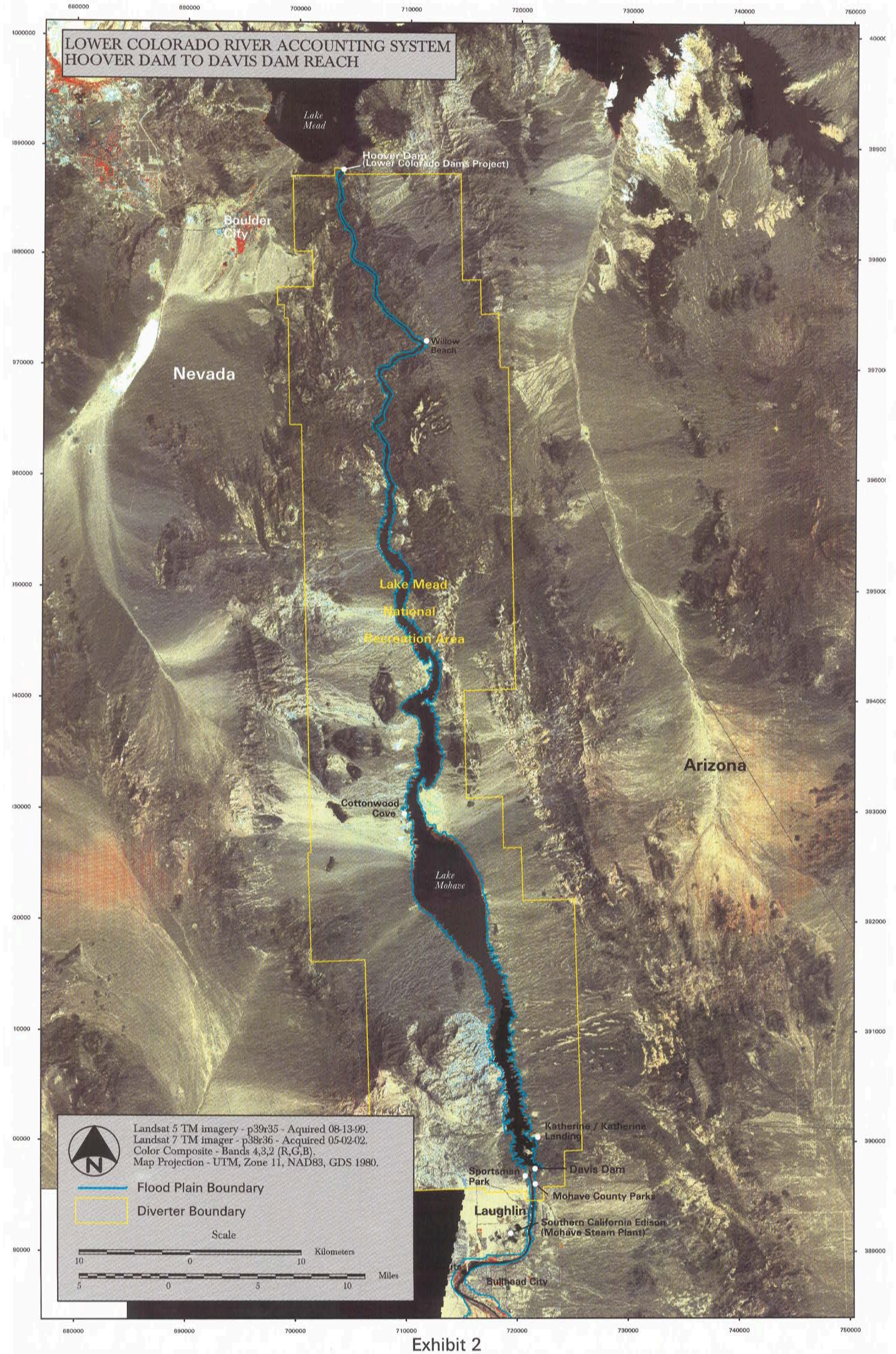
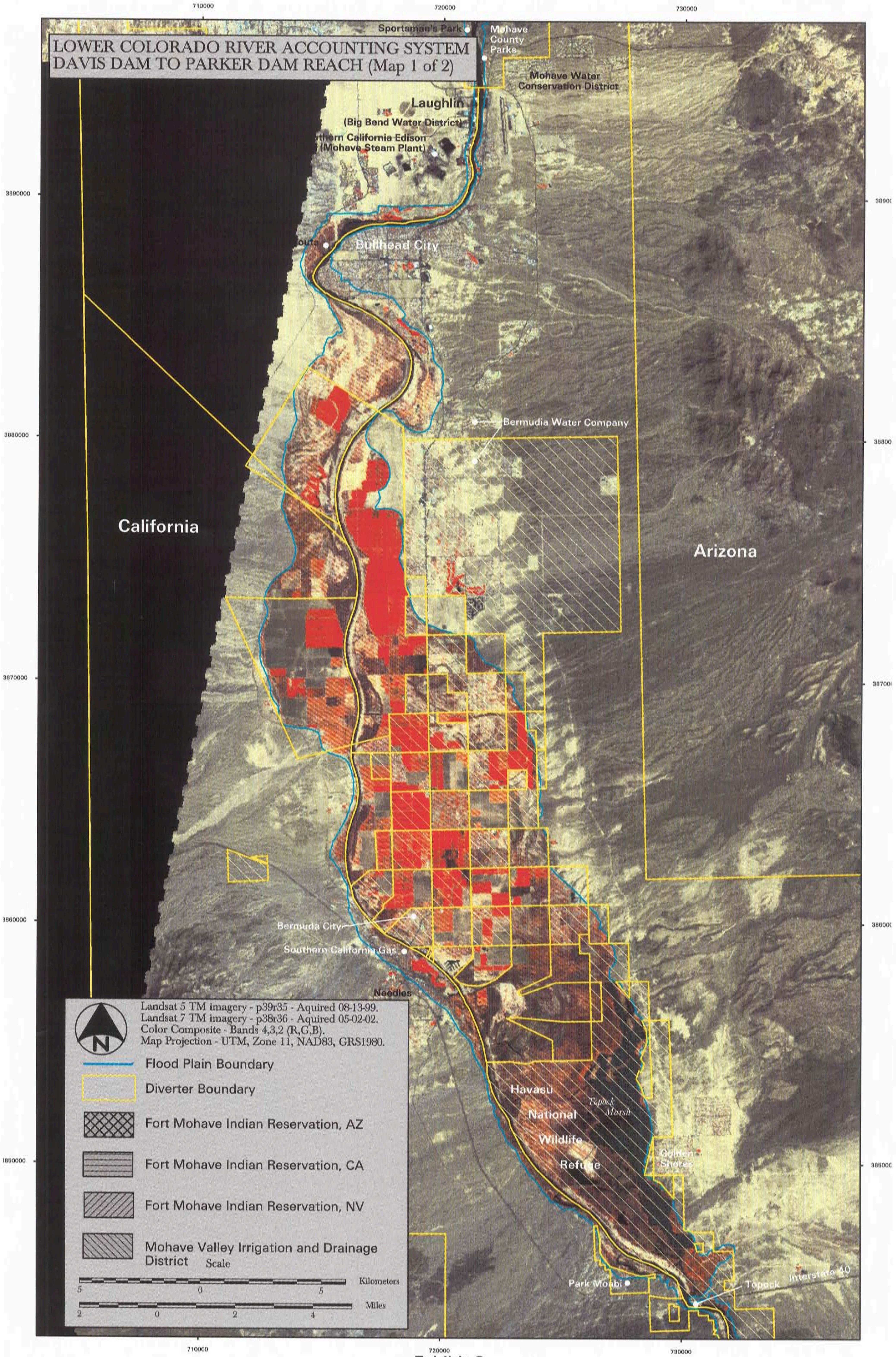


Exhibit 1



LOWER COLORADO RIVER ACCOUNTING SYSTEM
HOOVER DAM TO DAVIS DAM REACH
Lake Mead
Hoover Dam
(Lower Colorado Dams Project)
Boulder City
Willow Beach
Nevada
Lake Mead
National
Recreation Area
Arizona
Cottonwood Cove
Lake Mohave
Katherine / Katherine Landing
Davis Dam
Sportsman Park
Mohave County Parks
Laughlin
Southern California Edison
(Mohave Steam Plant)
Bullhead City
Landsat 5 TM imagery - p39r35 - Aquired 08-13-99.
Landsat 7 TM imager - p38r36 - Acquired 05-02-02.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD83, GDS 1980.
N
Flood Plain Boundary
Diverter Boundary
Scale
Kilometers
10 0 10
Miles
5 0 5 10
680000
690000
700000
710000
720000
730000
740000
750000

Exhibit 2

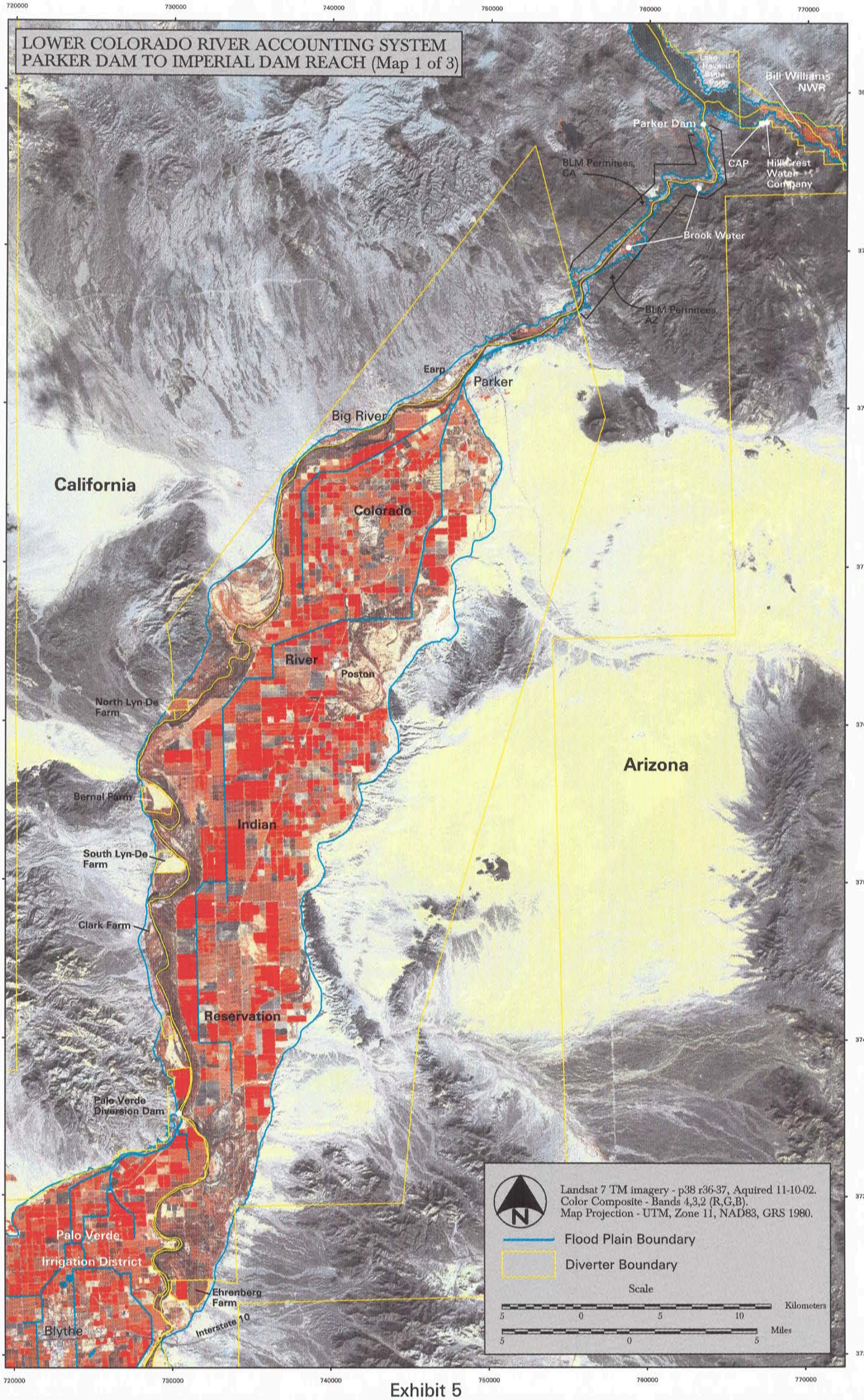


LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 1 of 2)
710000
720000
730000
Sportsman's Park
Mohave County Parks
Mohave Water Conservation District
Laughlin
(Big Bend Water District)
(Mohave Steam Plant)
Bullhead City
Bermudia Water Company
California
Arizona
Bermuda City
Southern California Gas
Needles
Havasu
National
Wildlife
Refuge
Topock Marsh
Golden Shores
Park Moabi
Topock
Interstate 40
3890000
3880000
3870000
3860000
3850000
Landsat 5 TM imagery - p39r35 - Aquired 08-13-99.
Landsat 7 TM imagery - p38r36 - Aquired 05-02-02.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD83, GRS1980.
N
Flood Plain Boundary
Diverter Boundary
Fort Mohave Indian Reservation, AZ
Fort Mohave Indian Reservation, CA
Fort Mohave Indian Reservation, NV
Mohave Valley Irrigation and Drainage District
Scale
Kilometers
5
0
5
Miles
2
0
2
4

Exhibit 3


LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 2 of 2)
Park Moabi
Interstate 40
Topock
Havasu
National
Wildlife
Refuge
Arizona
Havasu Water Company
of Arizona
Chemehuevi
Indian
Reservation
Lake Havasu City
Havasu Water Company
of California
Lake
Havasu
Chemehuevi Indian
Reservation
Chemehuevi
Indian
Reservation
Lake Havasu State Park
California
Black Meadow, CA
Lake
Havasu
State
Park
Hill Crest
Water
Company
MWD
Parker Dam
CAP
Bill Williams
NWR
Colorado River
Indian Reservation
Earp
Parker
Landsat 7 TM imagery - p38 r36 and p38r37,
Aquired 05-02-02.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD83, GRS1980.
Flood Plain Boundary
Diverter Boundary
Scale
Kilometers
Miles
730000
740000
750000
760000
840000
830000
820000
810000
800000
790000
780000

Exhibit 4



LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 1 of 3)
Bill Williams NWR
Parker Dam
CAP
Hillcrest Water Company
BLM Permitees, CA
Brook Water
BLM Permitees, AZ
Earp
Parker
Big River
California
Colorado
River
Poston
North Lyn-De Farm
Bernal Farm
Indian
South Lyn-De Farm
Clark Farm
Reservation
Arizona
Palo Verde Diversion Dam
Palo Verde
Irrigation District
Blythe
Ehrenberg Farm
Interstate 10
Landsat 7 TM imagery - p38 r36-37, Aquired 11-10-02.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD83, GRS 1980.
N
Flood Plain Boundary
Diverter Boundary
Scale
Kilometers
5 0 5 10
Miles
5 0 5
720000
730000
740000
750000
760000
770000
3800000
3790000
3780000
3770000
3760000
3750000
3740000
3730000
3720000

Exhibit 5

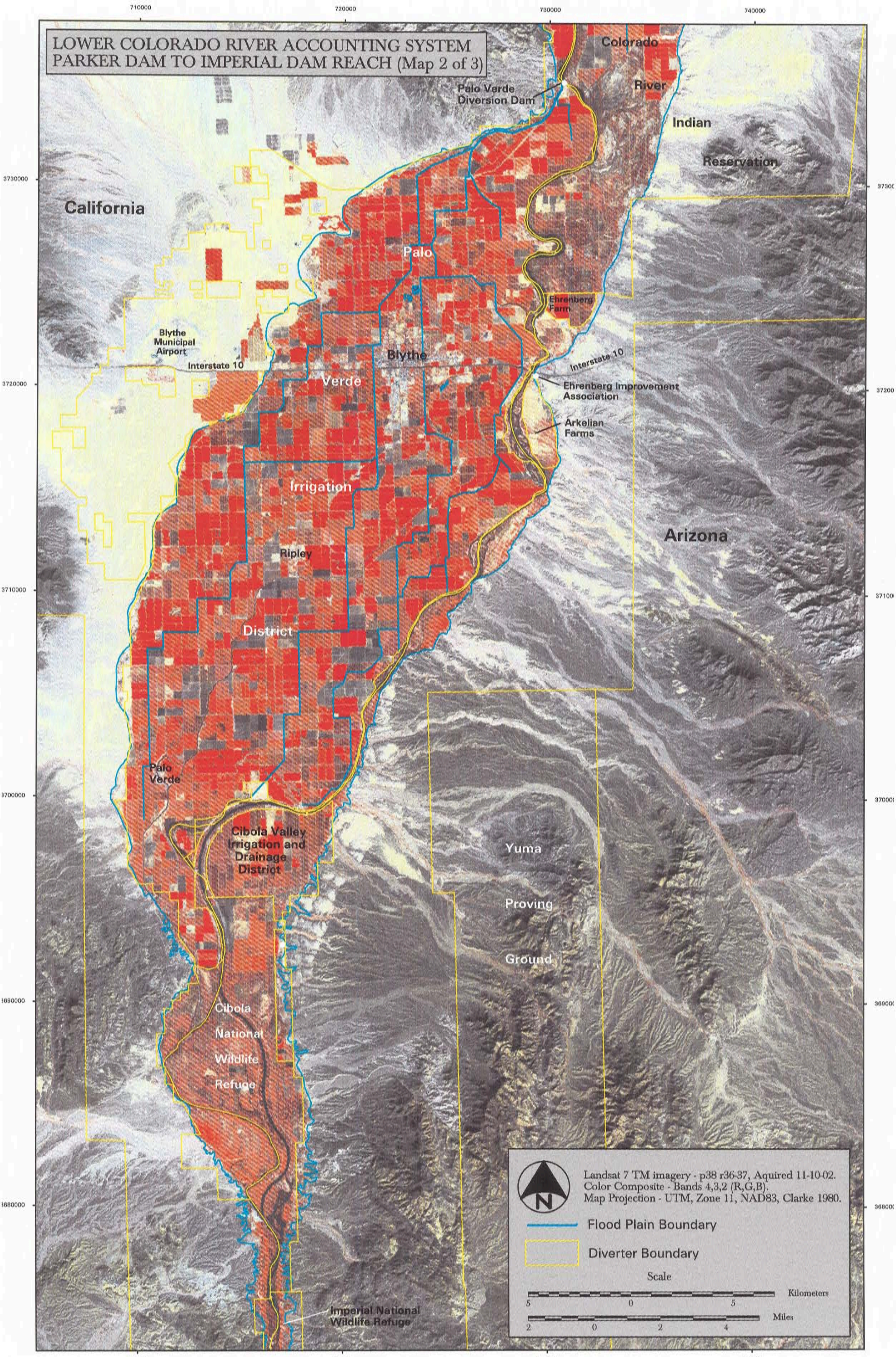

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 2 of 3)
710000
720000
730000
740000
Colorado
River
Indian
Reservation
Palo Verde
Diversion Dam
California
Palo
Ehrenberg
Farm
Blythe
Municipal
Airport
Interstate 10
Blythe
Interstate 10
Verde
Ehrenberg Improvement
Association
Arkelian
Farms
Irrigation
Arizona
Ripley
District
Palo
Verde
Cibola Valley
Irrigation and
Drainage
District
Yuma
Proving
Ground
Cibola
National
Wildlife
Refuge
Imperial National
Wildlife Refuge
Landsat 7 TM imagery - p38 r36-37, Aquired 11-10-02.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD83, Clarke 1980.
N
Flood Plain Boundary
Diverter Boundary
Scale
Kilometers
Miles

Exhibit 6

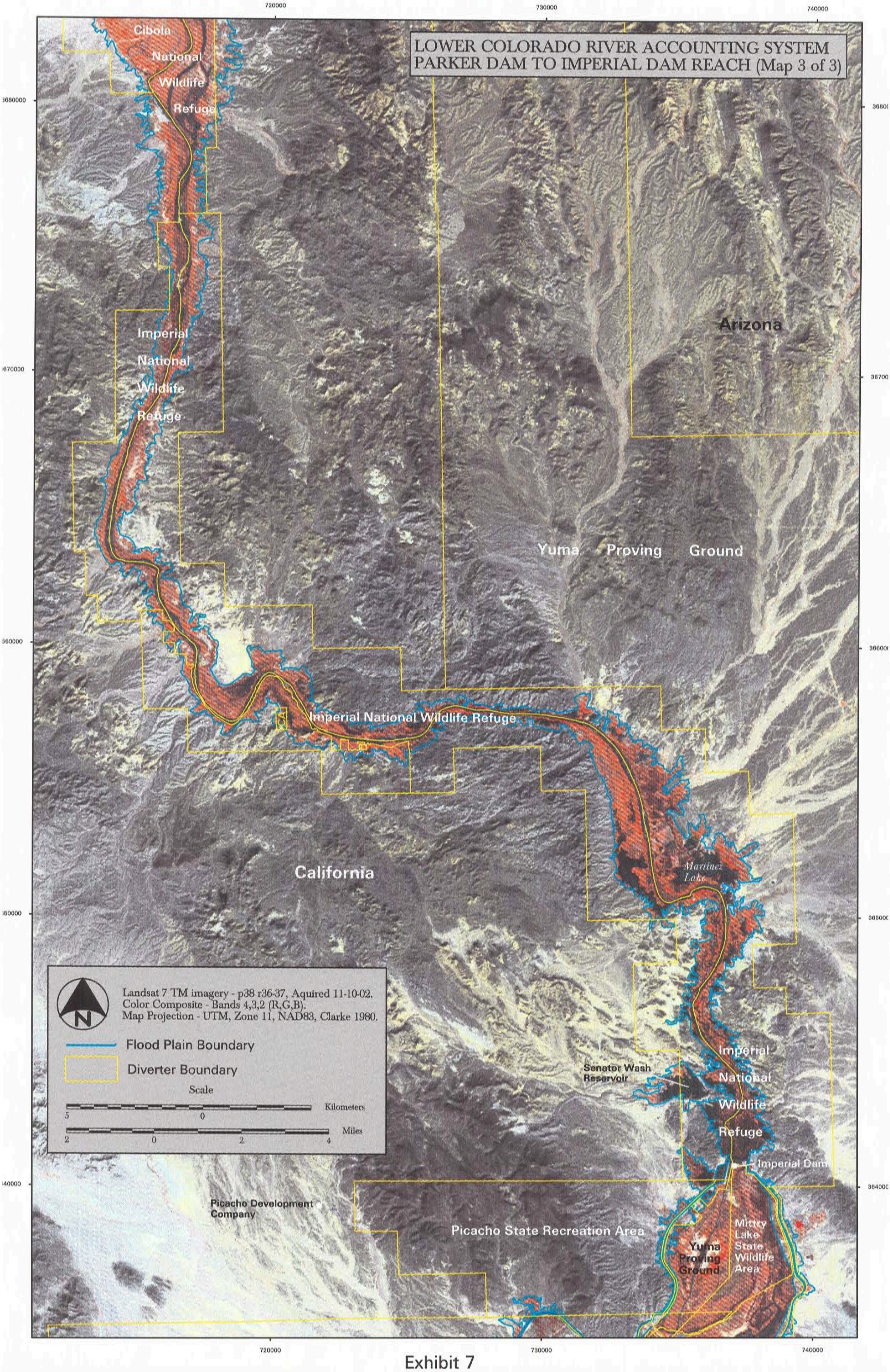

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 3 of 3)
720000
730000
740000
Cibola National Wildlife Refuge
Imperial National Wildlife Refuge
Arizona
Yuma Proving Ground
Imperial National Wildlife Refuge
California
Martinez Lake
Senator Wash Reservoir
Imperial National Wildlife Refuge
Imperial Dam
Picacho Development Company
Picacho State Recreation Area
Yuma Proving Ground
Mittry Lake State Wildlife Area
N
Landsat 7 TM imagery - p38 r36-37, Aquired 11-10-02.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD83, Clarke 1980.
Flood Plain Boundary
Diverter Boundary
Scale
Kilometers
5
0
Miles
2
0
2
4

Exhibit 7

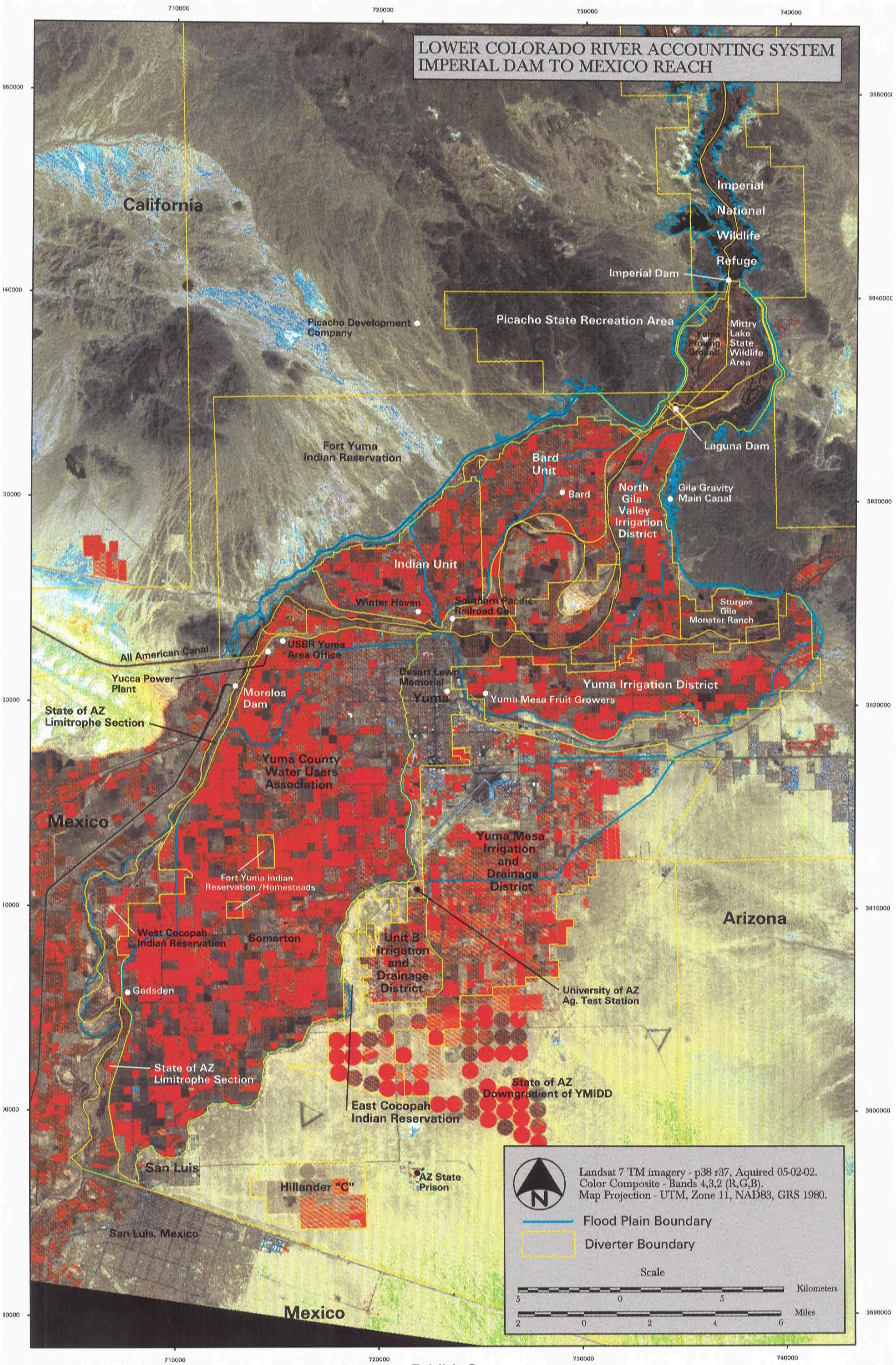

LOWER COLORADO RIVER ACCOUNTING SYSTEM
IMPERIAL DAM TO MEXICO REACH
California
Imperial
National
Wildlife
Refuge
Imperial Dam
Picacho Development Company
Picacho State Recreation Area
Yuma Proving Ground
Mittry Lake State Wildlife Area
Laguna Dam
Fort Yuma Indian Reservation
Bard Unit
Bard
North Gila Valley Irrigation District
Gila Gravity Main Canal
Indian Unit
Winter Haven
Southern Pacific Railroad Co.
Sturges Gila Monster Ranch
All American Canal
USBR Yuma Area Office
Yucca Power Plant
Desert Lawn Memorial
Yuma
Yuma Irrigation District
Yuma Mesa Fruit Growers
Morelos Dam
State of AZ Limitrophe Section
Yuma County Water Users Association
Mexico
Yuma Mesa Irrigation and Drainage District
Fort Yuma Indian Reservation /Homesteads
West Cocopah Indian Reservation
Somerton
Unit B Irrigation and Drainage District
Arizona
University of AZ Ag. Test Station
Gadsden
State of AZ Limitrophe Section
State of AZ Downgradient of YMIDD
East Cocopah Indian Reservation
San Luis
Hillander "C"
AZ State Prison
San Luis, Mexico
Mexico
Landsat 7 TM imagery - p38 r37, Aquired 05-02-02.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD83, GRS 1980.
N
Flood Plain Boundary
Diverter Boundary
Scale
Kilometers
5 0 5
Miles
2 0 2 4 6
710000
720000
730000
740000
3650000
3640000
3630000
3620000
3610000
3600000
3590000

Exhibit 8

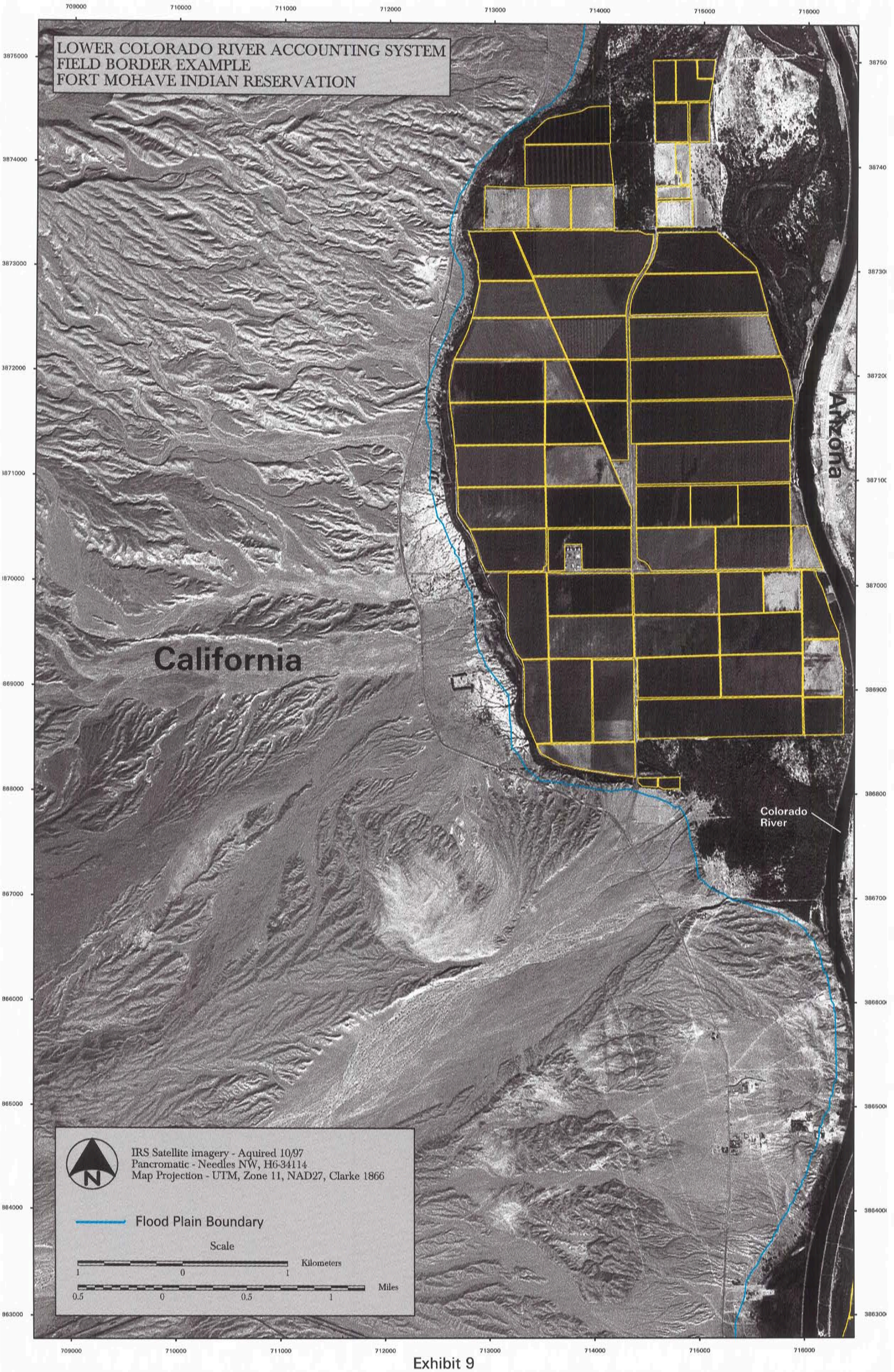

LOWER COLORADO RIVER ACCOUNTING SYSTEM
FIELD BORDER EXAMPLE
FORT MOHAVE INDIAN RESERVATION
California
Arizona
Colorado River
IRS Satellite imagery - Aquired 10/97
Pancromatic - Needles NW, H6-34114
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
N
Flood Plain Boundary
Scale
Kilometers
1 0 1
Miles
0.5 0 0.5 1

Exhibit 9

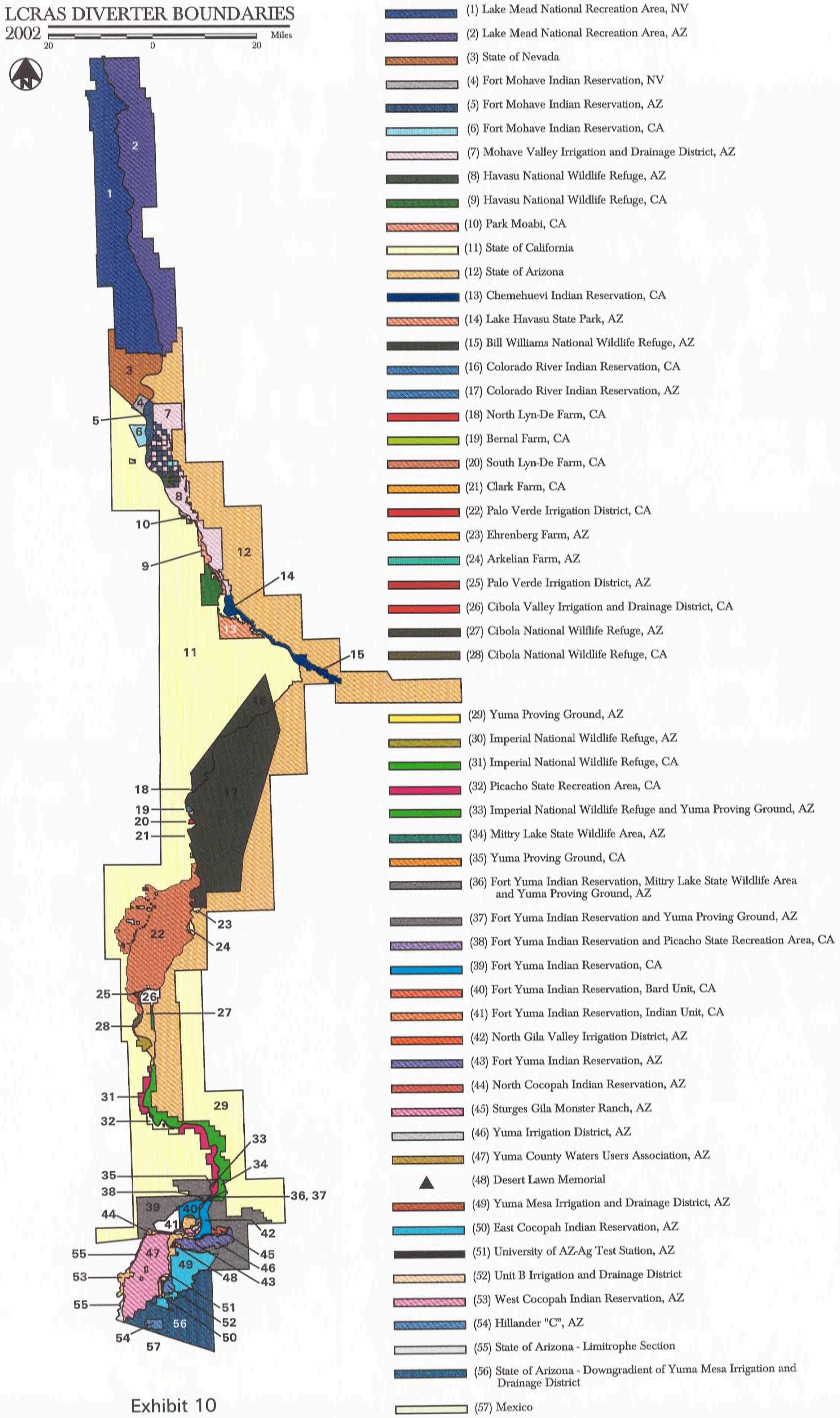

LCRAS DIVERTER BOUNDARIES
2002
20 0 20
Miles
(1) Lake Mead National Recreation Area, NV
(2) Lake Mead National Recreation Area, AZ
(3) State of Nevada
(4) Fort Mohave Indian Reservation, NV
(5) Fort Mohave Indian Reservation, AZ
(6) Fort Mohave Indian Reservation, CA
(7) Mohave Valley Irrigation and Drainage District, AZ
(8) Havasu National Wildlife Refuge, AZ
(9) Havasu National Wildlife Refuge, CA
(10) Park Moabi, CA
(11) State of California
(12) State of Arizona
(13) Chemehuevi Indian Reservation, CA
(14) Lake Havasu State Park, AZ
(15) Bill Williams National Wildlife Refuge, AZ
(16) Colorado River Indian Reservation, CA
(17) Colorado River Indian Reservation, AZ
(18) North Lyn-De Farm, CA
(19) Bernal Farm, CA
(20) South Lyn-De Farm, CA
(21) Clark Farm, CA
(22) Palo Verde Irrigation District, CA
(23) Ehrenberg Farm, AZ
(24) Arkelian Farm, AZ
(25) Palo Verde Irrigation District, AZ
(26) Cibola Valley Irrigation and Drainage District, CA
(27) Cibola National Wilflife Refuge, AZ
(28) Cibola National Wildlife Refuge, CA
(29) Yuma Proving Ground, AZ
(30) Imperial National Wildlife Refuge, AZ
(31) Imperial National Wildlife Refuge, CA
(32) Picacho State Recreation Area, CA
(33) Imperial National Wildlife Refuge and Yuma Proving Ground, AZ
(34) Mittry Lake State Wildlife Area, AZ
(35) Yuma Proving Ground, CA
(36) Fort Yuma Indian Reservation, Mittry Lake State Wildlife Area and Yuma Proving Ground, AZ
(37) Fort Yuma Indian Reservation and Yuma Proving Ground, AZ
(38) Fort Yuma Indian Reservation and Picacho State Recreation Area, CA
(39) Fort Yuma Indian Reservation, CA
(40) Fort Yuma Indian Reservation, Bard Unit, CA
(41) Fort Yuma Indian Reservation, Indian Unit, CA
(42) North Gila Valley Irrigation District, AZ
(43) Fort Yuma Indian Reservation, AZ
(44) North Cocopah Indian Reservation, AZ
(45) Sturges Gila Monster Ranch, AZ
(46) Yuma Irrigation District, AZ
(47) Yuma County Waters Users Association, AZ
(48) Desert Lawn Memorial
(49) Yuma Mesa Irrigation and Drainage District, AZ
(50) East Cocopah Indian Reservation, AZ
(51) University of AZ-Ag Test Station, AZ
(52) Unit B Irrigation and Drainage District
(53) West Cocopah Indian Reservation, AZ
(54) Hillander "C", AZ
(55) State of Arizona - Limitrophe Section
(56) State of Arizona - Downgradient of Yuma Mesa Irrigation and Drainage District
(57) Mexico

Exhibit 10

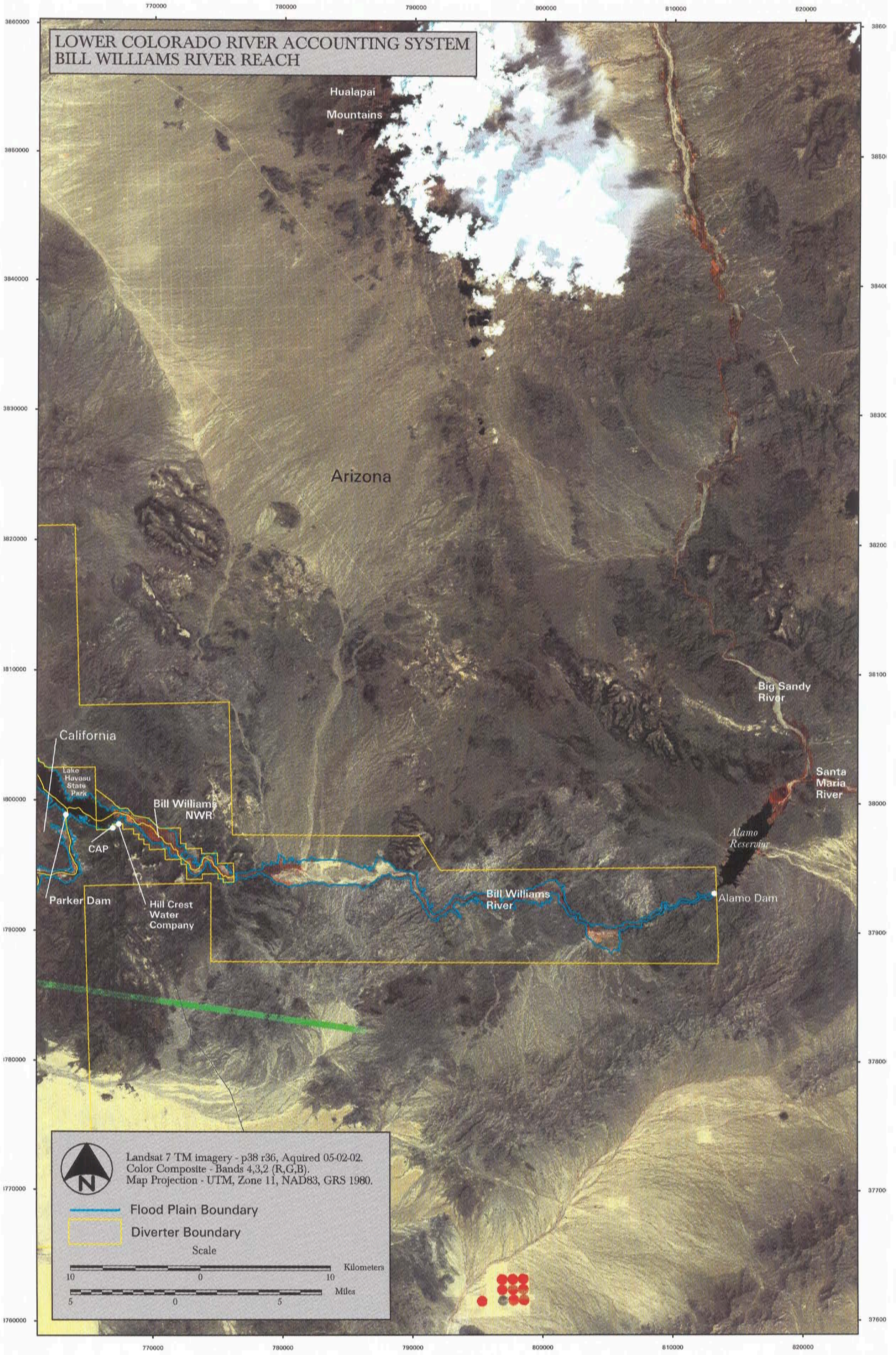

LOWER COLORADO RIVER ACCOUNTING SYSTEM
BILL WILLIAMS RIVER REACH
Hualapai
Mountains
Arizona
California
Lake Havasu State Park
Bill Williams NWR
CAP
Parker Dam
Hill Crest Water Company
Bill Williams River
Big Sandy River
Santa Maria River
Alamo Reservoir
Alamo Dam
Landsat 7 TM imagery - p38 r36, Aquired 05-02-02.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD83, GRS 1980.
Flood Plain Boundary
Diverter Boundary
Scale
Kilometers
10 0 10
Miles
5 0 5

Exhibit 11

Chapter 3

LCRAS Improvements

The LCRAS program operates in an environment of continuous process improvement. Each application of LCRAS is reviewed and the lessons learned are incorporated in subsequent reports. Reclamation also makes modifications to each application of LCRAS in response to information provided by water users and as modified processes are made available from analysis of long-term questions and issues.

The following paragraphs describe improvements made since the 1999 LCRAS Demonstration of Technology report was issued, and potential improvements which have been under active consideration during the past year. Completed improvements or potential improvements identified in the previous reports which have been assigned a low priority are not repeated here.

Diverter Boundaries

Reclamation consults with irrigation districts, Indian reservations, and other users with a defined service area to resolve discrepancies that may exist between Reclamation's understanding of boundaries and a particular water user's understanding of their boundaries. Information gained through such consultations, and other information that may become available, is used to update diverter boundaries used by LCRAS. Such information sharing and gathering is an ongoing effort.

There were no diverter boundary changes made for calendar year 2000.

Crop Delineation and Acreage Summaries

The following improvements were incorporated for calendar year 2000:

USBR personnel visited Cibola Wildlife Refuge areas to characterize some of the unique management practices in the agricultural fields (ie. wet management units, etc.) that are difficult to classify with remote sensing procedures. This data was incorporated into final summary tables.

Grass categories in the annual summary were further subdivided into bermuda, bermuda/rye, klein grass, and timothy grass.

Field visits were conducted in the Bill Williams reach to verify changes in agricultural practices in this area. Agricultural fields were added to the database in this area and this data was incorporated into final summary tables.

Open Water Acreage

Improved open water delineations developed by the Bureau of Reclamation Environmental Group and outside contractors was used to create an open water database for calendar year 2000. This data was checked against current (July 2000) Landsat TM data to ensure no significant changes in open water areas occurred during calendar year 2000.

Domestic Use

The following improvements to domestic calculations were made for calendar year 2000,

1. Population estimates from the 2000 census were used to update populations for the following municipalities,

   A. Poston,AZ,
   B. Cibola, AZ,
   C. Palo Verde CA,
   D. Big River CA,
   E. Blythe CA and,
   F. Yuma (County), AZ.,

2. The estimate of domestic use for the Chemehuevi Indian Reservation, CA was changed from a diversion multiplied by a coefficient of 0.6 (they have long been noted as not reporting a value of diversion) to a per capita use multiplied by an estimate of population, using a newly available 2000 U.S. Census reported population of 345,

3. The estimates of domestic use through the use of a diversion times a coefficient of 0.6 for the following,

    1. Somerton AZ,
    2. Gadsden AZ,
    3. San Luis AZ,

    have been replaced with estimates of domestic use made through the use of 2000 U.S. census population data. Diversion information for Somerton, Gadsden, & San Luis in Arizona have been from data used by Reclamation for modeling purposes which has not been recently updated. In the absence of recent measured diversion information, the use of 2000 U.S. Census population data and a per capita use value of 0.14 acre-feet per person per day should yield an initial estimate of domestic consumptive use that is more reflective of current conditions and,

4. The diverter name East Cocopah Bingo, AZ has been replaced by the diverter name Cocopah Indian Reservation AZ and the diverter name Yuma Valley Irrigation District, AZ has been replaced by the diverter name Yuma County WUA, AZ (Yuma County Water Users Association).

Canal Losses

This calendar year 2000 report introduces calculations which distribute evaporation from the All-American Canal between Imperial Dam and Pilot Knob and the Gila Gravity Main Canal to the diverters that receive water from these canals. Water use by phreatophytes which intercept leakage from these canals, distributed to users along these canals by the current decree accounting report methods, is not yet included in LCRAS.

This calendar year 2000 report also introduces the addition of evaporation from the Palo Verde and Colorado River Indian Reservation main canals to the crop evapotranspiration calculated for the Palo Verde Irrigation District and Colorado River Indian Reservation respectively.

Crop Evapotranspiration

This calendar year 2000 report introduces an adjusted coefficient for perennial alfalfa. The adjustment is slightly upward through a reevaluation of the reduction factor for potential alfalfa ET (reduction factor) from 0.85 to 0.92. Potential alfalfa ET is the rate at which alfalfa would use water under ideal irrigation practices in uniform soil conditions in the climate found in the lower Colorado River basin. Reclamation has observed that very few alfalfa fields are in ideal conditions, thus requiring a reduction factor to represent actual conditions. The reevaluation of the reduction factor also takes into account the use of the ASCE recommended standardized reference ET equation (discussed in greater detail in Attachment 6), which produces a somewhat lower reference ET than the average of the reference ET values reported by CIMIS and AZMET, upon which the previous reduction factor was based.

The adjustment to the reduction factor was recommended by Dr. Marvin Jensen upon a comparison of the results of the ET methods used by LCRAS with the results of studies performed in arid regions worldwide. This change results in an increase of overall crop ET from Hoover Dam to Mexico of about 4.5%.

Phreatophyte Evapotranspiration

Reclamation has initiated an effort to improve the phreatophyte evapotranspiration estimates used by LCRAS through a cooperative study with the Nevada District of the Geological Survey. The objective of this study will be to measure the parameters required to estimate evapotranspiration and, from these parameters, estimate the evapotranspiration of the most common phreatophyte communities found along the lower Colorado River. The parameters required to estimate evapotranspiration will be measured by four micro-meteorological stations placed above stands of phreatophytes in Topock Marsh and adjacent to the Bill Williams River. These micro-meteorological stations will be in operation for a minimum of two years.

The resultant phreatophyte evapotranspiration will be compared to phreatophyte evapotranspiration calculated using the phreatophyte evapotranspiration coefficients and reference ET currently used by LCRAS. The results of this comparison will be used to evaluate potential adjustments to the evapotranspiration coefficients currently in use.

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 and calculated terms used by the water balance for each reach. For example, a bias might be inferred if the residual in a reach is consistently positive or negative over time.

Table 10 displays the water-balance residuals for each of the reaches used by LCRAS for calendar years 1995 through 2000.

Table 10 — Residuals By Reach And By Year

(Units: annual acre-feet)

	Hoover Dam to Davis Dam		Davis Dam to Parker Dam		Parker Dam to Imperial Dam		Imperial Dam to Mexico		Hoover Dam to Mexico	
Year	Acre-Feet	% of Q_{us}	Acre-Feet	% of Q_{us}	Acre-Feet	% of Q_{us}	Acre-Feet	% of Q_{us}	Acre-Feet	% of Q_{us}
1995	125,815	1.47%	-376,267	-4.52%	-180,481	-2.69%	106,064	1.89%	-324,869	-3.80%
1996	-62,469	-0.63%	-198,208	-2.00%	14,051	0.19%	142,625	2.34%	-104,001	-1.04%
1997	-94,144	-0.81%	-6,429	-0.06%	-43,780	-0.52%	98,706	1.34%	-45,647	-0.39%
1998	-114,548	-0.90%	-81,568	-0.63%	175,118	1.69%	31,365	0.34%	10,367	0.08%
1999	-223,980	-2.03%	-169,837	-1.53%	35,137	0.42%	-2,522	-0.04%	-361,202	-3.27%
2000	-178,133	-1.67%	-265,510	-2.48%	226,712	2.87%	102,702	1.57%	-114,229	-1.07%
Average	-91,243	-0.76%	-182,970	-1.87%	37,793	0.33%	79,823	1.24%	-156,597	-1.58%

Identifiable Patterns In Adjustments to Flows at the Reach Boundaries

The pattern, or change, in the adjustments to the flows at the reach boundaries over time may assist with understanding the potential for bias in the gaged flows. For example, a bias might be inferred if the adjusted flow at a reach boundary is consistently positive or negative over time.

Table 11 displays the adjustments to the gaged flows at the reach boundaries for calendar years 1996 through 2000 (the technique currently used to adjust the gaged flows at the reach boundaries was not in use when the 1995 LCRAS Demonstration of Technology report was issued).

Table 11 — Adjustments to Flows at the Reach Boundaries

(Units: annual acre-feet)

Year	Below Hoover Dam		Below Davis Dam		Below Parker Dam		At Imperial Dam		Flow to Mexico	
	Acre-Feet	%	Acre-Feet	%	Acre-Feet	%	Acre-Feet	%	Acre-Feet	%
1996	142,602	1.43%	80,192	0.81%	-110,991	-1.52%	-97,677	-1.60%	-14,130	-0.89%
1997	82,301	0.71%	-11,794	-0.10%	-18,031	-0.21%	-60,165	-0.81%	7,638	0.26%
1998	65,611	0.51%	-48,872	-0.38%	-128,965	-1.24%	41,721	0.46%	70,501	1.47%
1999	264,618	2.40%	40,851	0.37%	-123,599	-1.48%	-89,845	-1.25%	-92,026	-3.09%
2000	192,165	1.80%	14,215	0.13%	-241,391	-3.06%	-25,284	-0.39%	60,293	2.84%
Average	149,459	1.37%	14,918	0.17%	-124,595	-1.50%	-46,250	-0.72%	6,455	0.12%

Phreatophyte Water Use

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

Reclamation has undertaken a series of meetings in an effort to develop consensus on the framework for a solution to this question. Reclamation has opened this discussion to other Interior agencies, State water agencies, and Indian Reservations along the lower Colorado River. This issue remains unresolved and is left open in this report.

Chapter 4

Conclusion and Future Activities

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

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

1. Reclamation plans to implement LCRAS upon the resolution of the question concerning the amount, if any, of the phreatophyte water use that should be included in the calculation of consumptive use for diverters. The resolution of this question was initially projected to be available in time to implement LCRAS for calendar year 2000. This question however, remains unresolved. Reclamation will use the current decree accounting report methods to develop the official decree accounting report until LCRAS is implemented.

2. Reclamation will continue to produce the LCRAS Demonstration of Technology reports in parallel with the current decree accounting report for calendar year 2001 and future years until the question above is resolved. The purpose of this exercise is to compare the results of the two methods and to acquaint the users of the decree accounting report with LCRAS.

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Attachment 1

Colorado River History and Legal Framework

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

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

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

Colorado River Compact

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

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

Boulder Canyon Project Act of 1928

This act accomplished the following:

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

Mexican Water Treaty of 1944

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

Arizona v. *California* Supreme Court Decision and Decree

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

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

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

1968 Colorado River Basin Project Act

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

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

Attachment 2

Measured and Unmeasured Flows for Each Reach

Measured Flows

Reach	Description	Flow in acre-feet	Station Number
Hoover Dam to Davis Dam			
	Colorado River below Hoover Dam	10,692,000	09421500
	Change in storage, Lake Mohave [A]	20,200	09422500
Davis Dam to Parker Dam			
	Colorado River below Davis Dam	10,716,200	09423000
	Colorado River Aqueduct [B]	1,300,014	09424150
	Bill Williams River below Alamo Dam	16,960	09426000
	Central Arizona Project Canal [B]	1,424,158	09426650
	Change in storage, Lake Havasu [A]	1,000	09427500
Parker Dam to Imperial Dam			
	Colorado River below Parker Dam	7,895,700	09427520
	Change in storage, Senator Wash [A]	1,003	
	Colorado River at Imperial Dam	6,527,141	09429490
Imperial Dam to Mexico			
	Diversion to Mittry Lake	10,444	09522400
	All-American Canal (Station 60)	5,268,800	09523000
	All-American Canal below Pilot Knob	3,450,600	09527500
	Gila Gravity Main Canal (Station 60) [C]	834,627	09522500
	Wellton-Mohawk Canal [C]	402,651	09522700
	Colorado River below Imperial Dam	413,270	09429500
	Gila River near Dome	6,557	09520500
	Colorado River at NIB [D]	1,898,700	09522000
	Eleven Mile wasteway [D]	6,476	09525000
	Cooper wasteway [D]	820	09531850
	Twenty-one Mile wasteway [D]	1,367	09533000
	Main drain + 242 wells [D]	115,443	09534000
	West Main Canal wasteway [D]	8,974	09534300
	East Main Canal wasteway [D]	5,218	09534500

A. Geological Survey - December 1999 minus December 2000.
B. Provided by the user and published by the Geological Survey.
C. Bureau of Reclamation open-channel acoustic velocity meter data.
D. Provided by International Boundary and Water Commission on a monthly basis.

Unmeasured Tributary Inflow Estimates

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

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

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

Attachment 3

Results in Tabular and Graphical Form

Units: annual acre-feet

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS			**Decree Accounting Report**	
Nevada				
Lake Mead National Recreation Area, NV.	319	0	278	Lake Mead National Recreation Area, diversion from Lake Mohave (Cottonwood). Reported as a diversion.
Cottonwood Cove (domestic consumptive use).	0	167		
Southern California Edison (domestic consumptive use).	0	13,401	13,402	Southern Nevada Water Authority (Southern California Edison), pumped from Sec 24 T32S R66E. Diversion = consumptive use.
Big Bend Water District (domestic consumptive use).	0	2,168	2,168	Big Bend Water District Diversion Sec 12 T32S R66E. Reported as a consumptive use.
Sportsman's Park.	0	0	0.1	Sportsman's Park.
Boy Scouts (domestic consumptive use).	0	1	1	Boy Scouts of America. Reported as a diversion.
Total Fort Mojave Indian Reservation, NV	8,240	3,333	6,448	Fort Mohave Indian Reservation (Avi), Hotel and Golf Course, 2 wells, sections 27 & 5. Reported as a diversion.
Fort Mojave Indian Reservation, NV.	8,240	2,141		
Fort Mojave Indian Reservation, NV (Avi) (domestic consumptive use).	0	1,192		
State of Nevada[A].	11,979	0		Not reported.
Subtotal: Uses below Hoover Dam.	20,538	19,070	22,297	Subtotal: Uses below Hoover Dam.
Uses above Hoover Dam [B].		299,687	299,687	Uses above Hoover Dam.
			2,128	Unmeasured return flow credit to Nevada.
Nevada Totals.	20,538	318,757	319,856	Nevada Total[C].

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

[B] From the 2000 decree accounting report.

[C] May include some unquantified amount of phreatophyte water use.

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS			**Decree Accounting Report**	
California				
Total, Fort Mojave Indian Reservation, CA.	4,737	13,315	23,303	Fort Mohave Indian Reservation, delivered by City of Needles, and pumped from river and wells. Reported as a diversion.
Fort Mohave Indian Reservation Agriculture	4,737	13,279		
Fort Mohave Indian Reservation domestic use		36		
Needles (domestic consumptive use).		824	826	City of Needles, Pumped from river and wells. Reported as a consumptive use.
Havasu Water Company.		36	60	Havasu Water Company. 1 well, T5N/R25E Sec31.
Metropolitan Water District of Southern California (Colorado River Aqueduct export).		1,295,792	1,300,014	Metropolitan Water District, diversion from Lake Havasu. Reported as a consumptive use.
Parker Dam and Government Camp (domestic consumptive use).		195	195	Parker Dam and Government Camp, diversion at Parker Dam. Reported as a consumptive use.
Total Colorado River Indian Reservation, CA[D].	36,712	614	26,808	Colorado River Indian Reservation, pumped from 11 pumps and wells, 4 pumps Big River. Reported as a diversion[E].
Colorado River Indian Reservation, CA.	35,374	0		
North Lyn-De Farm, CA[F].	2	4		
South Lyn-De Farm, CA.	3	0		
Bernal Farm, CA.	1,195	0		
Clark Farm, CA.	138	610		
Total Chemehuevi Indian Reservation, CA.	51	265	342	Chemehuevi Indian Reservation, pumped from river and wells (Reported as a diversion).
Chemehuevi Indian Reservation, CA.	51	217		
Chemehuevi Indian Reservation, CA. (domestic use).		48		
Park Moabi, CA.	272	0		Not Reported.

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

[E] 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.

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

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Havasu National Wildlife Refuge, CA.	6,174	0		Not reported.
Total BLM Permittees (Lake Havasu and Yuma Field offices)	0	334	557	
BLM-Black Meadow (Domestic Consumptive Use)		114		
BLM Permittees (Lake Havasu Field Office and Yuma Field Office), CA.		220		
Total Palo Verde Irrigation District, CA.	8,794	401,852	511,947	Palo Verde Irrigation District, diversion from Palo Verde Dam. Reported as a consumptive use.
Palo Verde Irrigation District, CA.	8,232	399,413		
Palo Verde Irrigation District, AZ.	562	651		
Blythe (city, domestic consumptive use).		1,702		
Ripley (domestic consumptive use).		53		
Palo Verde (domestic consumptive use).		33		
Cibola National Wildlife Refuge, CA.	18,494	0		
Imperial National Wildlife Refuge, CA.	19,461	0		Not reported.
Fort Yuma Indian Reservation and Picacho State Recreation Area, CA.	5	0		
Total Picacho State Recreation Area, CA.	4,595	0		Not reported.
Picacho State Recreation Area (Parker to Imperial)	4,475	0		
Picacho State Recreation Area (Imperial to Mexico)	120	0		

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use		Diverter Name
LCRAS			**Decree Accounting Report**		
All-American Canal below Pilot Knob[G].		3,465,305	3,260,618		Sum of IID and CVWD
				2,931,251	Imperial Irrigation District, diversion at Imperial Dam.
				329,367	Coachella Valley Water District, diversion at Imperial Dam.
					Reported as consumptive uses.
Earp (domestic consumptive use).		133			Not reported.
Vidal (domestic consumptive use).		5			Not reported.
Big River (domestic consumptive use).		177			Not reported.
Southern California Gas (domestic consumptive use).		47	78		Southern California Gas (2 wells). Reported as a diversion.
Pacific Gas & Electric		0	0		Pacific Gas & Electric
Imperial National Wildlife Refuge and Yuma Proving Ground, CA.	48	0			Not reported.
Yuma Proving Ground, CA.	8,353	30			Not reported.
Fort Yuma Indian Reservation and Yuma Proving Ground, CA .	839	0			Not reported.

[G] Final estimate of export at USGS gauge number 09527500.

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Total Fort Yuma Indian Reservation, CA.	13,874	42,636	45,246	Total Fort Yuma Indian Reservation, CA
Fort Yuma Indian Reservation, Indian Unit, CA.	498	16,138	40,725	
			29,582	Yuma Projects, Res. Div., Indian Unit, div. at Imp. Dam (consumptive use).
Fort Yuma Indian Reservation, Bard Unit, CA.	822	22,245	50,076	
Bard (domestic consumptive use).		215	38,933	
Winterhaven (domestic consumptive use).		74	124	Total Winterhaven (diversion).
			124	
				Town of Winterhaven, 1 well, 6S-22E 27DAA (Not Reported).
Fort Yuma Indian Reservation, CA.	12,554	3,964	480	Valdez, M (diversio
			480	Living Earth Farm, Sec 02 T16S R23E BBC (diversion).
			1,157	
			0	Valdez, Mike, Sec 22 T16S R23E BDD (diversion).
			2,040	
			240	

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Total of Other Users, State Of California[H].	49,584	8,673	15,437	Total of Other State of California
Other Users, State of California (Davis to Parker)	19,504	1,296	0	
Other Users, State of California (Parker to Imperial)	27,637	854	834	Ida Cal, 11N/21E -36ADD.
Other Users, State of California (Imperial to Mexico)	2,443	6,523	468	
				The above Ida Cal wells irrigate lands north of Fort Mohave Irrigation District in CA.
			135	
			600	Harp, P. (R. Harp), (C-8-23) 13AAD.
			4,196	
			225	Horizon Farms, (C-10-22) 7ABD.
			217	
			225	Horizon Farms, (C-10-22) 6DCB.
			225	
			0	Horizon Farms, (C-8-22) 6BCD.
			225	
			338	Horizon Farms, (C-8-23) 1DCC.
			193	
			1,277	Horizon Farms, (C-8-22) 6CBA.
			59	
				Ed Weavers Farms, (C-8-22) 6BCD (Not Reported).
			217	
			316	Ed Weavers Farms, (C-8-23) 1BAD.
			1,828	Horizon Farms (C-8-23) 12AAC
			0	
			0	Valdez, Mike, Sec T16S R23E SEC 30 ADD.
			1,362	
			180	Harp, Robert, (C-8-23) 12 DAC.

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

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS			**Decree Accounting Report**	
			2,265	
			43	Wilson Farms, (C-8-23) 12 BBA.
			0	
				Wells below have not been located, but are presumed to be within the State of CA polygons.
			5	
			1	Williams, Jerry.
			3	
			100,530	Unmeasured return flow credit to California.

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

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS			**Decree Accounting Report**	
Arizona				
Total Lake Mead National Recreation Area, AZ.	1,115	561	944	Lake Mead National Recreation Area, AZ, Diversions from Lake Mohave, (Katherine, Willow Beach). Reported as a diversion.
Lake Mead National Recreation Area, AZ (Hoover Dam to Davis Dam).	726	0		
Lake Mead National Recreation Area, AZ (Davis Dam to Parker Dam).	389	0		
Katherine Landing and Willow Beach (domestic consumptive use).		561		
Lower Colorado Region Dams Project (domestic consumptive use).		0.3	26	
Bullhead City (domestic consumptive use).		4,876	8,007	Bullhead City, Pumped from wells. Reported as a diversion.
Mohave County Parks (domestic consumptive use).		74	122	
Arizona State Parks (Windsor Beach)		12	18	Arizona State Parks (Windsor Beach).
Total Mohave Valley Irrigation and Drainage District	34,480	25,754	37,432	
MVIDD (domestic consumptive use)[J].		2,788	37,432	Mohave Valley Irrigation and Drainage District, Pumped from wells. Reported as a diversion.
Mohave Valley Irrigation and Drainage District, AZ (includes no domestic use).	34,480	22,966		
Fort Mojave Indian Reservation, AZ.	34,151	37,819	65,883	Total: Fort Mohave Indian Reservation.
			65,871	
			12	Delivered by City of Needles
Golden Shores (domestic consumptive use).		328	547	Golden Shor wells. Repor
Topock (domestic consumptive use).		126		Not reported.

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

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Crystal Beach Water Conservation District		54	90	
Havasu Water Company, AZ (domestic consumptive use).		391	651	
Mohave Water Conservation District (domestic consumptive use).		417	694	Mohave Water Conservation District; pumped from wells. Reported as a diversion.
Brook Water (domestic consumptive use).		249	416	
Havasu National Wildlife Refuge, AZ[K].	51,022	405	36,894	Havasu National Wildlife Refuge, Inlet-NW NE NW Sec 33 T9N RSSW, well 8N/23E-15Aa (Topock Marsh). Reported as a consumptive use.
Lake Havasu City & MCWUA, AZ (domestic consumptive use).		8,776	14,630	
Bill Williams National Wildlife Refuge (Lake Havasu).	646	0		Not reported.
Central Arizona Project Canal (export).		1,419,532	1,424,158	
Town of Parker (domestic consumptive use).		563	942	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[L].	3,725	0		
Poston (domestic consumptive use).		54		Not reported.
Total, Colorado River Indian Reservation	134,992	337,205	392,306	
Colorado River Indian Reservation, AZ.	134,992	337,138		
CRIR Domestic Use (Delivered by town of Parker)		67		
Ehrenburg Improvement Association (domestic consumptive use).		264	441	Ehrenburg Improvement Association, 1 pump SW Sec 3 T3N R22W G&SRM. Reported as a diversion.

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

[L] May have missed a golf course.

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Ehrenberg Farm, AZ.	1	2,479	5,088	Total Jack Rayner at Ehrenberg Farm
				4,577
				511 Jack Rayner (B-04-22)34 DCC (DCD).
				Reported as diversions.
Arkelian Farms, AZ.	3,199	1,581	2,208	
				2,208 George Arkelian (B-03-22)16 DBD (DAD).
				0
				Reported as (
Total Bureau of Land Management permittees (domestic consumptive use).	0	611	1,122	Bureau of Land Management permittees (LHFO & YFO). Reported as a diversion.
Bureau of Land Management permittees (Davis Dam to Parker Dam).		115		
Bureau of Land Management permittees (Parker Dam to Imperial Dam).		496		
Hillcrest Water Company (domestic consumptive use).		14	23	
Total Yuma Proving Ground.	369	554	923	Yuma Proving Ground, diversion at Imperial Dam, wells X,Y,M. Reported as a consumptive use.
Yuma Proving Ground.	369	0		
Yuma Proving Ground (domestic consumptive use).		554		

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Fort Yuma Indian Reservation and Homesteads, AZ.	3,851	1,373	9,986	Total of wells reported within Fort Yuma Indian Reservation & Homesteads, AZ
				7,958 Dulin, A (C-8-22) 9 CCC.
				468 Dulin, A (C-8-22) 8 DAC.
				0 Glen Curtis Cit (C-8-22) 18 CBD.
				600 Glen Curtis Cit (C-8-22) 18 DDD.
				0 Glen Curtis Cit, (C-8-22) 7 CCD.
				960 Yowelman, R., Sec 17 T08S R22W CBC.
				Reported as diversions.
Martinez Lake (domestic consumptive use).		1		Not reported.
Cibola Valley Irrigation and Drainage District, AZ.[M]	6,227	14,779	30,565	Total: Cibola Valley Irrigation District.
				30,085 Cibola Valley Irrigation District, 3 pumps Sections 20, 21, and 26T1N R23W. Reported as a diversion.
				480 Cibola Sportsman Sec. 31, T1S, R23W, CCB
Cibola National Wildlife Refuge, AZ.	46,214	6,671		nal Wildlife Refuge, 5 pumps, Section 2 and W. Reported as a diversion.
Total Imperial National Wildlife Refuge, AZ.	32,163	113	9,000	Imperial National Wildlife Refuge, 2 wells, Sec 13 T5S R22W G&SRM. Reported as a diversion.
Imperial Wildlife Refuge (Parker to Imperial Reach)	26,494	0		
Imperial Wildlife Refuge (Imperial to Mexico Reach)	5,669	113		
Mittry Lake State Wildlife Area, AZ.	10,074	183		Pumper L. Pratt Sec 14 T7S R22W ABC.
Sturges Gila Monster Ranch, AZ.	49	6,069	10,798	Sturges, diversions at Imperial Dam (Warren Act). Reported as a consumptive use.
City of Yuma (domestic consumptive use).		16,001		City of Yuma, diversion at Imperial Dam (All-American Canal), diversion at Imperial Dam (Gila). Reported as a consumptive use.
Marine Corps Air Station [N] (domestic consumptive use).		1,217	2,030	Marine Corps Air Station (Yuma), diversion at Imperial Dam. Reported as a diversion.

[M] Part of the district is located on the California side of the river.

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

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
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	
Total University of Arizona Agricultural Station.	0	269	950	University of Arizona, diversion at Imperial Dam (Warren Act). Reported as a diversion.
University of Arizona Agricultural Station Crop CU & Phreatophyte water use.	0	269		
Underflow to Mexico from the application of water by the U. of A.[O]	0			
Yuma Union High School (domestic consumptive use).		127	211	
Desert Lawn Memorial.	0	396	447	Desert Lawn Memorial, diversion at Imperial Dam. Reported as a diversion.
North Gila Valley Irrigation District, AZ.	833	18,127	21,060	
Yuma Irrigation District, AZ.	306	30,017	53,121	Total for Yuma Irrigation and Drainage District
			52,729	
			347	Cameron Bros Sec 24 T08S R22W CCB.
			33	
			12	Judd T. Ott Sec 30 T08S R22W BAB.
				Individual wells are reported as diversions.

[O] The portion of the underflow to Mexico across the Southerly International Boundary presumed to result from the application of water within the service area of the University of Arizona; presumed to be negligible and is considered to be zero in this report.

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS			**Decree Accounting Report**	
Total for Yuma Mesa Irrigation and Drainage District, AZ	0	132,030	179,139	Yuma Mesa Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use[P].
Yuma Mesa Irrigation and Drainage District, AZ.	0	69,531		
Underflow to Mexico[Q].		35,242		
State of AZ-Down Gradient from YMIDD (Consumptive use by down gradient users[R]).	0	22,270		
Hillander "C" Irrigation District, AZ .	0	4,975		
State Prison (domestic consumptive use).		12		

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

[Q] See, "Distribution of Underflow To Mexico To Water Users Below The Northerly International Boundary," below.

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

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS			**Decree Accounting Report**	
Total Yuma County Water Users Association, AZ.	4,165	180,258	185,106	Total Yuma County Water Users Association
Yuma County Water Users Association, AZ.	18	126,035	178,526	Yuma County Water Users Association, diversion at Imperial Dam and pumped from wells[S].
Underflow to Mexico[T].		48,189	300	Burrell, Sec 33 T08S R24W BAB.
State of Arizona - Limitrophe Section.	4,147	2,739	299	Farmland Management Sec 19 T09S R24W BAD.
City of Somerton (domestic use).		1,017	264	Farmland Management, Sec19 T09S R24W BDD.
City of Gadsden (domestic use).		133	64	Farmland Management, Sec19 T09S R24W BDA
City of San Luis (domestic use).		2,145	842	Waymon Farms, Sec 36 T09S R24W AAA.
			1,178	Waymon Farms Sec 31 T09S R24W BBB.
			1,106	J.W. Cumings, (C-10-25) 1BBA.
				State of Arizona Limitrophe Section:
			597	J.W. Cumings (C-10-25), 14ADB.
			480	C & J Cummings, (C-10-25) 26BAB.
			480	J. Barkley, (C-10-25) 25CBA.
			600	Brown, Rodger S., (C-11-25) 2BBA.
			370	Earl Huges, (C-11-25) 3DAC.

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

[T] See, "Distribution of Underflow To Mexico To Water Users Below The Northerly International Boundary," below.

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Total Unit B Irrigation and Drainage District, AZ.	0	9,854	21,665	Total Unit “B” Irrigation and Drainage District
Unit B Irrigation and Drainage District, AZ.	0	7,604	21,565	Unit "B" Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use[U].
Underflow to Mexico[V].		2,250	100	Camille, Alec, Jr., diversion at Imperial Dam (Warren Act). Reported as a diversion. (Located with Unit B’s contract service area)
Yuma Area Office, Bureau of Reclamation (Domestic consumptive use).		968	968	Yuma Area Office, USBR diversion from Well No.8. Reported as a consumptive use.
Yucca Power Plant [W](domestic consumptive use).		77	587	Yucca Power Plant. Sec 36 T16S R21E CBA. Reported as a diversion.
Yuma County (domestic consumptive use).		7,779		Not reported.

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

[V] See, “Distribution of Underflow To Mexico To Water Users Below The Northerly International Boundary,” below.

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

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Total Cocopah Indian Reservation	6,713	6,844	16,941	Total Cocopah Indian Reservation
Subtotal, West Cocopah Indian Reservation, AZ.	5,993	5,961	14,622	
West Cocopah Indian Reservation, AZ.	5,993	5,335	12,061	Cocopah Indian Reservation, diversion at Imperial Dam. Pumped from wells, West Cocopah
Underflow to Mexico[X].		626	630	
			1,950	P. Sibley, (C-10-25) 2CDA.
Subtotal, North Cocopah Indian Reservation, AZ.	720	739	2,319	Subtotal, North Cocopah Indian Reservation
North Cocopah Indian Reservation, AZ.	720	535	779	
Cocopah Bend RV (domestic consumptive use)[Y].		204	1,200	Huerta Packing 16S/21E-25DAA.
			340	
				Reported as diversions.

[X] See, “Distribution of Underflow To Mexico To Water Users Below The Northerly International Boundary,” below.

[Y] Located within North Cocopah Indian Reservation.

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS			**Decree Accounting Report**	
Total of Other Users, State of Arizona[z].	34,318	8,739	21,864	Total Other State of Arizona
Other Users, State of Arizona (Davis to Parker)	4,163	0	432	
Other Users, State of Arizona (Parker to Imperial)	20,158	0	121	Amigo Farms (Sec 28 T16S R22E CDA.
Other Users, State of Arizona (Imperial to Mexico)	9,997	8,739	286	
			2,850	R.E. & P. Power (Sec 29 T16S R22E BCC
			687	
			0	Ogram, George, Sec23 T08S R23W CDA (Indeterminate location)
			610	
			1	Arizona State Parks, Lake Havasu S.P.
			10,155	
			572	Ott, Judd T., (C-8-22) 19CCA
			300	
			4,941	Glen Curtis Cit (C-8-22) 24BDD
			909	
				Reported as diversions.

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

Diverter Name	Phreatophyte Water Use	Crop, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Arizona Subtotal (Below Hoover Dam, less Wellton-Mohawk Irrigation and Drainage District).	409,470	2,284,651	2,596,387	Arizona Subtotal (Below Hoover Dam, less Wellton-Mohawk Irrigation and Drainage District).
				Pumped from South Gila Wells (drainage pump outlet channels): Returns.
Arizona uses above Hoover Dam[AA].		132	132	Arizona uses above Hoover Dam.
			111	Lake Mead Nat'l Recreation, AZ. Diversions from Lake Mead (Temple Bar).
			21	Marble Canyon Company.
Wellton-Mohawk Irrigation and Drainage District [AA].		275,747		awk Irrigation and Drainage District.
			169,244	Unmeasured return flow credit to Arizona.
Arizona Totals.	409,470	2,560,530		Arizona Total[BB].
Lower Basin Totals.	602,001	8,109,540	8,038,289	Total Lower Basin Use[BB].

[AA] From the 2000 decree accounting report.

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

Distribution of Underflow to Mexico To Water Users Below The Northerly International Boundary With Mexico

Underflow to Mexico resulting from the application of Colorado River water diverted from the mainstream, either directly as a surface diversion or through underground pumping, must be added to the crop, domestic, and other water uses calculated to take place within a water user's contract service area. Underflow to Mexico resulting from the application of Colorado River water must be considered consumptive use because it is not available for consumptive use in the United States or for satisfaction of the Mexican treaty obligation.

The following worksheet calculates,

1. the final estimate of underflow to Mexico across the Southerly International Boundary (SIB) and the Limitrophe Section based upon,

   A. the adjustment to the flow to Mexico from table 6 in Chapter 2, above,
   B. the distributed value of underflow to Mexico from Sheet A of the Imperial Dam to Mexico water balance table and,
   C. the assumption that the ratio of the final estimates of underflow across the SIB and the Limitrophe Section is the same as the ratio of the initial estimates of these underflows and,

2. the distribution of the underflow to Mexico as consumptive use to water users below the Northerly International Boundary (NIB).

The blue colored cells are entered data. All other values are calculated by the worksheet.

Worksheet: Distribution of Underflow to Mexico To Water Users Below The Northerly International Boundary With Mexico			
Initial Estimate of Underflow to Mexico Across SIB (Acre-Feet/Year)		62,443	75.7%
Initial Estimate of Underflow to Mexico Across Limitrophe section (Acre-Feet/Year)		20,000	24.3%
	Initial Estimate of Total Underflow to Mexico	82,443	100%
	Final Estimate of Total Underflow to Mexico	99,054	
Final Estimate of Underflow to Mexico Across SIB (Acre-Feet/Year)		74,984	75.7%
Final Estimate of Underflow to Mexico Across Limitrophe section (Acre-Feet/Year)		24,070	24.3%
	Check Total	99,054	100%

Water User or Source of Underflow	Distribution of Underflow Across SIB to Water Users Below NIB (See Attachment 5)	Amount of Underflow Across SIB Distributed to Water users as Consumptive Use (Acre-Feet)	
Unit B	3.0%	2,250	
YMIDD & Yuma Mesa Canals	47.0%	35,242	
YCWUA & Yuma Valley Canals	33.0%	24,745	
YID	0.0%	0	
River (Mor. - SIB)	10.0%	7,498	
Other Sources	7.0%	5,249	
Total Underflow Across SIB	100.0%	74,984	
Water User	**Acres of Crops (Including Double Cropping)**	**Percentage of Total**	**Amount of Underflow Across Limitrophe Section Distributed to Water users as Consumptive Use**
Yuma County Water Users Association	75,054	97.4%	23,444
West Cocopah Indian Reservation	1,974	2.6%	626
Check Totals	77,028	97%	
Total Underflow - Limitrophe			24,070

Selected Results in Graphical Form

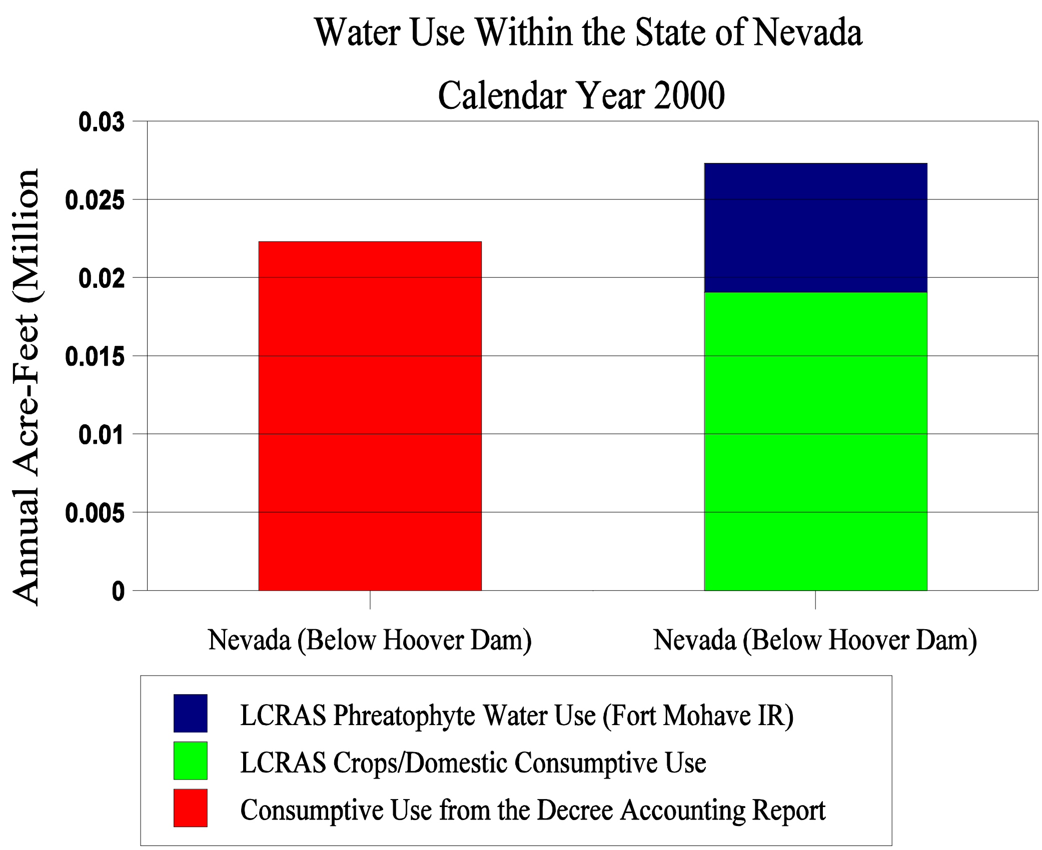
A list of the bar charts included on the following pages and a short interpretation of the information displayed upon them are presented below:

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

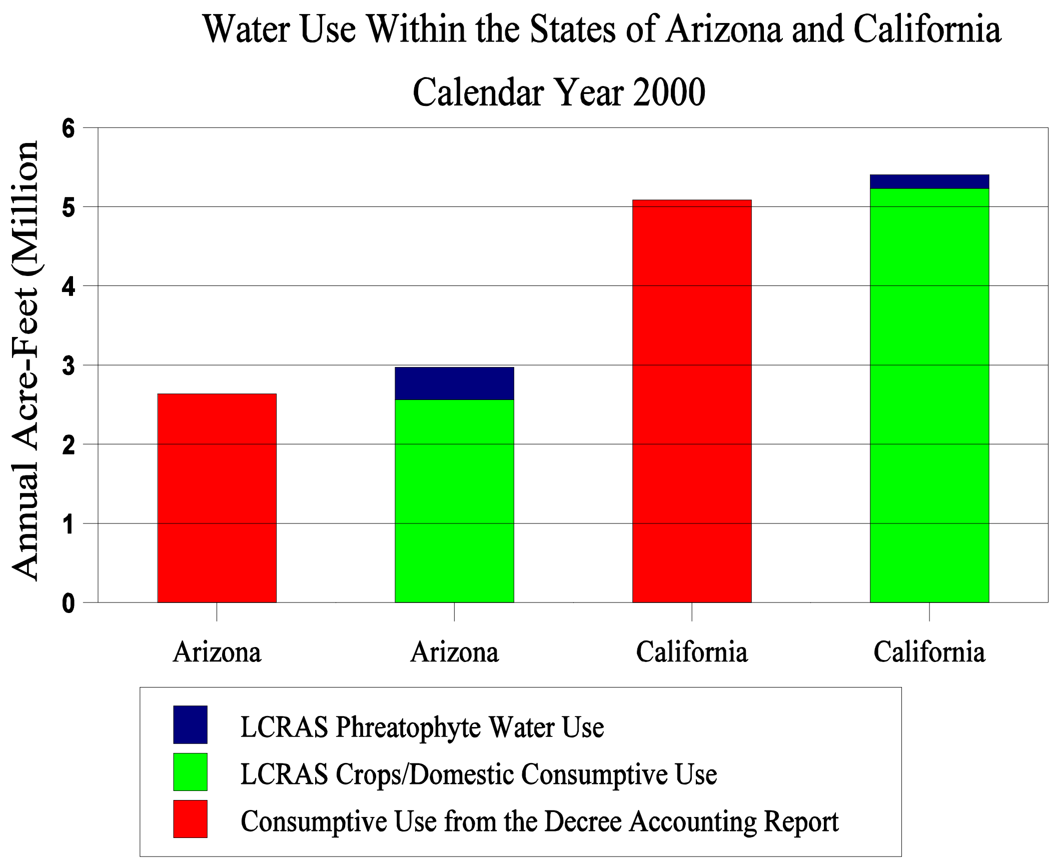
The following bar charts show the consumptive use reported for calendar year 2000 by the decree accounting report, and crop and domestic consumptive uses, and phreatophyte water uses produced by LCRAS for State totals and selected irrigation districts and wildlife refuges. These bar charts highlight the importance of determining the amount of phreatophyte water use, if any, that should be reported as part of a diverter's consumptive use[CC].

The state-total consumptive use values shown from the decree accounting report include unmeasured return flows calculated for diverters within the state, but credited to the state. The consumptive use values shown from the decree accounting report for individual diverters do not include unmeasured return flows calculated for diverters, but reported only as basin and state totals.

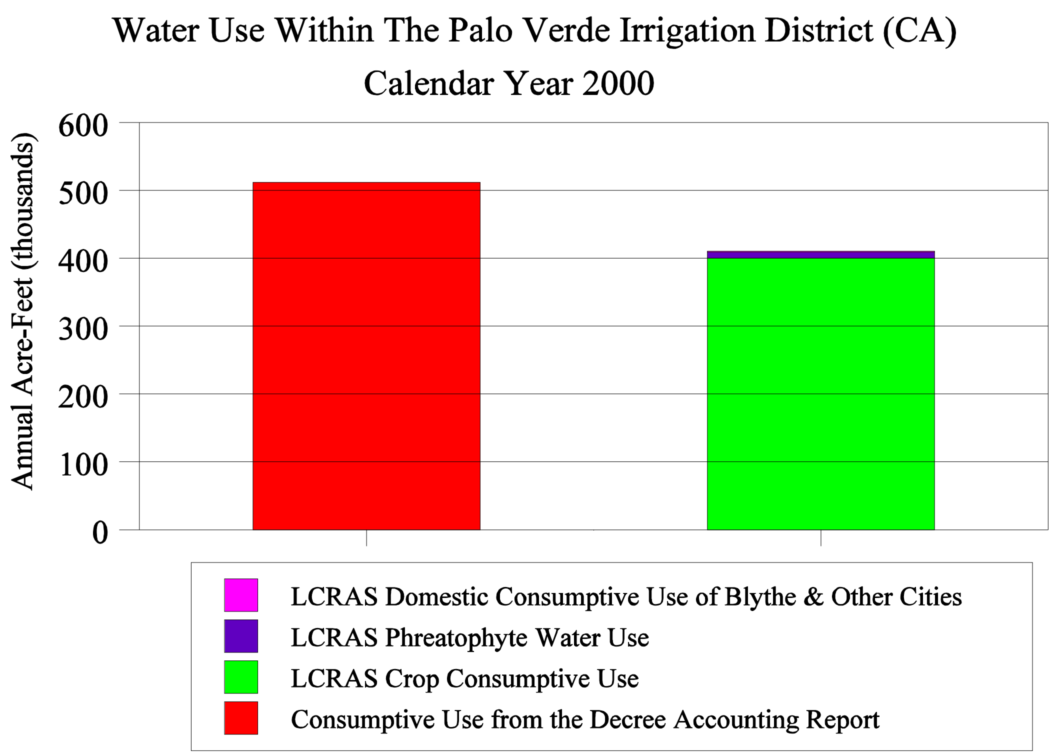
[CC] Consumptive use reported by the decree accounting report currently includes some unquantified amount of phreatophyte water use.



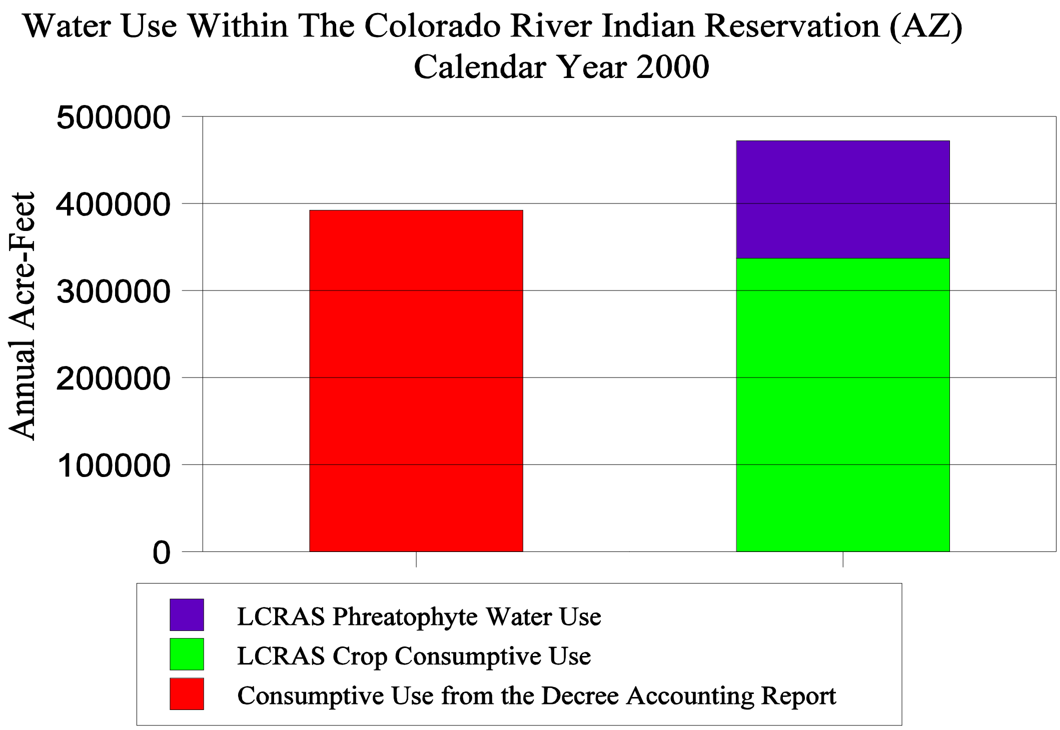
The bar chart above compares the crop and domestic consumptive uses and the phreatophyte water use identified by LCRAS and the consumptive uses reported by the decree accounting report (with estimates of unmeasured return flows from the decree accounting report applied to the Lower Basin as a whole proportioned to Nevada). New for this report, is the presentation of phreatophyte water use identified in irrigated areas in Nevada. The amount of phreatophyte water use, if any, that should be added to the crop and domestic use of a diverter to arrive at a complete picture of consumptive use is unresolved at this time and remains an open question.



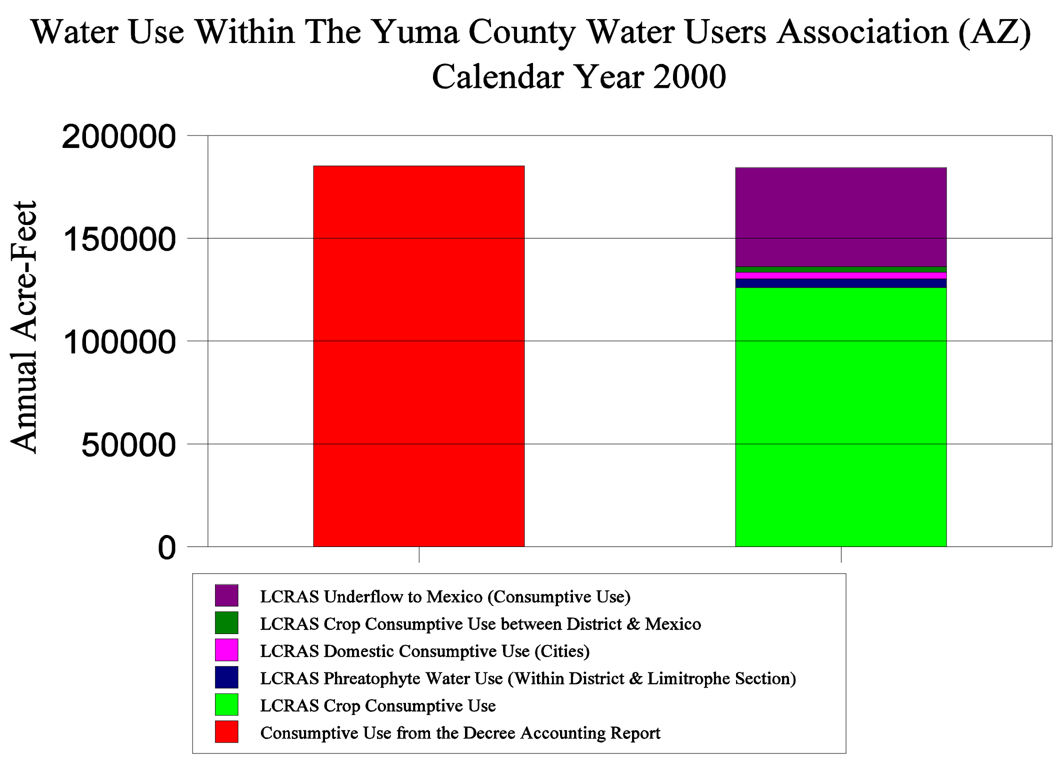
These bar chart above compares the crop and domestic consumptive uses and the phreatophyte water use identified by LCRAS and the consumptive uses reported by the decree accounting report (with estimates of unmeasured return flows from the decree accounting report applied to the Lower Basin as a whole proportioned to Arizona and California). The bar chart above also shows the minor amount of phreatophyte water use on a statewide basis for Arizona and California. The amount of phreatophyte water use, if any, that should be added to the crop and domestic use of a diverter to arrive at a complete picture of consumptive use is unresolved at this time and remains an open question.



The bar chart for the Palo Verde Irrigation District shows the sum of crop and domestic consumptive uses, and phreatophyte water use identified within the Palo Verde Irrigation District compared with the consumptive use reported in the decree accounting report. The consumptive use reported for the Palo Verde Irrigation District in the decree accounting report does not include the estimate of unmeasured return flow from the Palo Verde Irrigation District that is applied to the Lower Basin as a whole.

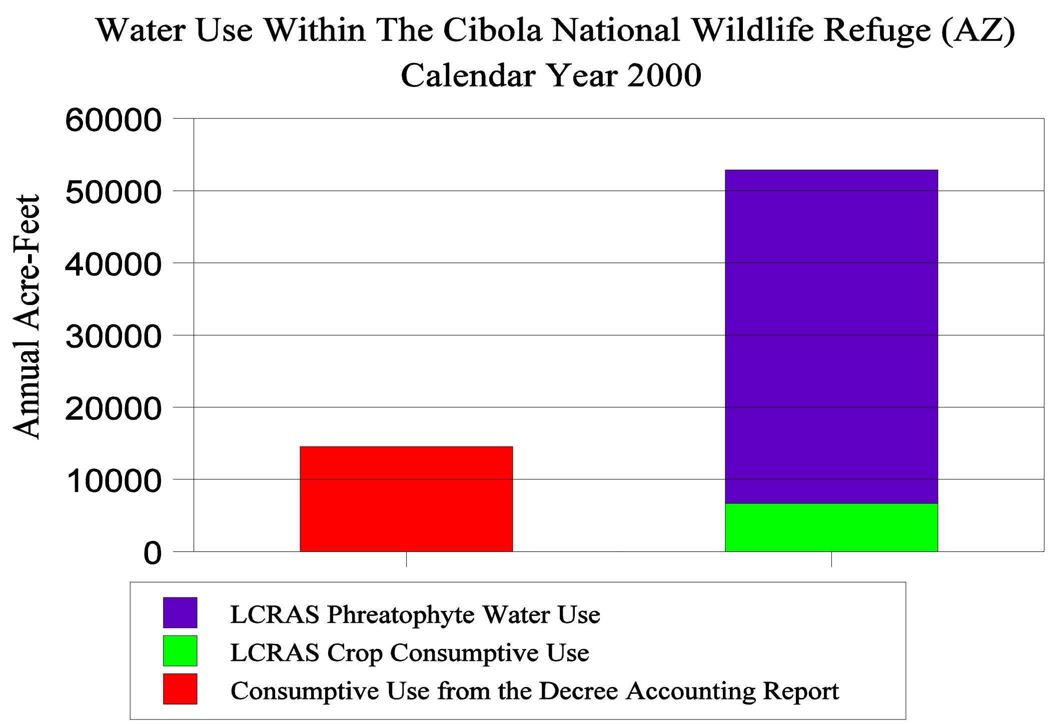


The bar chart for the Colorado River Indian Reservation (AZ) compares the crop consumptive use and phreatophyte water use identified by LCRAS within the Colorado River Indian Reservation with the consumptive use reported in the decree accounting report. The consumptive use reported for the Colorado River Indian Reservation in the decree accounting report does not include the estimate of unmeasured return flow from the Colorado River Indian Reservation that is applied to the Lower Basin as a whole. The domestic consumptive use within CRIR is not included in the LCRAS values shown on the chart.

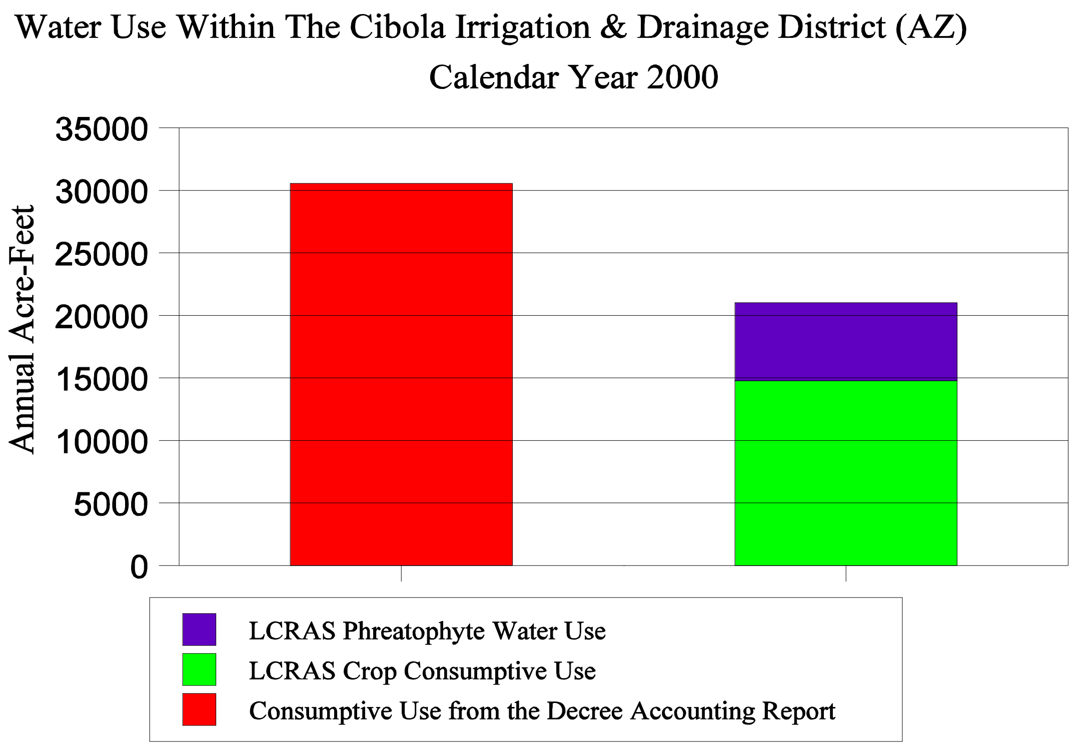


The bar chart for the Yuma County Water Users Association (YCWUA) compares the crop and domestic consumptive uses and the phreatophyte water use identified by LCRAS within the district boundary, plus an estimate of the underflow to Mexico that results from the unconsumed portion of the water applied within the district, plus crop consumptive use and phreatophyte water use between the district boundary and the Mexican border; with the consumptive use reported in the decree accounting report. The consumptive use reported for the YCWUA in the decree accounting report does not include the estimate of unmeasured return flow from the YCWUA that is applied to the Lower Basin as a whole, but does include pumping by wells within the district boundaries reported in the decree accounting report as part of "Other Users Pumping from Colorado River and Wells in Flood Plain Davis Dam to International Boundary."

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



The bar chart for the Cibola National Wildlife Refuge compares the crop consumptive use and phreatophyte water use identified by LCRAS within the Cibola National Wildlife Refuge with the consumptive use reported in the decree accounting report (a diversion with no return flow). The consumptive use value reported for the Cibola National Wildlife Refuge in the decree accounting report does not include the estimate of unmeasured return flow from the Cibola National Wildlife Refuge that is applied to the Lower Basin as a whole. This is another example of LCRAS's ability to identify and quantify phreatophyte water use, and a situation where a determination of the amount of phreatophyte water use that should be included in the consumptive use of a diverter is critical.



The bar chart for the Cibola Irrigation and Drainage District compares the crop consumptive use and phreatophyte water use identified by LCRAS within the Cibola Irrigation and Drainage District with the consumptive use reported in the decree accounting report (a diversion with no return flow). The consumptive use value reported for the Cibola Irrigation and Drainage District in the decree accounting report does not include the estimate of unmeasured return flow from the Cibola Irrigation and Drainage District that is applied to the Lower Basin as a whole. This is another example of LCRAS's ability to identify and quantify phreatophyte water use, and a situation where a determination of the amount of phreatophyte water use that should be included in the consumptive use of a diverter is critical.

Attachment 4

Remote Sensing and GIS Procedures

Overview

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

Field Border Database

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

Changes in field borders, noted during the acquisition of ground reference data throughout the year, have served as a data source for updates to the field-border database since 1995. This process continued for calendar year 2000. Reclamation also uses 5-meter Indian Remote Sensing satellite imagery on an annual basis to update field borders in areas where ground reference data show significant changes in field border locations.

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

Refer to Table 4.1 for metadata on this field-border database. Five field-border databases cover the project area (Figure 4.1). The extent of these field border databases define individual spectral processing areas for the crop classification. Each field in the database has a unique identification number (FIELD-

ID) as well as various other attributes. “CROP-LABEL” contains the crop group assigned by the spectral classification process. “CROP-TYPE” is populated with the name of a specific crop if the field is a ground reference field. Other attributes such as “AVG-HT,” “GROWTH-STAGE,” etc., are populated for ground reference fields. “AA” designates if the field is a ground reference field that has been reserved for accuracy assessment.

Table 4.2 presents a comparison of acreage calculated for fields based on the field border database captured from SPOT image data and acreage calculated using GPS control points. This comparison was made to ensure that acreage values derived from field borders captured from the SPOT satellite data fall within an acceptable degree of error when compared to GPS-generated acreage for the same fields. Total acreage for 30 fields using both methods differed by approximately 0.22 percent.

Table 4.1 — 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	EXTRA-FIELD	2	2	N	-
59	CROP-TYPE	8	8	N	2
67	HEIGHT	4	12	F	2
71	GROWTH-STAGE	2	2	I	-
73	CROP-PCT	3	3	I	-
76	OTHER-PCT	3	3	I	-
79	CONDITION	2	2	I	-
81	MOISTURE	2	2	N	-
83	SIGNATURE	2	2	N	-
85	BORDER-CHANGE	4	4	N	2
89	COMMENTS	80	80	C	-
169	STUDY-AREA	2	2	I	-
171	AA	1	1	I	-
172	ACRES	12	12	N	2

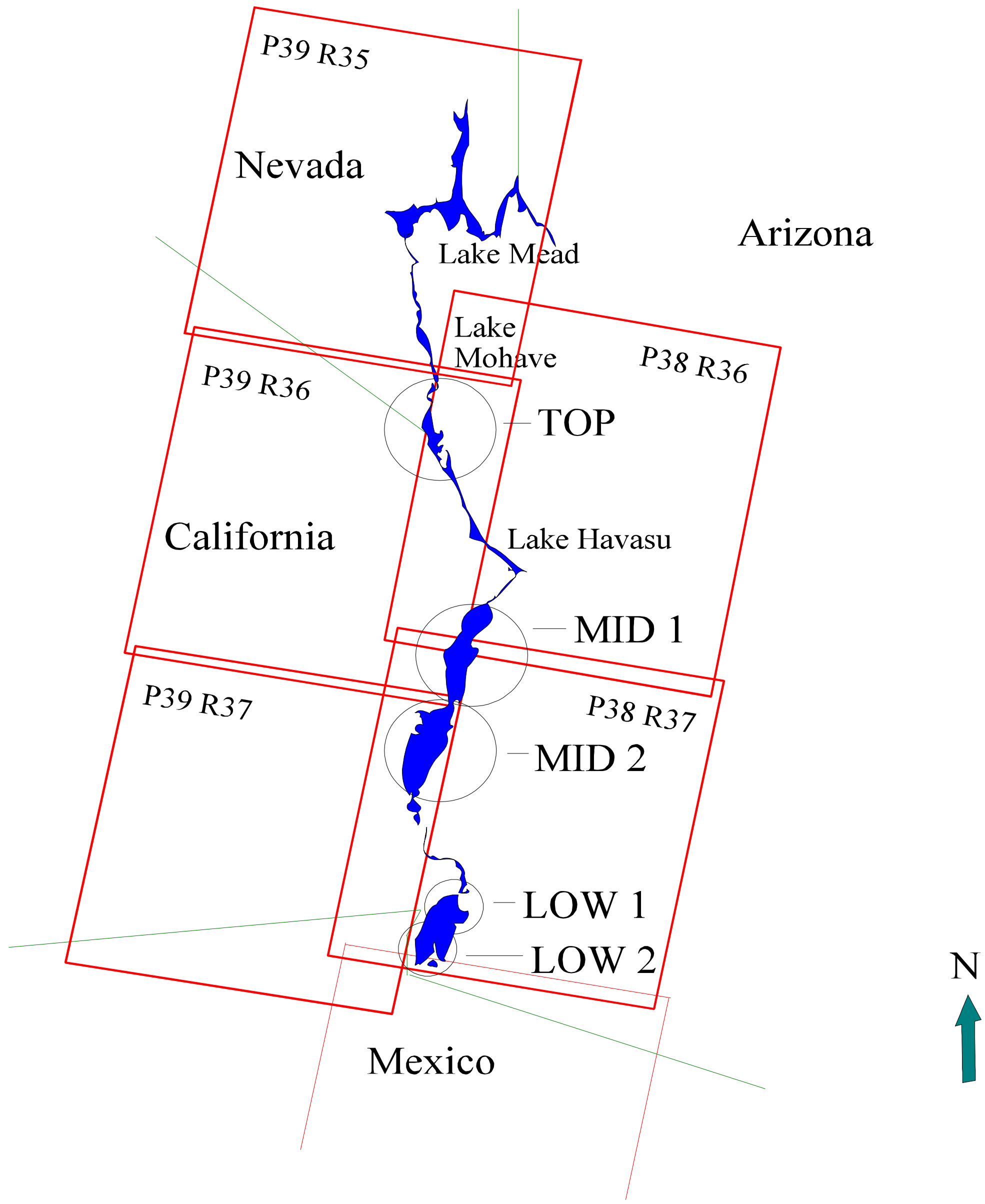


Figure 4.1 — Image Processing Areas and Landsat Scene Boundaries.

Table 4.2 — Field Acreage (SPOT Image Data & GPS Control Points)

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

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

COMMENTS:

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

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

Classification of Irrigated Areas

Introduction

Irrigated areas are classified four times annually with the exception of the 'TOP' processing area (figure 4.1) which is classified twice each year. The number of classifications necessary and the 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 of data for image classification. Note, the successful launch of Landsat 7 in 1999 now provides two satellite platforms for Thematic Mapper Imagery. Alternate sources of imagery (in the case of sensor failure or cloud cover for Landsat TM data) include Indian Remote Sensing (IRS) multi-spectral data, SPOT multi-spectral data, Space Imaging IKONOS multi-spectral data, and Japanese (JERS) LISS-III multi-spectral data. Ground reference data for training the spectral classifier are collected during a 10-day period. This period is chosen based on the Landsat satellite flyover date and crop planting practices.

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

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

Ground Reference Data Collection

Ground reference data are collected four times each year, coinciding with each classification time. Each data collection period takes approximately 8 days over a 10-day period using three ground reference crews. Each ground reference crew consists of a driver and coder (a person who records the data). Ground reference collection periods are chosen to coincide as closely as possible with the Landsat satellite fly-over dates.

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

Each ground reference crew is provided with 7.5 minute quadrangle plots for navigation. Plots have a panchromatic IRS image backdrop, field borders with unique identifiers (id's), and annotation noting road names and other significant navigational features such as locations of canal bridges. Fields to be sampled (ground reference fields) are uniquely colored for ease of identification, and colors indicate the crop that was present during the last ground reference visit, which often helps in identifying crop residue or any significant changes in planting practices. Data are collected with laptop computers using a data collection program written for this project. Table 4.3 lists ground-reference attributes that are collected. Table 4.4 is a complete crop list.

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

Table 4.3 — Ground Reference Attributes

Attribute	Comments
Date	MM/DD/YR
7.5' Geological Survey Quad Name	
Field-ID	Unique ID from field border database (ARC/INFO)
Crop Name	See Table 4.4 for a crop name and group list
Average Height	Inches
Growth Stage	Emergent, pre-bloom, bloom, senescent, harvested, seeded, wind rowed, baled, defoliated
Crop Vegetative Cover	Percent crown closure
Other Vegetative Cover	Percent crown closure if other vegetation > 10% (Crop Vegetative Cover + Other Vegetative Cover = Total Vegetative Cover)
Crop / Field Condition	Good, spotty/weedy, spotty/exposed soil, diseased, stressed, weeds & soil, residue
Moisture	Dry/Semi moist, saturated, ponding
Signature	Yes/No - Desirable as training sample
Border Change	Yes/No - indicating field border update from field observation
Comments	Minor weeds, currently being irrigated/harvested, grazed, etc.

Spectral Classification

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

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

Automated Signature Generation

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

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

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

A number of Landsat band combinations and region-growing spectral and spatial thresholds were tested to determine the best combination for this application. Figure 4.5 shows ground reference fields partitioned into spectral regions.

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

Table 4.4 — Crop Group and Name List used for Calendar Year 2000

Crop Group	Crop Name	Crop Group	Crop Name
Alfalfa	Alfalfa	Fallow	Idle with weeds (green)
Cotton	Cotton		Idle with weeds (senescent)
Small Grain	Oats		Bare Soil (cultivated)
	Rye		Bare Soil (not cultivated)
	Barley		Flooded Fallow
	Millet	Dates	Dates
	Wheat	Safflower	Safflower
Field Grain	Field Corn	Deciduous Orchards	Pecans
	Sorghum		Peaches
	Milo		Other
Lettuce	Head Lettuce	Small Vegetables	Carrots
	Leaf Lettuce (green)		Celantro
	Leaf Lettuce (red)		Celery
	Spinach		Garlic
	Other Lettuce		Onions (dry)
Melons	Watermelon		Onions
	Honeydew		Parsley
	Cantaloupe		Radishes
	Squash		
Bermuda/Rye Grass	Bermuda	Root Vegetables	Beets (table)
	Bermuda Over- Seeded with Rye Grass		Parsnip
	Klein Grass		
	Timothy Grass		
Citrus	Young, 1-2 Meter		Turnip & Rutabaga
	Mature, 2 + Meter	Perennial Vegetables	Artichokes
	Declining		Asparagus
Tomatoes	Tomatoes	Sugar Beets	Sugar Beets (summer)
Sudan	Sudan		Sugar Beets (winter)
Legume/Solanum Vegetables	Beans (green)	Grapes	Grapes
	Beans (dry)	Crucifers	Broccoli
	Beans (Garbanzo)		Cauliflower
	Peas		Cabbage
	Peanuts		Bok-Choy
	Peppers		Mustard
			Kale

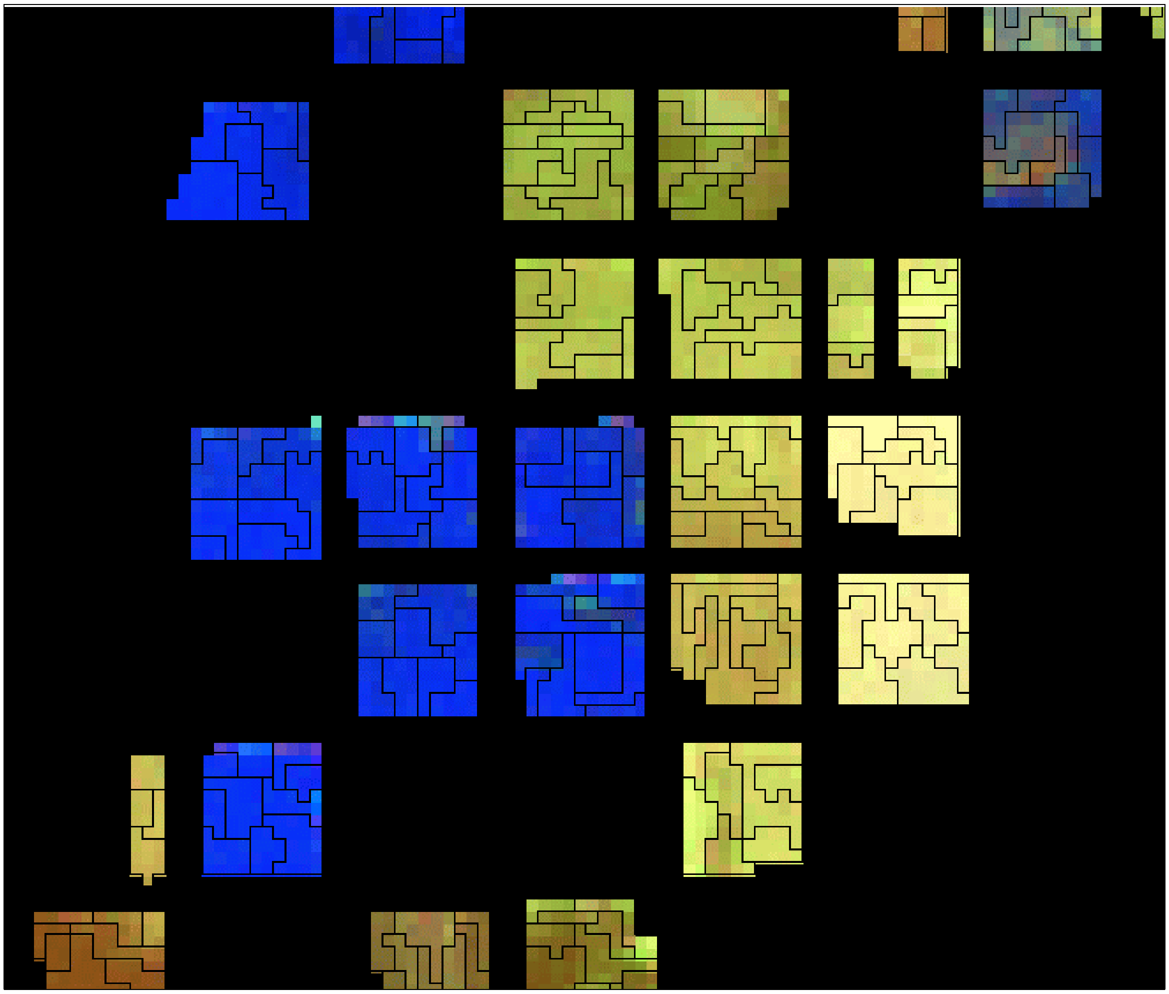


Figure 4.5 — Ground Reference Fields - masked and partitioned into spectral regions for signature generation. Black lines denote spectral regions plotted on Landsat bands 4, 3, 2.

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

Image Classification

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

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

Accuracy Assessment

Accuracy assessment error matrices are generated for all final crop classifications. Errors of omission and commission are reported based on crop group acreage and number of fields correct. For each classification time, about one third of the ground reference fields are reserved as an independent sample for accuracy assessment purposes.

This is a random stratified sample which represents the relative proportions of crop groups being grown at each classification time, as well as the variety of conditions for each crop group. Due to crop rotation practices, some crop groups for a particular classification time are under-sampled with respect to accuracy assessment needs. However, these crop groups generally represent crops that are either grown in such a minor amount that an adequate sample is not possible or are not grown at that particular time of year. In both cases, any error associated with these crop groups typically does not represent significant acreage and therefore has a minor effect on consumptive use (of water) calculations.

Accuracy assessment matrices

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

Tables 4.5, 4.6, 4.7, and 4.8 are accuracy assessment error matrices for each classification time. These error matrices represent the established standard for reporting classification accuracies of maps produced using remotely sensed data (Campbell, 1987; Story and Congalton, 1986). In this case, columns in the matrix represent "truth" derived from ground observation (GROUND REFERENCE FIELDS) and rows represent the label given by the spectral classification process for the same reference fields (MAP LABEL). An error matrix represents the accuracies of each crop group in the map and can be interpreted with respect to both errors of exclusion (omission errors) and errors of inclusion (commission errors). An omission error occurs when an area (in this case an irrigated field) is excluded from the group to which it actually belongs (reported in the columns of the error matrix). A commission error occurs when an area is included into a group to which it does not belong (reported in the rows of the error matrix). Every error of omission from the correct group is also an error of commission to a wrong group.

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

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

Table 4.5 — February 2000 Accuracy Assessment Error Matrix - by Acreage

Ground Reference Fields

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Legume/ Solanum Vegetables	Crucifers	Fallow	Dates	Safflower	Deciduous Orchards	Small Vegetables	Root Vegetables	Perennial Vegetables	**TOTALS**	%correct	% correct with
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		(commission)	fallow
Alfalfa	**1**	**7147.43**		501.87		100.25								72.68				29.58			**7851.81**	91.03%	91.95%
Cotton	**2**		**0**																		**0.00**		
Small Grain	**4**	171.93		**1121.16**		47.28							73.05	17.77				38.12			**1469.31**	76.31%	77.51%
Corn	**5**				**0**																**0.00**		
Lettuce	**6**			83.52		**1241.29**							95.91	26.06				10.14			**1456.92**	85.20%	86.99%
Melons	**7**						**0**														**0.00**		
Bermuda Grass	**8**							**477.93**													**477.93**	100.00%	100.00%
Citrus	**9**								**750**												**750.00**	100.00%	100.00%
Tomatoes	**10**									**0**											**0.00**		
Sudan Grass	**11**										**0**										**0.00**		
Legume/Solanum Vegetables	**12**											**19.25**									**19.25**	100.00%	100.00%
Crucifers	**13**												**389.76**	19.39				11.79			**420.94**	92.59%	97.20%
Fallow	**14**	18.35		218.47		37.18							18.48	**5605.46**				109.62			**6007.56**	93.31%	100.00%
Dates	**15**														**182.57**						**182.57**	100.00%	100.00%
Safflower	**16**															**0**					**0.00**		
Deciduous Orchards	**17**																**18.31**				**18.31**	100.00%	100.00%
Small Vegetables	**18**	52.91																**559.21**			**612.12**	91.36%	91.36%
Root Vegetables	**19**																		**0**		**0.00**		
Perennial Vegetables	**20**																			**0**	**0.00**		
TOTALS		**7390.62**	**0.00**	**1925.02**	**0.00**	**1426.00**	**0.00**	**477.93**	**750.00**	**0.00**	**0.00**	**19.25**	**577.20**	**5741.36**	**182.57**	**0.00**	**18.31**	**758.46**	**0.00**	**0.00**	**19266.72**	Total Samples	
%correct by crop		97%		58%		87%		100%	100%			100%	68%	98%	100%		100%	74%			**17512.37**	Total Correct	
																					91%	**% correct**	
total with fallow correction		7165.78	0.00	1339.63	0.00	1241.29	0.00	477.93	750.00	0.00	0.00	19.25	408.24	5605.46	182.57	0.00	18.31	668.83	0.00	0.00	17877.29		
% correct with fallow correction		97%		70%		87%		100%	100%			100%	71%	98%	100%		100%	88%			**93%**		

Table 4.6 — April 2000 Accuracy Assessment Error Matrix - by Acreage

Ground Reference Fields

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Legume/ Solanum Vegetables	Crucifers	Fallow	Dates	Safflower	Deciduous Orchards	Small Vegetables	Root Vegetables	Perennial Vegetables	TOTALS	%correct	% correct with
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		(commission)	fallow
Alfalfa	**1**	**8418.87**		85.43	8.91		82.51				356.27	49.38		34.75							**9036.12**	93.17%	93.55%
Cotton	**2**		**0**																		**0.00**		
Small Grain	**4**	29.74		**2573.75**	16.04						58.05			10.67		32.07		14.05			**2734.37**	94.13%	94.52%
Corn	**5**				**334.59**		44.79														**379.38**	88.19%	88.19%
Lettuce	**6**					**0**															**0.00**		
Melons	**7**	48.52	92.18	106.47	9.47		**385.82**				49.69	35.69				39.38					**767.22**	50.29%	50.29%
Bermuda Grass	**8**							**600**													**600.00**	100.00%	100.00%
Citrus	**9**								**750**												**750.00**	100.00%	100.00%
Tomatoes	**10**									**0**											**0.00**		
Sudan Grass	**11**	81.03			9.51						**417.41**										**507.95**	82.18%	82.18%
Legume/Solanum Vegetables	**12**			18.71			15.56					**78.73**						5.07			**118.07**	66.68%	66.68%
Crucifers	**13**												**11.31**								**11.31**	100.00%	100.00%
Fallow	**14**	81.66	1162.67	18.85	59.95	15.17	277.11				162.66	96.79	50.45	**5265.08**							**7190.39**	73.22%	100.00%
Dates	**15**														**162.7**						**162.70**	100.00%	100.00%
Safflower	**16**															**0**					**0.00**		
Deciduous Orchards	**17**																**53.85**				**53.85**	100.00%	100.00%
Small Vegetables	**18**																	**480.36**			**480.36**	100.00%	100.00%
Root Vegetables	**19**																		**0**		**0.00**		
Perennial Vegetables	**20**																			**0**	**0.00**		
TOTALS		**8659.82**	**1254.85**	**2803.21**	**438.47**	**15.17**	**805.79**	**600.00**	**750.00**	**0.00**	**1044.08**	**260.59**	**61.76**	**5310.50**	**162.70**	**71.45**	**53.85**	**499.48**	**0.00**	**0.00**	**22791.72**	Total Samples	
%correct by crop		97%	0%	92%	76%	0%	48%	100%	100%		40%	30%	18%	99%	100%	0%	100%	96%			**19532.47**	Total Correct	
																					86%	**% correct**	
total with fallow correction		8500.53	1162.67	2592.60	394.54	0.00	662.93	600.00	750.00	0.00	580.07	175.52	11.31	5265.08	162.70	0.00	53.85	480.36	0.00	0.00	21392.16		
% correct with fallow correction		98%	93%	92%	90%	0%	82%	100%	100%		56%	67%	18%	99%	100%	0%	100%	96%			**94%**		

Table 4.7 — July 2000 Accuracy Assessment Error Matrix - by Acreage

		Ground Reference Fields																					
		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Legume/ Solanum Vegetables	Crucifers	Fallow	Dates	Safflower	Deciduous Orchards	Small Vegetables	Root Vegetables	Perennial Vegetables	**TOTALS**	%correct	% correct with
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		(commission)	fallow
Alfalfa	**1**	**5339.72**	120.63		41.44						474.4	39.1		178.64							**6193.93**	86.21%	89.09%
Cotton	**2**	498.92	**3050.94**									17.98									**3567.84**	85.51%	85.51%
Small Grain	**4**			**0**																	**0.00**		
Corn	**5**		16.93		**308.49**						11.43										**336.85**	91.58%	91.58%
Lettuce	**6**					**0**															**0.00**		
Melons	**7**						**0**														**0.00**		
Bermuda Grass	**8**							**506.19**													**506.19**	100.00%	100.00%
Citrus	**9**								**750**												**750.00**	100.00%	100.00%
Tomatoes	**10**									**0**											**0.00**		
Sudan Grass	**11**	249.68			29.05						**436.15**										**714.88**	61.01%	61.01%
Legume/Solanum Vegetables	**12**	71.2										**0**									**71.20**	0.00%	0.00%
Crucifers	**13**												**0**								**0.00**		
Fallow	**14**	39.55	8.2		41.09						35.66	18.52		**5480.18**							**5623.20**	97.46%	100.00%
Dates	**15**														**182.57**						**182.57**	100.00%	100.00%
Safflower	**16**				43.87											**33.47**					**77.34**	43.28%	43.28%
Deciduous Orchards	**17**																**29.08**				**29.08**	100.00%	100.00%
Small Vegetables	**18**																	**0**			**0.00**		
Root Vegetables	**19**																		**0**		**0.00**		
Perennial Vegetables	**20**																			**0**	**0.00**		
TOTALS		**6199.07**	**3196.70**	**0.00**	**463.94**	**0.00**	**0.00**	**506.19**	**750.00**	**0.00**	**957.64**	**75.60**	**0.00**	**5658.82**	**182.57**	**33.47**	**29.08**	**0.00**	**0.00**	**0.00**	**18053.08**	Total Samples	
%correct by crop		86%	95%		66%			100%	100%		46%	0%		97%	100%	100%	100%				**16116.79**	Total Correct	
																					89%	**% correct**	
total with fallow correction		5379.27	3059.14	0.00	308.49	0.00	0.00	506.19	750.00	0.00	471.81	0.00	0.00	5480.18	182.57	33.47	29.08	0.00	0.00	0.00	16200.20		
% correct with fallow correction		87%	96%		66%			100%	100%		49%	0%		97%	100%	100%	100%				**90%**		

Table 4.8 — December 2000 Accuracy Assessment Error Matrix - by Acreage

		Ground Reference Fields																						
		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Legume/ Solanum Vegetables	Crucifers	Fallow	Dates	Safflower	Deciduous Orchards	Small Vegetables	Root Vegetables	Perennial Vegetables	**TOTALS**	%correct	% correct with
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		(commission)	fallow
Alfalfa	**1**	**5096.39**											36.25	246.62				39.22			**5418.48**	94.06%	98.61%
Cotton	**2**	35.08	**379.66**											183.6							**598.34**	63.45%	94.14%
Small Grain	**4**			**0**																	**0.00**		
Corn	**5**				**0**																**0.00**		
Lettuce	**6**	63.56				**1466.95**							184.4	7.85				35.78			**1758.54**	83.42%	83.87%
Melons	**7**						**0**														**0.00**		
Bermuda Grass	**8**							**343.93**													**343.93**	100.00%	100.00%
Citrus	**9**								**550**												**550.00**	100.00%	100.00%
Tomatoes	**10**									**0**											**0.00**		
Sudan Grass	**11**										**0**										**0.00**		
Legume/Solanum Vegetables	**12**											**0**									**0.00**		
Crucifers	**13**	9.54				16.9							**480.53**					17.67			**524.64**	91.59%	91.59%
Fallow	**14**	142.51	16.81			104.7							26.78	**6291.12**				47.67			**6629.59**	94.89%	100.00%
Dates	**15**														**113.73**						**113.73**	100.00%	100.00%
Safflower	**16**															**0**					**0.00**		
Deciduous Orchards	**17**																**58.25**				**58.25**	100.00%	100.00%
Small Vegetables	**18**												24.74					**0**			**24.74**	0.00%	0.00%
Root Vegetables	**19**																		**0**		**0.00**		
Perennial Vegetables	**20**																			**0**	**0.00**		
TOTALS		**5347.08**	**396.47**	**0.00**	**0.00**	**1588.55**	**0.00**	**343.93**	**550.00**	**0.00**	**0.00**	**0.00**	**752.70**	**6729.19**	**113.73**	**0.00**	**58.25**	**140.34**	**0.00**	**0.00**	**16020.24**	Total Samples	
%correct by crop		95%	96%			92%		100%	100%				64%	93%	100%		100%	0%			**14780.56**	Total Correct	
																					92%	**% correct**	
total with fallow correction		5238.90	396.47	0.00	0.00	1571.65	0.00	343.93	550.00	0.00	0.00	0.00	507.31	6291.12	113.73	0.00	58.25	47.67	0.00	0.00	15119.03		
% correct with fallow correction		98%	100%			99%		100%	100%				67%	93%	100%		100%	34%			**94%**		

Results

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

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

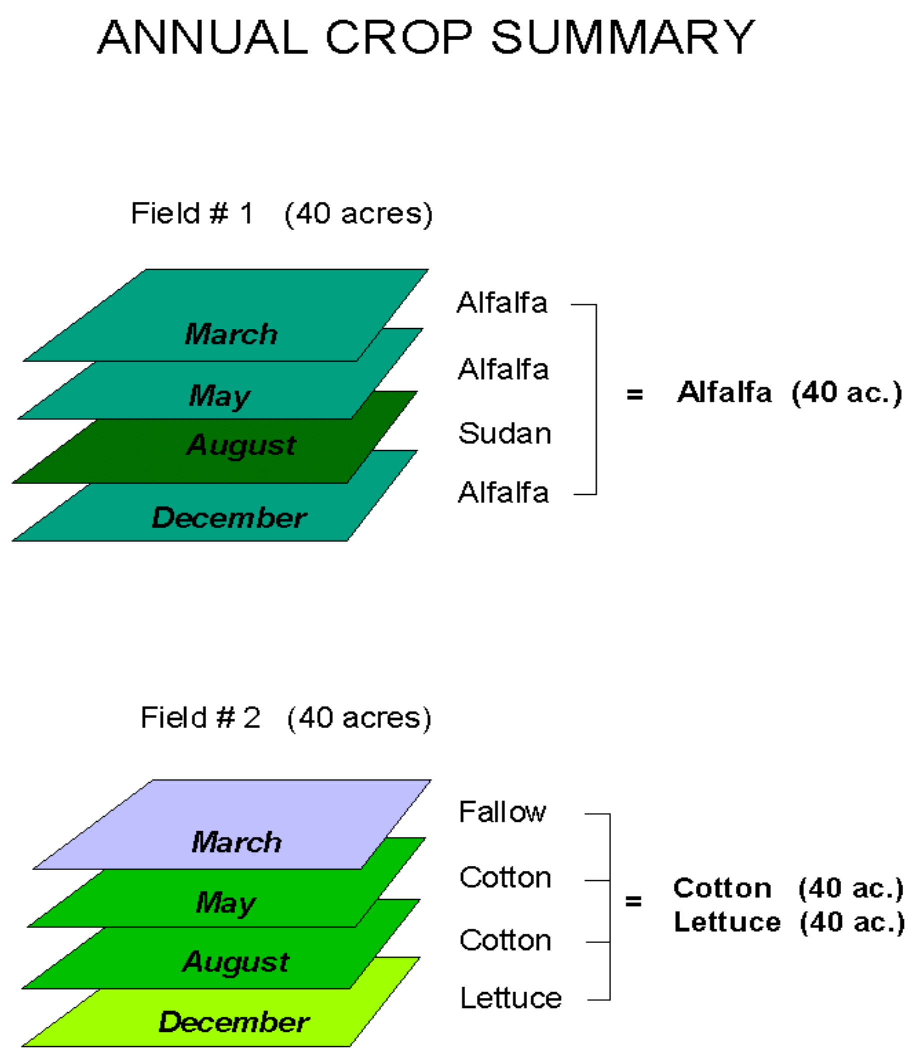
Annual Crop Group Summary

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

A computer program for crop group acreage calculations is used with the "regions" coverage database. This program contains logic that accounts for error indicated in the accuracy assessment data, ground reference data information from each classification period, and knowledge of the crop calendar. The program accounts for the majority of possible multi-temporal crop group combinations (over 800 unique combinations used for calendar year 2000) and assigns acreage of crop group(s) for each field. Figure 4.6

is a graphic example of how this program functions. In Figure 4.6, field #1 is assigned 40 acres of alfalfa for the year (alfalfa is generally an annual crop), yet the August classification classified the crop in field #1 as Sudan. Accuracy assessment data indicate that Alfalfa and Sudan are sometimes confused in the August classification. Because the crop in field #1 was classified as Alfalfa for all classification dates except August, the August Sudan label is assumed to be classification error. Other similar types of error between two crops can also be accounted for and corrected in the annual summary based on knowledge of the nature of the error (from the accuracy assessment matrices) and knowledge of crop planting practices. Field #2 is assigned double cropping of 40 acres of Cotton and 40 acres of Lettuce as this combination is expected from crop planting practices. Results of the annual summary program are extensively reviewed for error and edited where necessary.

Figure 4.6 — Annual Crop Group Summary.



Classification of Phreatophyte Areas

Introduction

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

Annual phreatophyte updates are accomplished using change detection methodologies. This procedure identifies spectral difference between image dates (i.e. May 1999 and May 2000) and focuses remapping efforts in areas of spectral change.

Ground Reference Data Collection

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

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

Classification Strategies

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

1. A texture band generated from band 4 added to the Landsat Thematic Mapper (TM) 6-band image.
2. A 5/4 ratio band added to the TM 6-band image.
3. Both the texture and ratio bands added to the TM 6-band image.

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

Spectral Classification

Image Preparation

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

Signature Generation, Analysis, and Classification

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

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

Polygon generation and labeling

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

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

Editing

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

Phreatophyte Update

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

Coregistration and image normalization

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

Image differencing

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

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

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

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

Classification

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

Accuracy Assessment

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

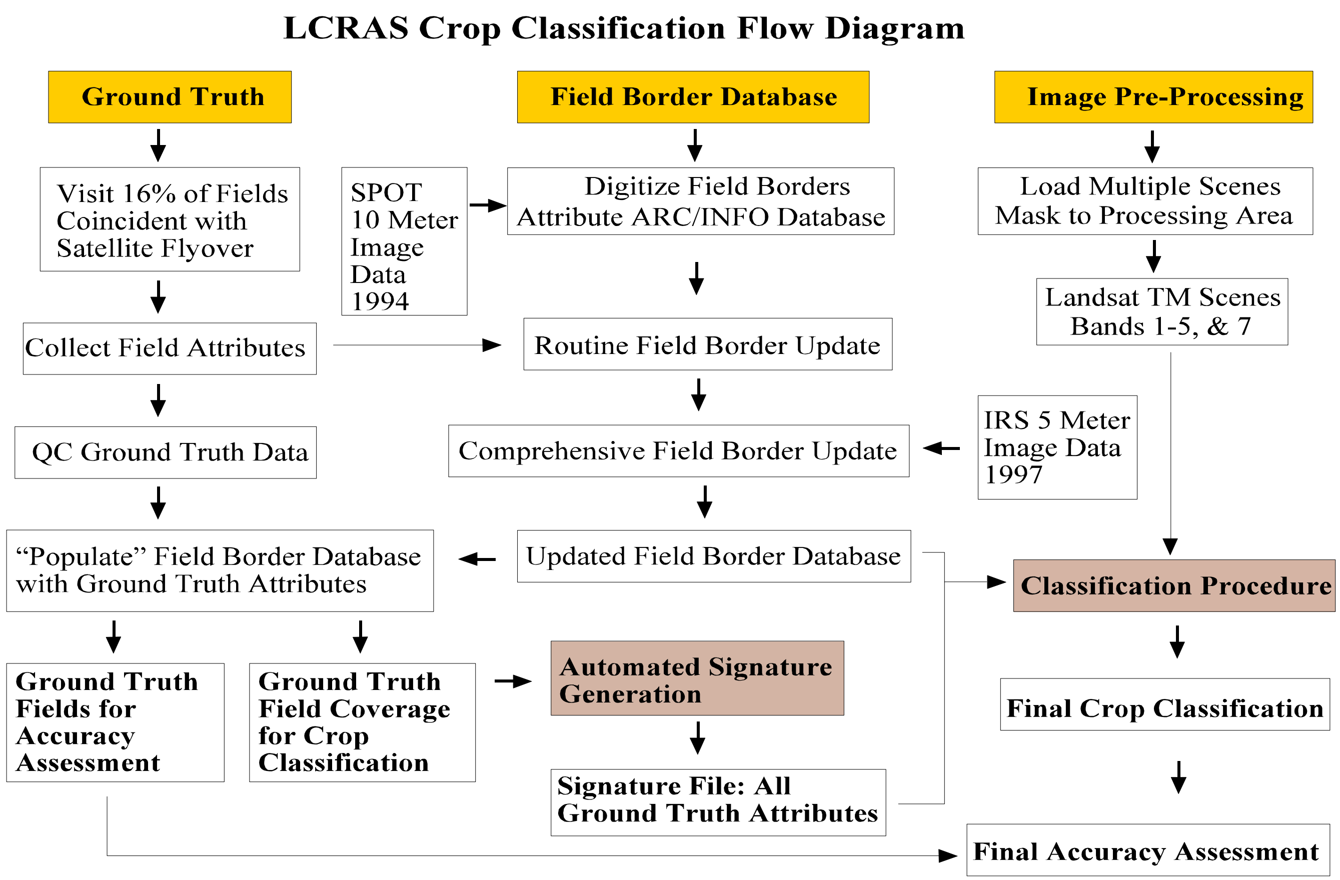


Figure 4.2 — LCRAS Crop Classification Flow Diagram.

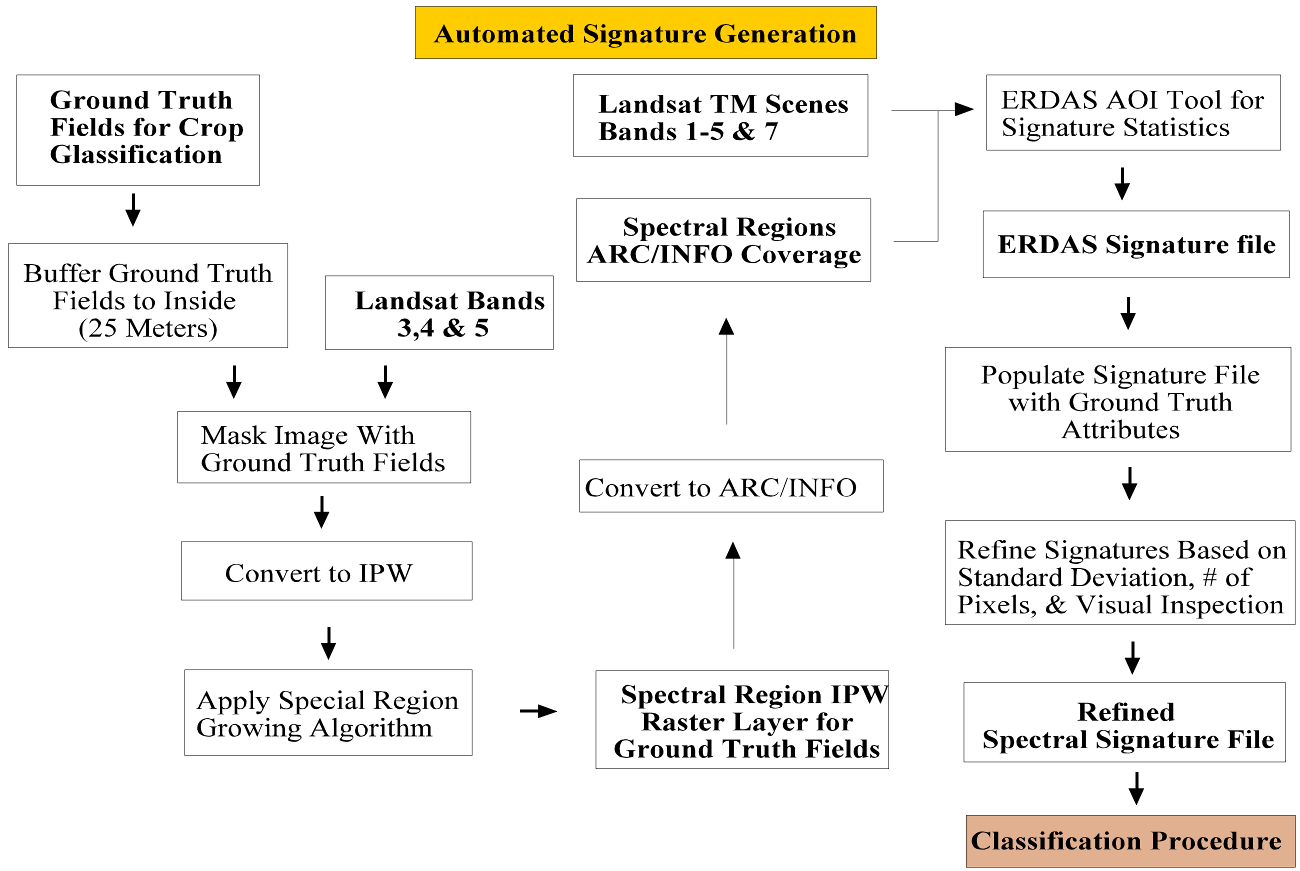


Figure 4.3 — Automated Signature Generation.

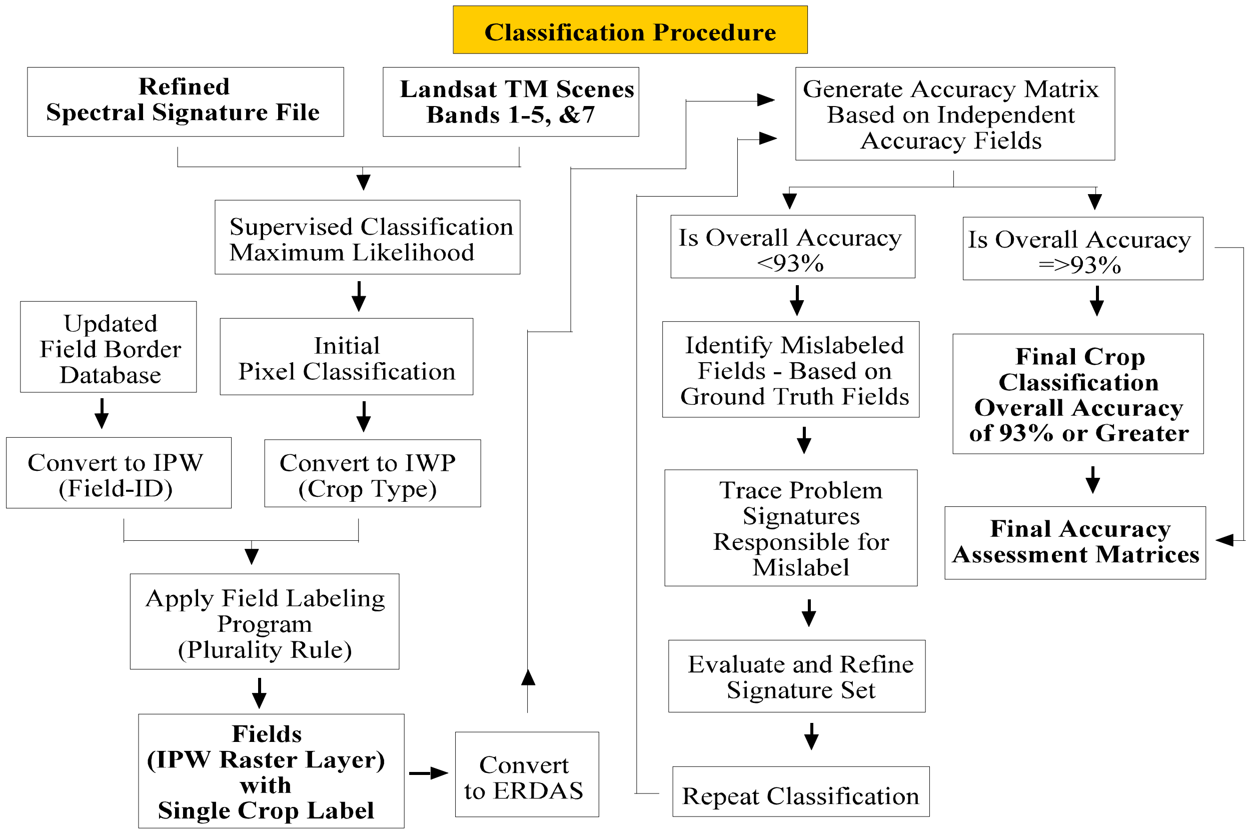


Figure 4.4 — Classification Procedure.

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Attachment 5

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

Introduction

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

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

Downstream of Morelos Dam, a considerable fraction of the water applied for irrigation flows into Mexico through the groundwater system and does not return to the Colorado River (underflow to Mexico). Because this underflow to Mexico is not available for delivery to other users in the United

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

States or in accordance with the Mexican treaty, it is a consumptive use. This underflow to Mexico, sometimes referred to as loss to Mexico, must be credited as a consumptive use to the entitlement of the district which diverted the water from the Colorado River.

Difference between the focus of the particle tracking study and the focus of LCRAS

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

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

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

Process

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

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

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

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

To begin;

1. Observe that the components of the underflow across SIB are listed with their respective acre-foot volumes on the first block on first spreadsheet,
2. Set the flow of the dependent components of the underflow to Mexico across SIB (Hillander "C" and the south Yuma Mesa) to zero (first block on first spreadsheet),
3. Calculate a single acre-foot volume for each independent component of the underflow to Mexico across SIB by averaging the acre-foot volumes derived from the analysis of particles which stop or pass through non-well weak-sink cells (column labeled "Average" on the first block on first spreadsheet),
4. Observe that the components of the water pumped by Hillander "C" and the south Yuma Mesa are listed with their respective acre-foot volumes (second and third blocks on first spreadsheet),
5. Set the dependent components of the water pumped by Hillander "C" and the south Yuma Mesa (the water pumped by Hillander "C" and the south Yuma Mesa components) to zero (second and third blocks on first spreadsheet),

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

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

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

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

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

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

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

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

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

Conclusion

This assessment presents a rational way to estimate the fractions of the "loss of water to Mexico" across SIB that must be credited to the diverters of the water as consumptive use. This assessment recognizes that even if there was no irrigation in the Yuma area south of Morelos Dam, there would still be underflow to Mexico as part of the natural system.

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

FIRST SPREADSHEET

Contributions to underflow across the Southerly International Boundary with Mexico (SIB) from irrigation in Arizona.

Data Source: "Determination of the Contributions of Recharge from Six Irrigated Areas near Yuma Arizona to Drainage Wells and Drains and to Underflow Across International Boundaries into Mexico Using Particle Tracking" by William Greer, Yuma Area Office, Bureau of Reclamation.

Note: Ranges in values represent differences from assuming particles stop in, or pass through, non-well weak-sink (NWWS) cells.

Total flow across SIB assumed to be 62,443 acre-feet annually.

FIRST BLOCK:

Source of Water	Particles Stop in NWWS Cells (Acre-Feet)	Particles Pass Through NWWS Cells (Acre-Feet)	Average	Adjustments from Hillander "C"	Adjustments from South Yuma Mesa	Total Average Contributions	Average Adjusted to Equal 62,443
Unit B	83	83	83	1,617	99	1,799	1,665
YMIDD	24,952	26,750	25,851	2,340	1,707	29,898	27,665
Yuma Mesa Canals	1,670	1,701	1,686	82	0	1,768	1,636
YCWUA	5,978	17,486	11,732	1,446	0	13,178	12,194
Yuma Valley Canals	6,169	10,804	8,487	856	0	9,343	8,645
Yuma Irrig. Dist. (YID)	0	0	0	0	0	0	0
Hillander "C" (HC) [B]	Included in others	Included in others		0	0	0	0
South Yuma Mesa [B]	Included in others	Included in others		0	0	0	0
River (Mor. - SIB)	5,570	7,547	6,559	0	0	6,559	6,069
Other Sources	9,873	0	4,937	0	0	4,937	4,568
Total	54,295	64,371	59,335	6,341	1,806	67,482	62,442

[B] Deep percolation from irrigation water applied in these areas is not considered a source because it is pumped water derived from other sources in this list, see breakouts below.

SECOND BLOCK:						
Contributions to water pumped by Hillander "C" wells (pumping assumed to be 17,842 acre-feet).						
Source of Water	Particles Stop in NWWS Cells (Acre-Feet)	Particles Pass Through NWWS Cells (Acre-Feet)	Average	Average Adjusted to Equal 17,842	Adjusted Average % (Rounded)	Average Volume of SIB Underflow "Contributed" by Hillander "C"
Unit B	3,892	3,892	3,892	4,549	25.5%	1,617
YMIDD	5,387	5,887	5,637	6,589	36.9%	2,340
Yuma Mesa Canals	190	196	193	226	1.3%	82
YCWUA	2,806	4,164	3,485	4,074	22.8%	1,446
Yuma Valley Canals	1,733	2,380	2,057	2,404	13.5%	856
Yuma Irrig. Dist. (YID)	0	0	0	0	0.0%	0
Hillander "C" (HC)[C]	Included in others	Included in others	0	0	0.0%	0
South Yuma Mesa [C]	Included in others	Included in others	0	0	0.0%	0
River (Mor. - SIB)	0	0	0	0	0.0%	0
Other Sources	0	0	0	0	0.0%	0
Total	14,008	16,519	15,264	17,842	100.0%	6,342
						6,341 Check Total

[C] Deep percolation from irrigation water applied in these areas is not considered a source because it is pumped water derived from other sources in this list, see breakout below.

THIRD BLOCK:						
Contributions to water pumped by US Wells south of the Yuma Mesa (pumping assumed to be 35,169 acre-feet).						
Source of Water	Particles Stop in NWWS Cells (Acre-Feet)	Particles Pass Through NWWS Cells (Acre-Feet)	Average	Average Adjusted to Equal 35,169	Adjusted Average %	Average Volume of SIB Underflow "Contributed" by South Yuma Wells
Unit B	1,765	1,765	1,765	1,938	5.5%	99
YMIDD	30,259	30,259	30,259	33,231	94.5%	1,707
YCWUA	0	0	0	0	0.0%	0
Yuma Irrig. Dist. (YID)	0	0	0	0	0.0%	0
Hillander "C" (HC)[D]	Included in others	Included in others	0	0	0.0%	0
South Yuma Mesa[D]	Included in others	Included in others	0	0	0.0%	0
Canal leakage	0	0	0	0	0.0%	0
Other sources	0	0	0	0	0.0%	0
Total	32,024	32,024	32,024	35,169	100.0%	1,806
						1,806 Check Total

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

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

Attachment 6

Reference Evapotranspiration Used by LCRAS

Introduction

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

Reference ET for use in LCRAS

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

Reclamation developed area-specific reference ET values for the Palo Verde/Parker valleys and the Yuma valley by averaging the reference ET values for stations sited within these two areas. The area-specific reference ET values for the Palo Verde/Parker area were developed by averaging the reference ET values calculated using the standardized equation and data collected by the three CIMIS stations sited in the Palo Verde Valley (Blythe North East, Palo Verde, and Ripley) and the Parker AZMET station sited in the Parker Valley. The area-specific reference ET values for the Yuma area were developed similarly, using data collected by the three AZMET stations sited in Yuma area (North Gila, Yuma Valley, and Yuma Mesa). The reference ET calculated using the standardized equation and data collected by the single AZMET station sited in the Mohave Valley was used for the Mohave Valley area. Table 6.1 lists the annual summation of the averaged daily reference ET values for calendar year 2000.

[A]AZMET and CIMIS stations are operated by the University of Arizona and the California Department of Water Resources respectively

Table 6.1 — Annual Summation of Area-Specific Averaged Daily Reference ET Values Used in this Report

(Units: inches)

Year	Mohave	Palo Verde/Parker	Yuma	Average
2000	80.18	75.71	76.50	77.46

The disparity in reference ET values reported by the AZMET and CIMIS stations and the need for consistent reference ET values for the LCRAS program

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

Table 6.2 lists the annual summation of daily reference ET values reported by the AZMET and CIMIS stations along the lower Colorado River for the years 1995 through 2000.

Table 6.2 — Annual Summation of Daily Reference ET Values Reported by AZMET and CIMIS Stations

(Units: inches)

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

This disparity in reference ET values reported by the AZMET and CIMIS networks presented a problem for LCRAS because a consistent set of ET coefficients is used to calculate the ET of crop and phreatophyte groups on the California and Nevada, and Arizona sides of the Colorado River. Therefore, the LCRAS program requires consistent reference ET values from the CIMIS and AZMET station sites.

Reclamation discussed this requirement with representatives from the CIMIS and AZMET networks and Reclamation's consultant. This discussion resulted in a recommendation to use an average of the reference ET values reported by the CIMIS and AZMET networks within specific geographic areas, to calculate crop and phreatophyte ET, as an interim solution until the disparity could be fully analyzed and a solution developed and implemented.

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

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

Analysis by representatives from the AZMET and CIMIS networks, and Reclamation's consultant identified four potential sources of the disparity in the reference ET values reported by the AZMET and CIMIS stations sited along the lower Colorado River,

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

This analysis concluded that,

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

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

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

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

Net radiation

Dr. Paul Brown of the University of Arizona evaluated the reference ET equations used by CIMIS and AZMET to identify the impact that the different methods used to calculate net radiation have on reported reference ET values. The evaluation concluded that the difference in methods used to calculate net radiation is the major source of the disparity in reported reference ET values between the AZMET and CIMIS networks.

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

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

[B]The CIMIS and AZMET networks do not measure net radiation directly because of the cost and maintenance requirements of the instrumentation required to do so.

reference ET during the fall, winter and spring which leads to an annual reference ET that is high by an average of about 6%.

Micro-climatic differences between station sites

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

Station siting conditions

Siting conditions, including crop conditions, at individual AZMET or CIMIS station sites most likely have an impact on the accuracy of the calculated reference ET, however the full impact of siting conditions has not been quantified. Reclamation and the University of Arizona (operators of the AZMET network) are cooperating in a study to identify the impact station siting conditions at individual stations have on reported reference ET values. Preliminary results indicate that a micro-meteorological station which is not located in an actively irrigated, reference field, reports a reference ET higher than a micro-meteorological station which is located in an actively irrigated, reference field.

Equipment used at AZMET and CIMIS stations

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

The standardized reference evapotranspiration equation solution

Representatives from the AZMET and CMIS networks, and Reclamation's consultant recommended a solution to the problem the disparity between the reference ET values presented to the LCRAS program. The recommended solution is to calculate reference ET using the standardized reference ET equation, recommended by the American Society of Civil Engineers, Evapotranspiration in Irrigation and Hydrology Committee (ASCE-ET), and the data collected by the AZMET and the CIMIS stations sited along the lower Colorado River. To implement this solution, reference ET is calculated using the standardized equation, for each AZMET and CIMIS station site based upon the data collected by each station. Area-specific reference ET values are calculated, as described at the beginning of this attachment using the reference ET values calculated with the standardized equation.

The Standardized Equation

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

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

[D] Walter, I.A., et. al. (2000). ASCE's Standardized Reference Evapotranspiration Equation. p. 209-215, IN R.G. Evans, B.L. Benham, and T.P. Trooien (eds), ASAE National Irrigation Symposium, Phoeniz, AZ, Nov. 14-16.

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

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

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

Where:

- ET_{ref} = short (ET_{os}) or tall (ET_{rs}) standardized reference evapotranspiration (mm/day),
- *R_n = net radiation at crop surface (MJ m^{-2}/day or hour),
- *G = soil heat flux density at the soil surface (MJ m^{-2}/day or hour),
- *T = mean daily or hourly air temperature at 1.5 to 2.5m height (°C),
- *u_2 = mean daily or hourly wind speed at 2 m height (m/s),
- *e_s = mean saturation vapor pressure at 1.5 to 2.5 m height (kPa),
- *e_a = mean actual vapor pressure at 1.5 to 2.5 m height (kPa),
- *Δ = slope of the vapor pressure-temperature curve (kPa $°C^{-1}$),
- γ = the psychrometric constant (kPa $°C^{-1}$),
- C_n = constant for reference type and calculation time step,
- C_d = constant for reference type and calculation time step.

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

Dr. Paul Brown of AZMET performed the calculations required to develop daily reference ET values for this report using the standardized equation and data collected at each of the AZMET and CIMIS stations along the lower Colorado River.

The annual summations of the daily reference ET values calculated for the AZMET and CIMIS sites along the lower Colorado River by Dr. Brown using the standardized equation are shown in Table 6.3

Table 6.3 — Annual Summation of Daily Reference ET Values calculated for the AZMET and CIMIS Sites along the lower Colorado River using the Standardized Equation

(Units: inches)

Year	Mohave	Parker	Blythe NE	Palo Verde	Ripley	North Gila	Yuma Mesa	Yuma Valley	Average
2000	80.18	73.72	73.39	74.82	71.00	76.26	70.85	82.35	75.32

Impact of using the standardized equation on ET coefficients

The standardized equation produces a reference ET which is 9.25% lower than the reference ET produced by the AZMET network and 8.32% higher than the reference ET produced by the CIMIS network, when annual summations of the daily reference ET values are compared. Reclamation asked Dr. Marvin Jensen to evaluate the need to adjust the ET coefficients developed for LCRAS in 1998 for use with the standardized equation. Dr. Jensen performed a brief analysis and, as expected, the ET values calculated using reference ET from the standardized equation and the ET coefficients developed for LCRAS in 1998 were within the expected range of water use by the subject crops as determined by the previous studies, with the possible exceptions of citrus and alfalfa.

For calendar year 2000, the ET coefficient for alfalfa has been increased slightly by adjusting the reduction factor, which relates potential alfalfa ET under ideal conditions to the real conditions observed along the lower Colorado River, from 0.85 to 0.92. No adjustments have been made to the ET coefficients for citrus. Reclamation continues to evaluate potential adjustments to ET coefficients.

Attachment 7

Calculation of Domestic Consumptive Use

Introduction and Summary

This attachment's purpose is to provide background and rationale, and to display the data and calculations used to develop the domestic consumptive use and per-capita consumptive use factors used by the Lower Colorado River Accounting System (LCRAS). Domestic consumptive use is calculated by one of four methods as described below,

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

2. 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 are available,

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

4. Occasionally, for unique cases, domestic consumptive use is estimated through the use of a method submitted by a diverter.

Domestic Consumptive Use Factor

The domestic consumptive use factor is a ratio of consumptive use to diversion. The domestic consumptive use factor of 0.6 was derived by examining the relationship between the measured diversion, measured return, and consumptive use of municipalities along the lower Colorado River.

There are only four cities with measured diversions and measured returns; Boulder City, Nevada[A], Laughlin, Nevada (Big Bend Water District), Needles[B], California; and Yuma, Arizona. Table 7.1 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. The use from the Robert B. Griffith Water Project (Las Vegas Valley, Henderson, and Boulder City, Nevada, combined) was added to Table 7.1 as a check value.

Table 7.1 — Domestic Consumptive Use Factors for Cities with Measured Returns
(Data from 1995 Decree Accounting Report[C] unless otherwise noted)

Units: acre-feet unless otherwise noted

City	Diversion	Wastewater or Return Flow	Domestic Consumptive use	Domestic Consumptive Use Factor[D]
Boulder City, NV[E]	5,430	1,368	4,062	0.75
Boulder City, NV (Household Use Only[F])	3,133	1,280	1,853	0.59
Laughlin, NV[G]	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

A Boulder City, Nevada, does not return water to the Colorado River. Waste water from Boulder City is discharged to a treatment plant where the unused portion of the diverted water is measured. Consumptive use for Boulder City, as used herein, 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 the amount of water diverted by the city until such time as the city returns water to the Colorado River.

B Needles, California, is credited with both a measured and unmeasured return flow through information supplied by the Colorado River Board of California.

C Compilation of Records in Accordance with Article V of the Decree of the Supreme Court of the United States in *Arizona* v. *California* dated March 9, 1964 Calendar Year 1995, Bureau of Reclamation, Lower Colorado Region, Boulder City, Nevada.

D Domestic Consumptive Use ÷ Diversion for Domestic Use (dimensionless).

E Average 1989 through 1992 values from Boulder City municipal records. Diversion does not include water delivered to municipal parks and golf course use. Landscape irrigation is significant in Boulder City.

F 1989 to 1992 average January value multiplied by 12 to approximate an annual value with minimal landscape irrigation (few people water their lawn and shrubs in January). The delivery for municipal landscape irrigation has also been removed.

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

Figure 7.1 is a bar graph showing the domestic consumptive use factors, from Table 7.1, for each of the cities mentioned above 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. A consumptive use factor of 0.6, or a similar value, will be used until additional information becomes available which would suggest the use of some other value.

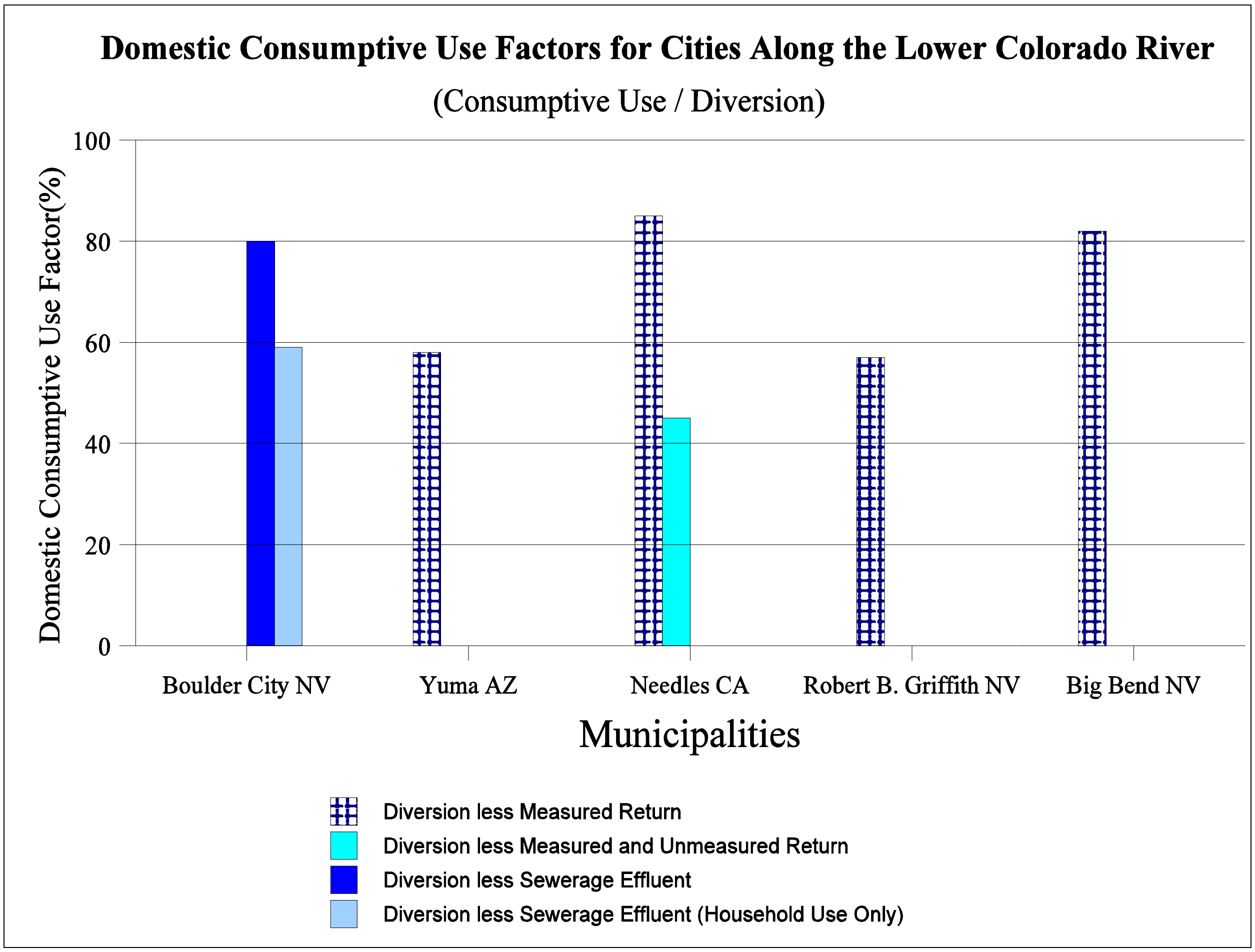

Figure 7.1 — Domestic Consumptive Use Factors for Cities with Measured Returns

Per-Capita Consumptive Use

The per-capita consumptive use factors used by LCRAS are derived from an analysis of the per-capita consumptive use 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 seasonal or visitor population. Given this setting, measurements of water delivered and wastewater generated are available for the entire community, and from this information, consumptive use and per-capita consumptive use can be calculated with confidence.

Reclamation compiled records of Boulder City's population (see table 7.2), diversions delivered to households and businesses, wastewater arriving at the municipal wastewater treatment plant, and water delivered to municipal golf course and parks (primarily for turf irrigation) from measurements taken by the city for calendar years 1989 through 1992, the most complete and readily available data at the time this study was performed (1994).

Domestic landscape irrigation is a significant part of domestic consumptive use in Boulder City. This is frequently not the case with communities along the lower Colorado River. To properly account for this consideration, per-capita domestic consumptive use was calculated for Boulder City in two ways, as per-capita domestic consumptive use which includes domestic landscape irrigation (total per-capita domestic consumptive use) and as per-capita domestic consumptive use which minimizes the impact of domestic landscape irrigation (household per-capita domestic consumptive use).

Total per-capita domestic consumptive use

Based on the records described previously, the annual total per-capita consumptive use in Boulder City ranged from a high of 0.37 to a low of 0.29 acre-feet per capita, with an average of 0.32 acre-feet per capita (see table 7.2). These values do not include the water delivered to municipal parks and the golf course for turf irrigation. They do, however, include water used for domestic landscape irrigation.

Total domestic consumptive use is calculated as the delivery for all uses in Boulder City, less the wastewater generated by the city, less the delivery of water by the city for use on municipal parks and the golf course (primarily turf irrigation). The total per-capita domestic consumptive use is calculated by dividing the total domestic consumptive use by the population of the city.

Table 7.2 — Boulder City, Nevada Population, Total Domestic Consumptive Use, and Total Per-Capita Domestic Consumptive Use

Year	Population	Total Domestic Consumptive Use (acre-feet)	Total Per-Capita Domestic Consumptive Use (acre-feet per capita)
1989	12,740	4,714	0.37
1990	12,760	3,763	0.29
1991	12,950	3,893	0.30
1992	12,810	3,879	0.30
Average	12,815	4,062	0.32

Household per-capita domestic consumptive use

An estimate was also made of the annual household per-capita consumptive use of water in Boulder City, which minimized the influence of domestic landscape irrigation. This was accomplished by examining the total per-capita consumptive use of water during the month of January (landscape irrigation is at or near minimum in January), and extrapolating the January water use rate for an entire year. The result of this analysis yields an annual household per-capita consumptive use of 0.14 acre-feet per capita. This annual household per-capita consumptive use will be used as a factor to determine domestic consumptive use when no water records are available, a population is known or can be approximated, and landscape irrigation is not a significant portion of the domestic water use, until additional information becomes available to suggest a more appropriate value. The delivery, wastewater, and municipal landscape irrigation data used in this analysis is shown in tables 7.3 and 7.4, on the following pages.

Table 7.3 — Boulder City, Nevada Deliveries, Wastewater, and Municipal Landscape Irrigation

Units: acre-feet

Municipal Diversion from the Colorado River													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
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	7,522.7
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	6,523.4
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	6,602.2
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	6,541.2
Average	283.7	276.8	364.6	513.2	661.7	796.3	887.6	829.0	724.2	603.1	501.6	355.6	6,797.4

Municipal Wastewater													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
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	1,327.4
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	1,384.5
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	1,410.6
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	1,348.9
Average	106.7	98.8	110.5	112.8	117.2	121.3	126.0	122.0	117.9	113.7	110.1	111.2	1,367.9

Municipal Landscape Irrigation (Golf Course and Parks)													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
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	1,480.8
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	1,376.2
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	1,298.8
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	1,313.3
Average	22.6	33.7	54.4	116.4	158.5	191.7	224.4	176.4	165.2	123.9	64.5	35.6	1,367.3

Table 7.4 — Total Domestic Consumptive Use

(Includes Domestic Landscape Irrigation = Diversion - Wastewater - Municipal Landscape Irrigation)

Units: acre-feet

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
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	4,714.4
1990	184.2	140.3	288.5	238.2	292.5	434.0	539.9	535.9	413.4	299.5	227.4	169.1	3,762.7
1991	130.8	147.0	160.5	265.2	393.5	465.0	502.7	508.9	374.7	358.2	446.2	140.3	3,892.8
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	3,878.9
Average	154.3	144.4	199.7	284.1	386.0	483.3	537.2	530.6	441.2	365.5	327.0	208.9	4,062.2

Table 7.5 shows the procedure for estimating household domestic consumptive use, an annual household domestic consumptive use factor, and the annual per-capita household consumptive use for Boulder City, Nevada. This procedure, which assumes that January reflects domestic consumptive use with minimal domestic landscape irrigation (few people watering their lawn and shrubs in January), is described as follows,

1. Approximate the amount of water delivered for household use with minimal domestic landscape irrigation in one month by subtracting the amount of water delivered for municipal landscape irrigation from the amount of water delivered for all uses in January (see table 7.3 and table 7.4),

2. Approximate the annual amount of water delivered for household use with minimal landscape irrigation by multiply the result from 1 by 12,

3. Approximate the consumptive use of the water delivered for household use in one month by subtracting the amount of water delivered for municipal landscape irrigation and the amount of wastewater generated by the city from the amount of water delivered for all uses in January (see table 7.3),

4. Approximate the annual consumptive use of the water delivered for household use by multiplying the result from 3 by 12,

5. Calculate an annual consumptive use factor by dividing the consumptive use of water delivered for household use in one year (from 4) by the amount of water delivered for household use (from 2).

6. Calculate an annual per-capita consumptive use by dividing the consumptive use of water delivered for household use in one year (from 4) by the latest estimate of Boulder City's population from Table 7.2.

Table 7.5 — Procedure For Estimating Household Consumptive Use, An Annual Household Consumptive Use Factor, And Annual Per-Capita Consumptive Use For Boulder City, Nevada.

Units: acre-feet unless otherwise noted

Description	Value	Calculation
Average January Diversion:	283.7	
Less Average January Municipal Landscape Use:	22.6	
Less Average January Waste Water:	106.7	
Equals Average January Household Consumptive Use:	154.4	(283.7 - 22.6 - 106.7)
Extrapolated Annual Household Consumptive Use Based Upon Average January Household Consumptive Use:	1852.8	(154.4 x 12)
Average Annual Diversion for Household Consumptive use:	3133.2	((283.7 - 22.6) x 12)
Average Annual Consumptive Use Factor for Household Use (dimensionless):	0.59	(1,852.8 ÷ 3,133.2)
Average Annual Per-Capita Household Consumptive Use(Acre-Feet Per Capita):	0.14	(1,852.8 ÷ 12,815)