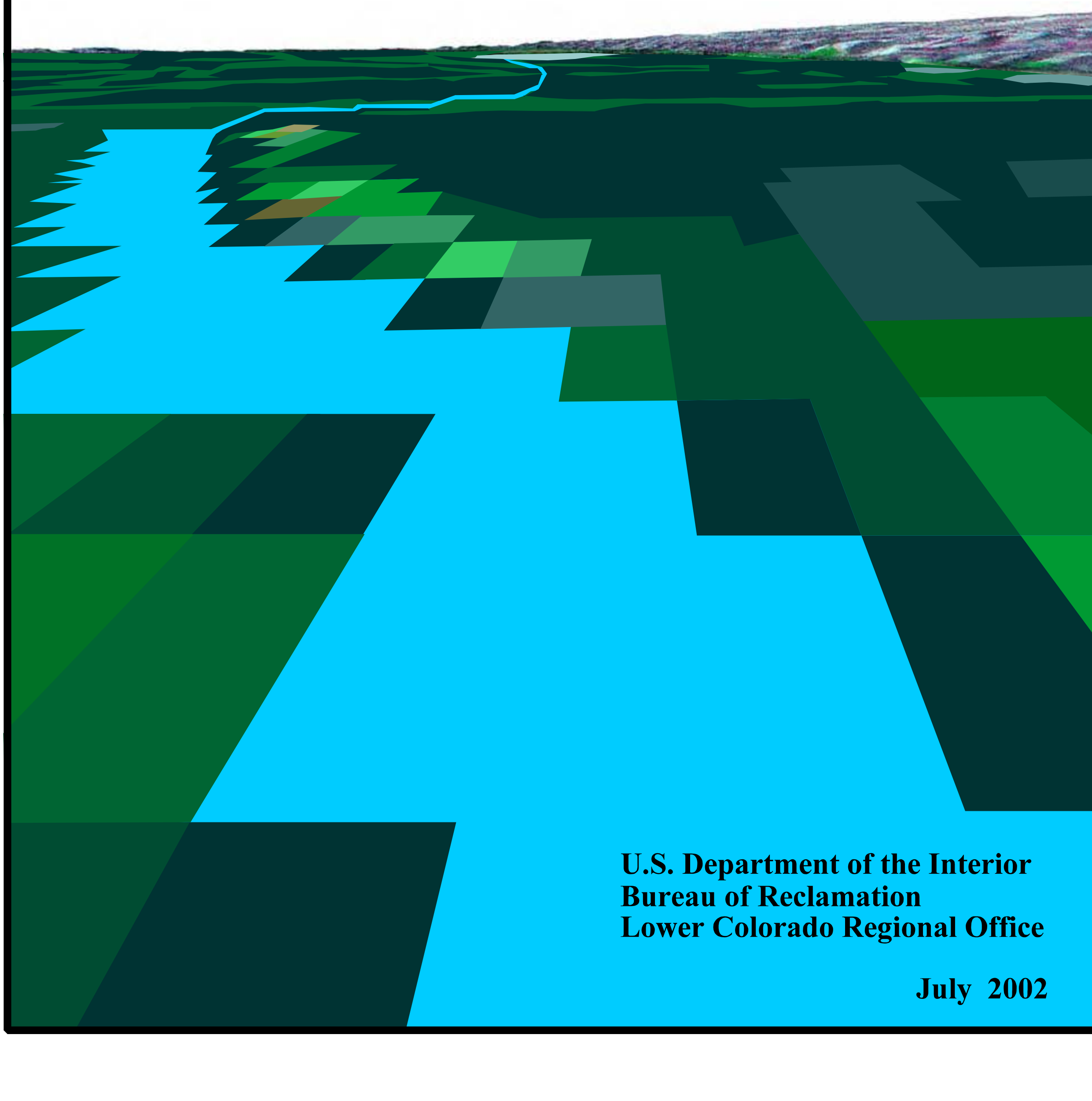
Lower Colorado River Accounting System

Demonstration of Technology

Calendar Year 2001



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

July 2002

Lower Colorado River Accounting System Demonstration of Technology Calendar Year 2001

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

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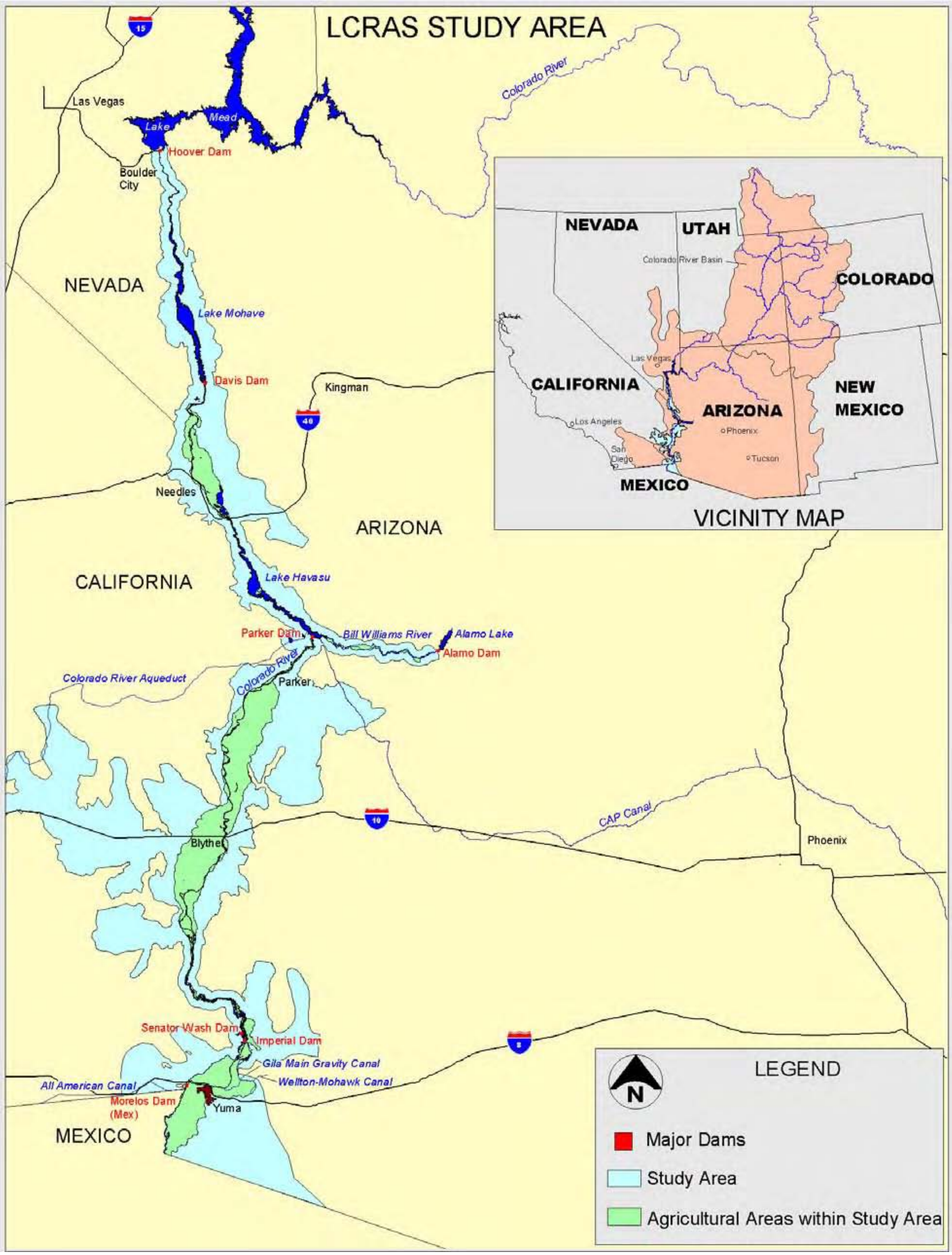

LCRAS STUDY AREA
15
Las Vegas
Lake
Mead
Hoover Dam
Boulder City
Colorado River
NEVADA
Lake Mohave
Davis Dam
Kingman
40
Needles
ARIZONA
CALIFORNIA
Lake Havasu
Parker Dam
Bill Williams River
Alamo Lake
Alamo Dam
Colorado River Aqueduct
Colorado River
Parker
10
CAP Canal
Blythe
Phoenix
Senator Wash Dam
Imperial Dam
8
Gila Main Gravity Canal
Wellton-Mohawk Canal
All American Canal
Morelos Dam (Mex)
Yuma
MEXICO
VICINITY MAP
NEVADA
UTAH
Colorado River Basin
COLORADO
Las Vegas
CALIFORNIA
ARIZONA
NEW MEXICO
Los Angeles
Phoenix
San Diego
Tucson
MEXICO
LEGEND
N
Major Dams
Study Area
Agricultural Areas within Study Area

Executive Summary

Introduction

The Colorado River is the principal source of water for irrigation and domestic use in Arizona, southern California, and southern Nevada. The U.S. Supreme Court Decree of 1964 in Arizona v. California (Supreme Court Decree) requires accounting of the use and distribution of water from the Colorado River below Lee Ferry (lower Colorado River). In addition to 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." The Bureau of Reclamation (Reclamation) provides these records annually by 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) present and document improved methods of quantifying the consumptive use of Colorado River water from Hoover Dam to Mexico that can be used in the preparation of the decree accounting report.

Background

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 (the agencies) to improve methods for estimating and distributing consumptive use to diverters between Hoover Dam and Mexico. This effort responded to a request from the lower Basin States for Reclamation to account for return flows in addition to those measured as surface flows (unmeasured return flows) in calculations of consumptive use. Calculations of consumptive use for the decree accounting report at that time did not address unmeasured return flows.

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 their development of LCRAS in the late 1980s, but did not published a final report 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 applications of LCRAS for calendar years 1995, 1996, 1997, 1998, 1999, and 2000 (Bureau of Reclamation 1997, 1998, 1999, 2000, 2000a, and 2001). This report documents Reclamation's application of LCRAS to calendar year 2001, including changes Reclamation has made to LCRAS since issuing the previous report.

What is LCRAS?

LCRAS is water balance of the lower Colorado River from Hoover Dam to Mexico. LCRAS balances inflows, outflows, and water uses between the major dams and delivery points, called reaches[1], which include agricultural and domestic water uses which Reclamation considers consumptive uses within the apportionments of Colorado River water available to Arizona, California, and Nevada. The water balance produces a residual, which is the difference between the summation of all flows entering the reach and, the summation of all flows leaving the reach and the summation of all water uses within the reach (residual = summation of inflows - summation of outflows - summation of water uses).

The residual is primarily a summation of the error in all the measurements and estimates used in the water balance. Reclamation distributes the residual back to all the measurements and estimates in proportion to the product of their magnitude and variance (see Lane, W. L., 1998), modifying each value. After the distribution of the residual, the modified values in the water balance produce a residual of zero. Reclamation terms the modified values of inflow, outflow, and water use as final values. Since the residual can be either a positive or negative value, the final values can be smaller or larger than the measured or estimated values used in the water balance.

Reclamation estimates water use from crops, natural vegetation (phreatophytes), canals, and open water bodies using evapotranspiration and evaporation calculations. Reclamation determines the acres of each crop group grown by each agricultural diverter, each phreatophyte group, and open water area from analysis of remotely sensed data and geographic information system (GIS) analysis. Image classification, identifies the location and type of each crop and phreatophyte group and GIS analysis identifies the number of acres of each crop and phreatophyte group and acres of open water within each known service or ownership boundary.

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[1] Reclamation used the following reaches for this report, Hoover Dam to Davis Dam, Davis Dam to Parker Dam, Parker Dam to Imperial Dam, and Imperial Dam to Mexico.

Agricultural ET becomes, at minimum, crop ET plus evaporation from canals which serve a diverter and bodies of open water maintained by a diverter. Agricultural consumptive use is the final value of agricultural ET (agricultural ET plus a portion of the residual). The amount of phreatophyte ET which should be added to the minimum agricultural ET to develop a complete ET value for agriculture is an unresolved question at this time. Therefore, this report presents estimates of agricultural consumptive use (which should be considered a minimum agricultural consumptive use) and phreatophyte water use separately for each diverter.

Reclamation estimates domestic water use by subtracting a measured return from a measured diversion, applying water use coefficients to measured diversions, applying per-capita consumptive use factors to the population of a town, city, or other municipal environment, or other methods unique to a specific domestic diverter. Reclamation chooses the appropriate method to estimate domestic water use based upon the circumstances and type of data available for each domestic diverter. Domestic consumptive use is the final value of domestic water use after distribution of the residual of the water balance.

Reclamation makes estimates of exports by measuring the amount of water diverted from the mainstream and exported out of the Colorado River valley. Sometimes, Reclamation adds an estimate of canal evaporation between the diversion point and export point to the measured export. Export consumptive use is the final value of exports after distribution of the residual of the water balance.

Results

The following pages present descriptions and qualitative assessments of the results for the major components of LCRAS.

Image classification

Image classification using single-date image classification processes and Landsat 5 and Landsat 7 image data provides excellent and reliable discrimination between crop groups. 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 2001). Reclamation mapped the phreatophyte vegetation along the lower Colorado River in 1994. Post-classification accuracy assessment of phreatophyte groups in this map indicate an overall accuracy of 87%. Reclamation updates the phreatophyte map each year using remote-sensing-based change detection methodologies. Reclamation field verifies major changes which are usually due to fire or development. Reclamation also uses image classification processes to quantify open-water areas. Reclamation found the results for lakes Mohave and Havasu 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

Reclamation evaluates the water balance closure by comparing the value of the residual to the presumed measurement error of the mainstream inflow to each reach. Reclamation considers distributing the residual to be optional if the value of the residual is about equal to or less than the presumed measurement error of the mainstream flow entering the reach. Reclamation chooses to distribute the residual of all reaches in LCRAS Demonstration of Technology reports to demonstrate the impact upon consumptive use values. Reclamation presumes the following standard errors of estimate for the measurements of mainstream flows entering each reach, 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})	10,209,400	10,567,500	7,699,400	6,148,954	10,209,400
Flow at the downstream boundary (Q_{ds})	10,567,500	7,699,400	6,148,954	1,782,987	1,782,987
Residual (Q_{res})	-521,194	-281,241	391,250	98,223	-312,962
Residual as a percentage of flow at the upstream boundary (Q_{us})	-5.11%	-2.66%	5.08%	1.60%	-3.07%
Difference between flow at the upstream and downstream boundaries (Q_{dif})	-358,100	2,868,100	1,550,446	4,365,967	8,426,413
Measured Tributary inflow (Trm)	0	5,357	0	6,954	12,311
Unmeasured Tributary inflow (Trum)	6,480	36,290	33,750	3,000	79,520
Exported flow (Q_{ex})	0	2,773,504	0	3,816,655	6,590,159
Evaporation (E)	122,083	118,011	66,724	9,027	315,845
Domestic consumptive use (CU_d)	757	40,968	4,220	33,249	79,194
Agricultural ET (ET_{ag})	0	76,193	761,725	344,201	1,182,119
Phreatophyte ET (ET_{pht})	734	177,812	364,752	74,566	617,864
Change in reservoir storage ()S_r)	46,000	4,500	-4,475	0	46,025
Change in aquifer storage ()S_a)	0	0	0	0	0

Consumptive use results

Table ES-2 compares state totals of agricultural and domestic consumptive use, and phreatophyte water use calculated by LCRAS with consumptive use as reported in the decree accounting report for calendar year 2001.

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

(Units: annual acre-feet)

LCRAS			Decree Accounting Report	
Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
Nevada				
Uses above Hoover Dam (from decree accounting report)		295,447	295,447	Uses above Hoover Dam
Uses below Hoover Dam	18,252	18,395	19,983	Uses below Hoover Dam
			1,492	Unmeasured return flow credit
Nevada Total	18,252	313,842	313,938	Nevada Total
California				
			5,254,722	Sum of individual diverters
			86,075	Unmeasured return flow credit
California Total	176,315	5,142,976	5,168,647	California Total
Arizona				
Subtotal (below Hoover Dam, less Wellton-Mohawk IDD)	0	0	60,814	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)		0	0	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (decree accounting report)		0	153,216	Wellton-Mohawk IDD
			124	Pumped from South Gila wells (drainage pump outlet channels [DPOCs]).
			2,687,811	Unmeasured return flow credit
Arizona Total	0	0	-2,473,905	Arizona Total
Lower Colorado River Basin Total				
Total Lower Basin Use	194,567	5,456,818	3,008,681	Total Lower Basin Use

Table ES-3 shows the final adjusted values of all the water balance components after distribution of the residual and after the adjustment of flows at the major dams and the flow to Mexico 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})	10,623,402	10,460,794	7,322,655	6,143,528	10,623,402
Flow at the downstream boundary (Q_{ds})	10,460,794	7,322,655	6,143,528	1,857,863	1,857,863
Residual (Q_{res})	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	162,608	3,138,139	1,179,127	4,285,665	8,765,539
Measured Tributary inflow (Trm)	0	5,378	0	6,952	12,330
Unmeasured Tributary inflow (Trum)	6,506	36,677	32,727	2,993	78,903
Exported flow (Q_{ex})	0	2,763,462	0	3,831,008	6,594,470
Evaporation (E)	121,823	117,897	66,835	9,029	315,584
Domestic consumptive use (CU_d)	757	40,966	4,220	33,253	79,196
Agricultural consumptive use (CU_{ag})	0	76,146	776,204	346,767	1,199,117
Phreatophyte water use (CU_{pht})	734	177,554	368,072	74,686	621,046
Change in reservoir storage (ΔS_r)	45,975	4,495	-4,475	0	45,995
Change in aquifer storage (ΔS_a)	-175	-326	998	867	1,364

Conclusions

Reclamation has taken the lead with the development of LCRAS to improve consumptive use calculations for the decree accounting report using state-of-the-art technologies. These technologies provide Reclamation with tools to fulfill the Supreme Court’s directive to manage the limited resources of the lower Colorado River in a manner that is equitable and consistent for all diverters. Reclamation presents LCRAS as a water accounting method which,

1. Uses the best technology available,

2. Provides a consistent and documented suite of tools developed specifically to account for the consumptive use of Colorado River water by all diverters from Hoover Dam to Mexico.

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

Future

Reclamation plans to continuously improve LCRAS methods as new information, techniques, and improvements identified through reviews and experience become available. An outstanding question that must be resolved is the appropriate crediting of phreatophyte water use, if any, to consumptive use. Reclamation will proceed with the accounting of water use in accordance with Article V of the Supreme Court Decree as follows,

1. Reclamation will continue to produce the current decree accounting report with the methods used in previous years until LCRAS is implemented.

2. Reclamation will continue to produce the Lower Colorado River Accounting System Demonstration of Technology reports, in parallel with the decree accounting report, for calendar years 2002 and 2003.

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Chapter 1 — Introduction

The lower Colorado River (the Colorado River below Lee Ferry[2]) is a critical part of the Southwest's environmental and economic structure. Extensive development of the lower Colorado River and tributaries thereto began in the early 1900's, primarily to meet irrigation and domestic water supply needs; and since the 1930s, to generate electric power. Urban communities receiving water from the lower Colorado River include Las Vegas, NV, Phoenix, AZ, and Los Angeles, and San Diego, CA. Today, the increasing needs of agriculture, cities and suburbs, Native Americans, recreationists, fish and wildlife habitat, and other interests in the United States and Mexico draw more intensely upon waters of the lower Colorado River than ever before. At the same time, the United States must continue to meet current contract obligations to power and water customers.

The “Law of the River”

Management of the lower Colorado River is unique. The Secretary of the Interior (Secretary) serves as the lower Colorado River Water Master and 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 diverted from the lower Colorado River with the exception of certain Federal entitlements, and reports the use of water in a manner consistent with the law. 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." The following paragraphs discuss the four major components of the “Law of the River.”

Colorado River Compact

The cornerstone of the "Law of the River," the seven Colorado River Basin States (Colorado, New Mexico, Utah, Wyoming, Arizona, California, and Nevada) and the Federal Government negotiated the Colorado River Compact in 1922. At that time, Colorado, New Mexico, Utah, and Wyoming were concerned that plans for Hoover Dam and other water development projects within Arizona, California, and Nevada 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 Colorado River Compact,

1) Defined the relationship between the States of the Upper Division (Colorado, New Mexico, Utah,

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[2] Lee Ferry is also referred to as Compact Point.

and Wyoming)—where most of the river's water source originates—and the States of the Lower Division (Arizona, California, and Nevada), where most of the water development was taking place,

2) Divided the Colorado River Basin into an Upper Basin (those parts of the States of the Upper Division which naturally drain into the Colorado River System above Lee Ferry) and a Lower Basin (those parts of the States of the Lower Division which naturally drain into the Colorado River System below Lee Ferry) and gave each basin the right to develop and use 7.5 million acre-feet of river water annually,

3) Specified that the upper and lower basins must share any obligation to Mexico.

The Colorado River Compact reserved water for future development within the States of the Upper Division, and allowed planning and development to proceed in the States of the Lower Division.

Boulder Canyon Project Act of 1928

The Colorado River Compact set the stage for the Boulder Canyon Project Act, which provided for the construction of works for the protection and development of the Lower Basin. The Boulder Canyon Project Act,

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

The Boulder Canyon Project Act set in place the management framework for the development of the Colorado River resources within the States of the Lower Division.

Mexican Water Treaty of 1944

The Mexican Water Treaty established the relationship between the use of Colorado River water in the United States and the use of Colorado River water in the Republic of Mexico.

The Mexican Water Treaty,

1. Committed 1.5 million acre-feet of the Colorado River's annual flow to Mexico,
2. 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.

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 the definition of Colorado River water. The opinion,

1. Concluded that Congress, in passing the Boulder Canyon Project Act, created a scheme for apportionment among Arizona, California, and Nevada of the Lower Basin’s share of mainstream Colorado River water,
2. Concluded 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,
3. 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 Decree of the Supreme Court of the United States in Arizona v. California Dated March 9, 1964 (Supreme Court Decree),

1. Established decreed rights for Indian Communities, wildlife refuges, and other 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,

2. Enjoined the Secretary from delivering water outside the framework of apportionments defined by the law,

3. Mandated that consumptive use of water will be charged against the State within which the consumptive use takes place,

4. Required the Secretary to develop an annual report documenting all diversion and consumptive uses of Colorado River water in all three States of the Lower Division.

Consumptive use of Colorado River water

Reclamation complies with the mandate of the Supreme Court Decree for an annual water use report through the publication of, "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 controversial portion of the decree accounting report is the calculation of consumptive use. Consumptive use is defined in Article I.(A) of the Supreme Court Decree 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."

Reclamation developed Lower Colorado River Accounting System (LCRAS) in response to the needs of state Colorado River water management agencies, individual water users, and Reclamation itself for improved calculations of consumptive use.

Originally, Reclamation calculated consumptive use primarily as a measured diversion less a measured return flow. In 1969, Arizona, California, and Nevada asked Reclamation to develop a method that would consider all return flows, measured and unmeasured, for each diverter in a consistent and equitable manner. Reclamation responded to this request by establishing the Task Force on Unmeasured Return Flow in 1970. In 1984, the task force chose to develop and apply a water balance approach to the lower Colorado River after extensive discussion and trials of other methods. The task force members accepted a proposal to develop and study a water balance method, named the Lower Colorado River Accounting System. 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 LCRAS to determine consumptive use along the lower Colorado River from Hoover Dam to Mexico for calendar year 2001. 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 in this report to be part of the apportionments of Colorado River water confirmed by the US Supreme Court to be available to Arizona, California, and Nevada.

Consumptive use in current decree accounting reports

Since 1964, Reclamation has reported consumptive use primarily as measured diversions from, less measured return flow to, the mainstream. Beginning in 1991, in parallel with the continued development of LCRAS, Reclamation augmented the calculation of consumptive use for the decree accounting report to include estimates of unmeasured return flow. Reclamation currently compiles the decree accounting report using estimates of unmeasured return flow based primarily upon comparisons between measured diversions less measured return flows, and other estimates of consumptive use from studies performed by the Arizona Department of Water Resources in 1991[3], a crop evapotranspiration study performed by Reclamation's Water Management Branch of the Operations and Maintenance Division in Boulder City, Nevada[4], and exchanges of information between Reclamation staff and staff of the Colorado River Board of California. Reclamation developed unmeasured return flow factors for large agricultural diverters and selected domestic diverters along the lower Colorado River by dividing estimates of unmeasured return flow (from the studies mentioned previously) by the reported diversion from the mainstream.

Reclamation has since applied unmeasured return flow factors to most diverters from the mainstream of

[3] Methods for Calculating Arizona's Colorado River Water use, ADWR, August 1991. Transmitted to Reclamation by letter to Mr. Alden Briggs, U.S. Bureau of Reclamation, Lower Colorado River Regional Office, P.O. Box 61470, Boulder City, Nevada; signed by Tim Henley, Colorado River Management Division, Arizona Department of Water Resources, 15 South 15th Avenue, Phoenix, Arizona 85007; dated August 9, 1991.

[4] This evapotranspiration study assessed on-farm irrigation efficiencies for calendar years 1984 through 1990.

the lower Colorado River based upon similarity of conditions between diverters identified in the studies described in the previous paragraph and other diverters from the mainstream.. Reclamation sums estimates of unmeasured return flow and reports the total for the Lower Colorado River Basin as a whole. Reclamation does not include estimates of unmeasured return flow in reported values of consumptive use for individual diverters. Reclamation identified some concerns with estimates of unmeasured return flows and the way they are reported by the decree accounting report. These concerns include,

1. reporting unmeasured return flows as a basin total only and not for individual diverters,

2. the unproven presumption that the relationship between diversion and unmeasured return flow is constant,

3. Reclamation has not developed unique unmeasured return flow factors for all diverters,

4. the lack of documentation for the underlying assumptions used to develop some of the unmeasured return flow factors and,

5. the lack of documentation for the assumptions, techniques, and decisions used to include and/or exclude water use by natural vegetation (phreatophyte) in the development of the unmeasured return flow factors.

How is LCRAS an improvement?

LCRAS provides a unique estimate of consumptive use values for each individual diverter each year. There is no need to rely upon, or to hold constant, relationships between diversion, return flow, and consumptive use from previous years or previous studies. LCRAS produces values of consumptive use and phreatophyte water use for each diverter, without the need for a correction to the Lower Basin total from unmeasured return flow.

What is LCRAS?

LCRAS is a water balance of the Colorado River from Hoover Dam to Mexico[5]. LCRAS balances inflows, outflows, and water uses between the major dams and delivery points, called reaches[6]. Reclamation considers some of the water uses used in the water balance to be consumptive uses within the apportionments of Colorado River water available to Arizona, California, and Nevada and some water uses to not be consumptive uses within state apportionments.

The water balance is used to calculate a residual. This residual is the difference between the summation of all flows entering the reach, the summation of all flows leaving the reach, and the summation of all water uses within the reach. The residual is primarily a summation of the error in all the measurements and estimates used in the water balance.

Residual = Summation of Inflows - Summation of Outflows - Summation of Water Uses

The residual is distributed back to all the measurements and estimates in proportion to the product of their magnitude and variance (see Lane, W. L., 1998), modifying each value. After distribution of the residual, the modified values in the water balance sum to a residual of zero. Reclamation terms the modified values of inflow, outflow, and water use as final values. Since the residual can be either a positive or negative value, the final values can be smaller or larger than the measured or estimated values used in the water balance.

LCRAS calculates three categories of consumptive use: agricultural consumptive use, domestic consumptive use, and export consumptive use. The subsequent paragraphs define these categories of consumptive use. The amount of phreatophyte water use that takes place within delineated service areas or ownership boundaries is also quantified, however the amount that should be added to the other consumptive uses to develop a complete value of consumptive use for individual diverters remains an unresolved question. Therefore, this report presents estimates of agricultural, domestic, and export consumptive use, and phreatophyte water use separately for each delineated service area or ownership

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[5] LCRAS has no impact on diversions and consumptive uses upstream of Hoover Dam.

[6] Reclamation uses the following reaches for this report, Hoover Dam to Davis Dam, Davis Dam to Parker Dam, Parker Dam to Imperial Dam, and Imperial Dam to Mexico.

boundary. Assuming diverters report all diversions from and measured returns to the mainstream, the consumptive use from LCRAS shall never exceed the measured diversion less the measured return flow for individual diverters. Upon resolution of the question concerning the proper crediting of phreatophyte water use to consumptive use, Reclamation would be able to prepare a single complete value of consumptive use for individual diverters.

Agricultural consumptive use and phreatophyte water use

Agricultural consumptive use is the final value of agricultural evapotranspiration (ET) after distribution of the residual from the water balance.   The residual can be either a positive or a negative number. Therefore, agricultural consumptive use can be either slightly larger or smaller than agricultural ET. Agricultural ET becomes, at minimum, crop ET plus evaporation from canals which serve a diverter and bodies of open water maintained by a diverter. The amount of phreatophyte ET which should be added to the minimum agricultural ET to develop a complete value for agricultural consumptive use is an unresolved question at this time.   Upon resolution of the question concerning the amount of phreatophyte ET which should be included in agricultural ET, a single complete value of agricultural consumptive use for individual diverters can be prepared.

Evapotranspiration and evaporation is calculated using,

1. reference evapotranspiration 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 (reference ET),
2. evapotranspiration coefficients for each crop and phreatophyte group (ET coefficients) and evaporation coefficients, and
3. the acreage of each crop and phreatophyte group, and the acreage of open water in canals and ponds maintained by diverters along the lower Colorado River from Hoover Dam to Mexico.

Analysis of remotely-sensed-data and geographic information systems (GIS) analysis determines the type and acreage of crops grown, the type and acreage of each phreatophyte group, and the number of acres of open water within each known service or ownership boundary.

Domestic consumptive use

Domestic consumptive use is the final value of domestic water use after distribution of the residual from the water balance. The residual can be either a positive or a negative number; therefore, domestic consumptive use can be either slightly larger or smaller than the estimate of domestic water use used in the water balance. Reclamation estimates domestic water use[7] for LCRAS,

1. by subtracting a measured return flow from a measured diversion, or
2. if a measured return flow is not available, 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 not available, 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. by other method unique to the specific circumstances of an individual domestic diverter.

Chapter 8 provides details of the derivation of the domestic use factors previously mentioned.

Export consumptive use

Export consumptive use is the final value of export water use after distribution of the residual from the water balance. Reclamation estimates export water use from measurements of the amount of water diverted from the mainstream and exported out of the Colorado River valley. Where appropriate, Reclamation adds to the measured export an estimate of canal evaporation between the diversion point and export point.

[7] While water use on wildlife refuges is also considered a domestic use, phreatophyte water use on wildlife refuges is not included here.

Comparison of current decree accounting reports with LCRAS

Chapter 4 presents a comparison between consumptive-use values compiled for the decree accounting report and consumptive use values developed by LCRAS. These include: the sum of agricultural consumptive use, domestic consumptive use, and consumptive use from water exported from the mainstream, and phreatophyte water use reported by a diverter, state total, and basin total basis.

Chapter 2 — LCRAS in Calendar Year 2001

The following paragraphs describe the major activities required to calculate consumptive use with LCRAS and provide an assessment of their success for calendar year 2001.

Remote sensing and geographic information systems

Reclamation identified and mapped crop and phreatophyte groups, and open water along the lower Colorado River from Hoover Dam to Mexico using remote sensing, field survey, and GIS processes. Reclamation projects all satellite data and GIS coverages into Universal Transverse Mercator (UTM), Zone 11, North American Datum 1927. Reclamation used the same flood plain boundary developed for Bureau of Reclamation 1999 (shown in exhibits 2 through 8) for calendar year 2001. Reclamation uses the flood plain boundary to identify phreatophyte areas that should be included in the image classification process. Reclamation includes cropped areas 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 in this analysis. Reclamation calculates agricultural and phreatophyte ET for each diverter and evaporation for each reach from these areas. The domestic diverter boundaries are not currently included in this GIS coverage. Reclamation plans to incorporate domestic diverter boundaries in the future.

Remote sensing is the process of using satellite imagery to identify and quantify areas of crop groups, fallow fields, phreatophyte groups, and open water along the lower Colorado River from Hoover Dam to Mexico. Field surveys provide information for crop and phreatophyte cover that does not lend itself as well to being identified by remote sensing. Reclamation determines the location and acreage quantification of orchards, for example, from field and airborne surveys. Reclamation uses GIS database management tools 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. Reclamation uses GIS database management tools 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

Reclamation performs remote sensing analysis 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. Reclamation has developed crop, phreatophyte, and open-water delineation processes 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, the sensors focus 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. Reclamation resamples the pixel size or spatial resolution of the Landsat TM data used for image analysis to 30 meters.

Reclamation selects image data which adequately cover the study area, are cloud free, and which capture the variation in crop planting practices during the year. Reclamation acquired TM image data for analysis during calendar year 2001 on the dates shown in table 2.1. Path and row designations in table 2.1 refer to image locations based on the World Reference System[8]. Figure 6.1 displays the image locations as defined by path and row upon a backdrop of the lower Colorado River from Lake Mead to Mexico.

Table 2.1 — TM Image path-row designations and acquisition dates

Path 38, rows 36 and 37	February 8, 2001		
Path 38, row 37	March 12, 2001		
Path 38, rows 36 and 37	April 29, 2001	Path 39, row 36	Not used for 2001
Path 38, rows 36 and 37	July 18, 2001	Path 39, row 36	Not used for 2001
Path 38, rows 36 and 37	November 15, 2001		

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. Reclamation analyzes these digital values to generate

[8] The World Reference System (WRS) catalogues Landsat 5 and 7 images by location (path and row) and date. The WRS for Landsat has 233 paths corresponding to the number of orbits required to cover the earth every 16 days. The Landsat 5 and Landsat 7 satellite orbits 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.

spectral statistics (signatures) that represent specific land cover groups on the Earth's surface, and makes use of ground reference data to correlate unique relationships between the spectral signatures derived from the image data and crop and phreatophyte groups on the ground.

Reclamation collects ground reference data for approximately 1,900 of the 13,800 irrigated fields in the study area. This represents about 15 percent of the total irrigated area. Reclamation uses from 60 to 65 percent of the ground reference data in image classification, and the remaining 35 to 40 percent to assess the accuracy of the crop classifications. Reclamation bases selections of ground reference sites on the distribution of crop groups in each major irrigated area along the mainstream of the lower Colorado River from Hoover Dam to Mexico. Reclamation selects irrigated fields randomly from a GIS database and adds additional fields to the random sample where necessary to ensure representation of all major crop groups, in order to provide a statistically valid data set for image classification procedures. The variability in planting and harvesting times for each crop group is a critical factor in the selection of optimum image dates.

Reclamation collects ground reference data and purchases satellite imagery four times a year. Reclamation collects ground reference data at times which coincide with the acquisition of the satellite imagery. Table 2.2 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. This report presents a complete listing of the crop groups and the individual crops within each group in chapter 6 by table 6.4, entitled, "2001 Crop Group and Name List." Reclamation groups phreatophyte types as shown in table 2.3.

Table 2.2 — Crop Groups			
Alfalfa - Perennial	Lettuce - Late	Citrus - Declining	Orchards
Alfalfa - Annual	Melons - Spring	Tomatoes	Small Vegetables
Alfalfa - Seed	Melons - Fall	Sudan	Root Vegetables
Cotton	Bermuda Grass	Legume and Solanum Vegetables	Perennial Vegetables
Small Grain	Bermuda Grass with Rye Grass	Crucifers	Sugar Beets
Field Grain	Citrus - Young	Dates	Grapes
Lettuce - Early	Citrus - Mature	Safflower	Fallow
			Herbs

Table 2.3 — 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
Moist Soil Unit	An area flooded in winter and irrigated in summer to maintain vegetation.
Seasonal Wetland	An area flooded in winter but not irrigated in summer to maintain a wetland.

Delineation of crop and phreatophyte groups, and open-water areas

This report presents a detailed description of the image processing and GIS processes used for this report in chapter 6.

Delineation of cropped areas

Reclamation 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. Reclamation has linked all the ground reference data collected for image classification to this field-border database. Reclamation originally derived the field borders from 10-meter Systemme Pour l'Observation de la Terre (SPOT) image data acquired in June and August of 1992. Reclamation on-screen digitized all field borders using the SPOT data as a backdrop. Reclamation has updated changes in field borders using notations from ground reference data collected throughout the year as a data source since 1995. 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. The image dates used for 2001 are March 21st (above Imperial Dam) and April 24th (below Imperial Dam). Field borders will continue to be routinely updated using these two practices.

Reclamation includes all areas along the mainstream of the lower Colorado River from Hoover Dam to Mexico known by Reclamation to divert or pump water in this analysis. Exhibits 1 through 8 show these areas. 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. Reclamation obtained excellent results for crop groups listed in table 2.2 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 (five dates in calendar year 2001).

Delineation of phreatophyte areas

Reclamation updates phreatophyte areas by delineating areas of spectral change using image-to-image comparisons (change detection methods) of Landsat TM imagery. Reclamation field checks areas of spectral change to confirm that the spectral change is actually due to land-cover change. Reclamation remaps areas of land-cover change and uses these maps to update the phreatophyte database. Reclamation used image dates of July 15, 2000 and July 18, 2001 to perform the update for this report.

Delineation of open water

Open water of the mainstream

The LCRAS program incorporated open water layers developed by Reclamation's Environmental Group and outside contractors for calendar year 2000. For calendar year 2001, Reclamation overlaid TM imagery acquired for July 18 and November 15th, 2001 on to the calendar year 2000 open water layer to identify significant (greater than 90 m^2) changes in open water acreage that may have occurred over the calendar year. This analysis identified corrections required for Senator Wash (to include the west third of the reservoir), and for the Colorado River below Parker Dam (inclusion of a portion of the river immediately south of and adjacent to Parker Dam).

Open water in major delivery canals

The calculation of agricultural ET for irrigation districts and Indian reservations includes evaporation from major canals which serve the district or reservation. For calendar year 2000, Reclamation identified bank to bank canal area (in acres) 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 Reclamation calculated the acreage of open water within each canal. For calendar year 2001, Reclamation overlaid July 18th, 2001 30-meter TM imagery onto the coverage used for calendar year 2000 to look for needed changes and improvements that could be made. This analysis identified exposed pools of water adjacent to the Gila Gravity Main Canal. The area of these pools was digitized and included in the open water area of the canal.

Water balance

Reclamation applies the water balance 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.[9] The

[9] The Imperial Dam to Mexico reach includes 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.

following equation shows the form of the water balanced Reclamation used for calendar year 2001. This is the same water balance used in Bureau of Reclamation 1999.

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

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} = The measured tributary inflow to the reach
T_{rum} = The unmeasured tributary inflow to the reach
Q_{ex} = The amount of water exported out of the basin from the reach
E = The open-water evaporation in the reach
CU_d = The domestic, municipal, and industrial use
ET_{pht} = The total phreatophyte ET in the reach
ET_{ag} = The total agricultural ET in the reach
ΔS_r = The change in reservoir storage in the reach
ΔS_a = The change in aquifer storage in the reach

Reclamation gathers data from Reclamation records and reports, and reports others provide to Reclamation. The following sections discuss data sources available to Reclamation and calculations Reclamation makes using the data.

Flow data

Flow data include flows at upstream and downstream reach boundaries, water diverted and exported from the mainstream, measured tributary inflows, and changes in reservoir storage. The Geological Survey (GS), Reclamation, the International Boundary and Water Commission (IBWC), Metropolitan Water District of Southern California (MWD), and the Central Arizona Project (CAP) provided flow data for this report.

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

The GS[10] reports the majority of mainstream flows used by LCRAS. Individual diverters and IBWC also report some mainstream flows. Table 2.4 shows the gages along the mainstream used by LCRAS and the reporting agency (items for which distributed values are not individually calculated are marked N/C in the column labeled, "Final Value After distribution of Residual").

Table 2.4 — Mainstream flows and reporting agency

Units: Annual acre-feet

Description	Station Number	Measured Flow	Final Value After Distribution of Residual	% Change (Final - Measured÷ Measured)	Reporting Agency
Colorado River below Hoover Dam	09421500	10,209,400	10,623,402	4.1%	GS
Colorado River below Davis Dam	09423000	10,567,500	10,460,794	-1.0%	GS
Colorado River below Parker Dam	09427520	7,699,400	7,322,655	-4.9%	GS
Colorado River at Imperial Dam	09429490	6,148,954	6,143,528	-0.1%	GS
Diversion to Mittry Lake	09522400	10,426	N/C	--	GS
All-American Canal (Station 60)	09523000	4,888,600	N/C	--	GS
Gila Gravity Main Canal (Station 30)	09522500	822,608	N/C	--	Reclamation
Colorado River below Imperial Dam	09429500	427,320	N/C	--	GS
Colorado River at NIB	09522000	1,566,430	1,613,812	3.0%	IBWC
Eleven Mile wasteway	09525000	13,613	13,628	0.1%	IBWC
Cooper wasteway	09531850	561	561	0.0%	IBWC
Twenty-one Mile wasteway	09533000	2,591	2,591	0.0%	IBWC
Main drain + 242 wells	09534000	106,194	106,890	0.7%	IBWC
West Main Canal wasteway	09534300	7,378	7,378	0.0%	IBWC
East Main Canal wasteway	09534500	3,777	3,777	0.0%	IBWC

[10] 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 2001.*

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 (NIB and SIB), and the southerly international boundary with Mexico. Reclamation must add the fraction of the underflow that crosses into Mexico which results from the application of Colorado River by agricultural and domestic users below NIB. The underflow which crosses the international boundaries defined by the limitrophe section and SIB is a consumptive use, not a return flow, 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.

Chapter 7 entitled, "Distribution of Underflow to Mexico To Water Users Below The Northerly International Boundary With Mexico," documents the fractions of the underflow which crosses the southerly international boundary which Reclamation adds to individual diverter's agricultural and domestic consumptive use in this report. The number of acres irrigated by diverters along and near the Limitrophe section form the basis for the fractions of the underflow that crosses the Limitrophe section, which Reclamation adds to individual diverters agricultural and domestic consumptive use in this report. The worksheet at the end of chapter 7 shows the diverters and their estimated contributions to the underflow across the Limitrophe section.

Reclamation currently estimates the underflow to Mexico to be 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 and the final adjustment of the flow to Mexico in table 2.10, the final value of underflow to Mexico across the Limitrophe section increased to 26,542 acre-feet and 82,684 acre-feet across SIB, for a total of 109,226 acre-feet, a change of about 32%. Of this total, all of the 26,542 acre-feet considered to cross the Limitrophe section and about 83% of the 82,684 acre-feet considered to cross SIB (or 68,628 acre-feet) is added to the agricultural and domestic consumptive use of irrigation districts in the Yuma, Arizona area who's operations contribute to the underflow to Mexico. Details of the distribution of the underflow to Mexico can be found on table 4.2.

Export flow (Q_{ex})

MWD and the Central Arizona Water Conservation District report flows into the Colorado River Aqueduct and the Central Arizona Project canal , respectively, from their own measurements. Reclamation calculates MWD's net export 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. CAP measures their export from Lake Havasu at the Havasu Pumping plant.

Reclamation measures diversions to the Wellton-Mohawk Irrigation and Drainage District (Wellton-Mohawk) in the Wellton-Mohawk Canal, using an open-channel acoustic velocity meter (AVMs). IID measures flows to the Imperial Irrigation District (IID) and the Coachella Valley Water District (Coachella) in the All-American Canal below Pilot Knob. The GS reports the data measured by IID.

Reclamation measured 40 acre-feet of water as discharged into the Main Outlet Drain (MOD) or Main Outlet Drain Extension (MODE) and bypassed to the Santa Clara Slough, from Drainage Pump Outlet Channels DPOC-1, DPOC-2, and DPOC-3, and drainage wells DW-1, DW-7, and DW-9 near Yuma, Arizona in calendar year 2001. Water discharged to the MOD/MODE does not returned to the Colorado River. The water balance considers water discharged to the MOD/MODE to be exported from the Colorado River system.

Table 2.5 shows measured values, final values after the distribution of the residuals from the water balance in each reach, and percentage change between measured and final values for exports by MWD, CAP, Wellton-Mohawk, IID, and Coachella. Reclamation presumes the standard error of estimate for export flows to be between 1 and 2 percent.

Table 2.5 — Export values used in this report

Units: Annual acre-feet

Export	Station Number	Measured Flow	Final Value after Distribution of Residual	% Change (Final - Measured÷ Measured)	Reporting Agency
Colorado River Aqueduct	9424150	1,250,412	1,245,885	-0.4%	GS
Central Arizona Project Canal	9426650	1,523,092	1,517,577	-0.4%	GS
Wellton-Mohawk Canal	9522700	404,253	405,773	0.4%	Reclamation
All American Canal below Pilot Knob	9527500	3,412,362	3,425,195	0.4%	GS

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

Measured tributary inflow data (T_{rm})

The lower Colorado River below Hoover Dam receives measured inflow from two tributaries—the Gila River in southwestern Arizona and the Bill Williams River in west-central Arizona. The GS measures and reports inflows from the Gila River near Dome and the Bill Williams River below Alamo Dam.

Only a fraction 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. Reclamation derives the inflow to the Colorado River at Lake Havasu from the Bill Williams River by subtracting estimates of the depletion between Alamo Dam and Lake Havasu[11] from the sum of the flow below Alamo Dam and estimates of unmeasured inflow to the Bill Williams River. Reclamation defines the boundary of Lake Havasu and the Bill Williams River 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. The extent of the accounting surface represents the maximum influence of Lake Havasu upon the Bill Williams River in a normal operating year based upon the areal

[11] Reclamation calculates evaporation and vegetative water uses on the Bill Williams River using the same remote sensing and reference ET methods used on the Colorado River mainstream. Reclamation does not consider water uses on the Bill Williams River below Alamo Dam to be Colorado River water uses because no water is diverted from the Colorado River to support these uses.

extent of the contiguous alluvium upstream into the Bill Williams River at the normal high annual operating elevation of Lake Havasu.

Table 2.6 shows the measured tributary inflow values used in this report.

Table 2.6 — Measured Tributary Inflows

Units: Annual acre-feet

Measured Trubutary	Station Number	Measured Flow	Final Value After Distribution of Residual	% Change (Final - Measured÷ Measured)	Reporting Agency
Bill Williams River below Alamo Dam	09426000	5,357	5,378	0.4%	GS
Gila River near Dome	09520500	6,954	6,952	0.0%	GS

Unmeasured tributary inflow data (T_{rum})

Reclamation uses the unmeasured tributary inflow values published by the GS in Owen-Joyce, Sandra J., 1987, with the exception of the unmeasured groundwater inflow from Sacramento Wash which is taken from an investigation by the Arizona Department of Water Resources. The flow values Owen-Joyce, Sandra J., 1987 presents are primarily compilations of existing studies, based upon mean annual precipitation, available at the time of publication.

Table 2.7 shows the unmeasured tributary estimates used in each reach for this report. Note that Reclamation does not include the unmeasured tributary inflows to the Bill Williams River in the unmeasured tributary inflows to the Lower Colorado River below Hoover Dam. Reclamation uses the unmeasured tributary inflows to the Bill Williams River only in a water balance of the Bill Williams River from Alamo Dam to Lake Havasu to estimate inflow to Lake Havasu from the Bill Williams River.

Table 2.7 — Unmeasured Tributary Inflow Estimates

Units: annual acre-feet

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

Reach		Description	Flow
	Groundwater Discharge		
		Bouse Wash	1,200
		Tyson Wash	350
		Vidal Wash	250
		Chuckwalla Valley	400
Imperial Dam to Mexico			
	Groundwater Discharge		
		Gila River	1,000
		Unmeasured runoff, Yuma area	2,000
Sum of unmeasured inflow to the lower Colorado River, Hoover Dam to Mexico			79,520
Sum of final values of unmeasured inflow after distribution of the residual			78,903
Difference in acre-feet (sum of final values - sum of values used in water balances)			-617
Difference in percent (difference in acre-feet ÷ sum of values used in water balances)			-0.8%

Evapotranspiration

Reclamation calculates ET for all crop and phreatophyte groups within the lower Colorado River flood plain and on the Palo Verde and Yuma Mesas.

ET calculations require the following:

5. Reference ET
6. ET coefficients for each crop and phreatophyte group
7. Number of acres covered by each crop and phreatophyte group
8. Effective precipitation (used to develop crop ET only).

Reference ET

Reclamation uses reference ET values for the two CIMIS and five AZMET automated weather station sites along the lower Colorado River from Hoover Dam to Mexico calculated using the standardized equation derived from the ASCE Penman Monteith equation[12] (standardized equation). The standardized

[12] 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.

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.

The use of reference ET values calculated using 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. Calculating reference-ET values using 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. Chapter 5 presents 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.

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. Reclamation uses reference-ET values for the Mohave Valley calculated using the standardized equation and data provided by the Mohave AZMET station. Figure 2.1 shows the reference-ET and precipitation values used to develop ET estimates for this report.

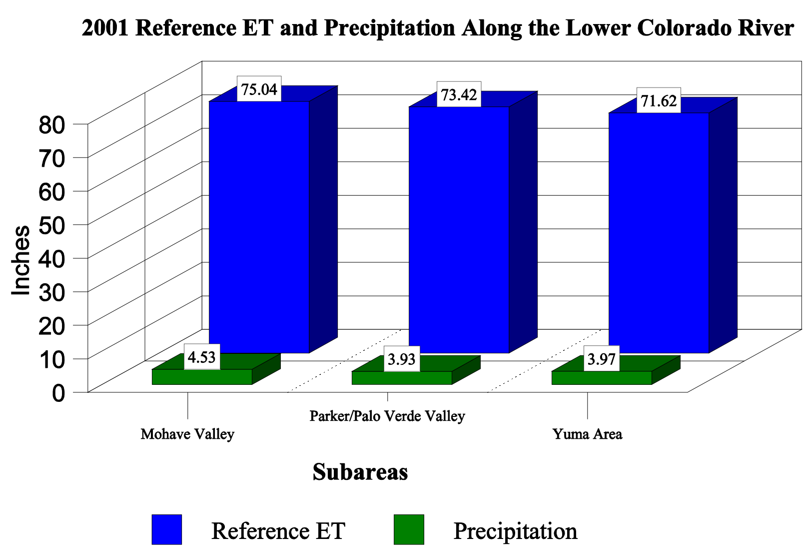


Figure 2.1 — Reference-ET and Precipitation Values by Subarea Along the Lower Colorado River.

ET coefficients for crop and phreatophyte groups

Reclamation adjusted the crop and phreatophyte groups, and ET coefficients for crops, phreatophytes and open water evaporation from those used in previous reports for calendar years 1999 and 2000 to prepare this report. Reclamation added a crop group for herbs and assigned new crops which have appeared along the lower Colorado River to appropriate crop groups. In addition, Reclamation adjusted growing seasons in response to information and data provided by agricultural water users. Reclamation added moist soil units and seasonal wetlands to the phreatophyte groups in response to observations made during field data collection. Reclamation adjusted the ET coefficients for crops, phreatophytes and open water evaporation to more accurately estimate evapotranspiration using the ASCE standardized reference ET Equation.

Jensen, 1998 presents the rationale used to develop the original crop and phreatophyte groups, and ET coefficients for use by the LCRAS program.   Jensen, 2002 presents the adjustments made to the crop and phreatophyte groups, and the ET and evaporation coefficients used in this report.

Table 6.4, in chapter 6, displays the crop groups and sub groups, and table 2.3, previous, shows a list of phreatophyte groups with a description for each group.

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 previously described in “Delineation of crop, phreatophyte, and open-water areas.”

Effective Precipitation

Reclamation calculates effective precipitation for this report as the product of recorded precipitation and an effective precipitation coefficient. 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) record precipitation along the lower Colorado River. Reclamation developed a single daily precipitation value for the Yuma area, Parker and Palo Verde area, and Mohave Valley by averaging precipitation measured at the AZMET, CIMIS and NWS stations located within each area. Jensen, Marvin E., 1993 contains the documentation for the effective precipitation coefficients used for this report.

Reclamation calculates effective precipitation for this report using the following equation,

Effective Precipitation = Daily Precipitation × Monthly Effective Precipitation Coefficient

The depth of precipitation that fell over the lower Colorado River Valley in calendar year 2001 ranged from 1.40 inches, measured by the Yuma Citrus NWS station, to 4.92 inches measured by the Mohave AZMET station.

Agricultural ET (ET_{ag})

Agricultural ET used in the water balance includes the ET of the crops plus an estimate of the evaporation from major delivery canals serving each district or Indian reservation and evaporation from ponds maintained within each district or Indian reservation. Agricultural ET currently does not include any ET from phreatophytes which may consume diverted Colorado River water. Therefore, agricultural ET, as defined here, should be considered a minimum agricultural ET.

The first step in calculating the ET of crops is to calculate an ET rate for each crop group. Reclamation multiplies the average daily reference ET-values (inches) by daily ET coefficients unique to each crop group (dimensionless), to develop the daily ET rate (inches) for each crop group. Reclamation considers the impact of rainfall on crop water use 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, Reclamation must determine the number of acres covered by each crop group within the diverter boundary. Reclamation calculates the number of acres covered by each crop group through the use of remotely sensed data and field surveys previously described in "Delineation of crop, phreatophyte, and open-water areas."

Reclamation calculates monthly ET for each diverter (in acre-feet) by summing the daily net ET rate for each month (inches), multiplying by the area (acres) covered by each crop group within each diverter boundary, and dividing by 12 (inches/foot). Table 2.2, shown previously, lists the crop groups used for this report. Reclamation sums monthly ET for each diverter for the year to yield the annual ET for each diverter.

The following example for cotton illustrates an ET calculation,

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

Where:

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

Σ_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)

Reclamation adds the evaporation from major delivery canals serving, and ponds maintained by, irrigation districts and Indian reservations to the previously calculated ET of crops to derive agricultural ET. The following subsection entitled, “Evaporation from major delivery canals serving irrigation districts and Indian reservations ” under the section entitled, “Evaporation (E) ” discusses canal evaporation calculations. The summation of agricultural ET for all diverters within a reach is the outflow, ET_{ag}, in the water balance.

The sum of the agricultural ET compiled for calendar year 2001 from Hoover Dam to Mexico is 1,182,119 acre-feet. After distribution of the residuals from the water balance in each reach, the final value increased to 1,199,117 acre-feet, a change of about one percent. Agricultural consumptive use is the final value of the agricultural ET, which accounts for about 15 percent of the consumptive use from agricultural, domestic, and export water uses along the lower Colorado River from Hoover Dam to Mexico.

Agricultural water use 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. Agricultural water use in IID and CVWD is included in the export at station 1117 on the All-American Canal, and agricultural water use in WMIDD is included in the export to WMIDD at station 792.87 on the Gila Gravity Main Canal. See the previous section entitled “Export flow (Q_{ex})” for more details.

Phreatophyte ET (ET_{pht})

Reclamation calculates phreatophyte water use for this report the same way as described in the previous section entitled "Agricultural ET (ET_{ag})," except that Reclamation makes no correction to the ET rates of phreatophytes for effective precipitation and there is no addition of evaporation from canals or other areas of open water to the phreatophyte ET term. The summation of ET for all phreatophyte groups within a diverter's boundaries yields the total phreatophyte ET for a diverter. The summation of phreatophyte ET for all diverters within a reach yields the phreatophyte ET_{pht} outflow term for the water balance.

Reclamation uses remote sensing processes, including analysis of aerial photography, to develop the original acreage values for each phreatophyte group used to calculate ET_{pht} in the 1995 LCRAS report. Table 2.3, previous, lists the phreatophyte groups.

Beginning with calendar year 1996 and continuing for calendar year 2001, Reclamation has updated phreatophyte acreage values using remote-sensing-based change detection methodologies. Reclamation field verifies major changes when identified, which usually result from fire or development.

The sum of the ET_{pht} calculated for calendar year 2001 from Hoover Dam to Mexico is 617,864 acre-feet. After distribution of the residuals from the water balance in each reach, the final value of phreatophyte water use increased to 621,046 acre-feet, a change of less than one percent. Phreatophyte water use accounts for about 7 percent of the combined use and loss from agriculture, domestic uses, exports, evaporation, and phreatophytes along the lower Colorado River from Hoover Dam to Mexico.

Evaporation (E)

<u>Evaporation from the mainstream</u>

Reclamation calculates mainstream evaporation from Lakes Mohave and Havasu, and 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 for this report. Reclamation does not consider water consumed by evaporation from the lower Colorado River mainstream, as required for the delivery of water, to be part of the States apportionments of Colorado River water, therefore this evaporation is not consumptive use. Water consumed by evaporation from backwaters is not included in consumptive use summations in this report, pending clarification of the status of these uses with respect to consumptive use.

Open-water evaporation is calculated as follows,

1. sum the average daily reference ET (inches) for a month,
2. multiply the monthly sum of daily reference ET by a monthly evaporation coefficient (dimensionless),
3. from the product in 2, subtract the 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,
5. multiply by the open-water area in acres to yield the monthly open-water evaporation in acre-feet,
6. perform the calculations previously described in 1 through 5 for all months of the year,
7. sum the monthly evaporation for all months of the year to yield an annual evaporation in acre-feet.

Reclamation developed open-water area for this report by analyzing images acquired July 18th, 2001 and November 15th, 2001. The section on remote sensing contains more details. Reclamation calculated evaporation from Hoover Dam to Mexico for calendar year 2001 to be 315,845 acre-feet. After distribution of the residuals from the water balance in each reach, the final value of evaporation decreased to 315,584 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 agriculture, domestic uses, exports, phreatophytes, and evaporation along lower Colorado River from Hoover Dam to Mexico.

Evaporation from major delivery canals serving irrigation districts and Indian reservations

Reclamation adds evaporation from major delivery canals serving irrigation districts and Indian reservations to crop evapotranspiration in the agricultural ET term as a portion of the losses associated with the delivery and use of water for growing crops. Reclamation calculates evaporation from major delivery canals using the same technique previously discussed for evaporation from the mainstream except that the open-water area used in this calculation is the open-water area in the major delivery canals. Reclamation initially digitized the open-water area in major delivery canals using a 5-meter panchromatic image acquired on October 20, 1999 by the Indian Remote Sensing IRS 1-C or 1-D sensors. The open water area of the Gila Gravity Main Canal was updated in 2001 using Landsat 7, 30-meter imagery acquired on July 18, 2001.

Reclamation categorized major delivery canals 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). The Colorado River Indian Reservation Main Canal is an example of a single user canal and the All American Canal is an example of a shared canal.

Reclamation adds evaporation from a single user canal to the crop ET of the irrigation district or Indian reservation which receives water from the canal to develop agricultural ET. Reclamation distributes evaporation from a shared canal among the irrigation districts or Indian reservations which receive water from the canal according to the proportionate use of the canal by each.

Reclamation calculates the proportionate use of a shared 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 district's or Indian reservation's points of diversion from the canal head works and weighing these distances by the diversion through each point (these values have units of miles),

2. multiply the value from 1, previous, for each irrigation district or Indian reservation 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.

The proportionate use of the canal, calculated in step 3, can be expressed as fractions or percentages.

Reclamation assigns a portion the open-water area of the shared canal to each irrigation district or Indian reservation served by the canal based upon the proportionate use of the canal.

Once Reclamation assigns the portion of the open-water area of the shared canal to each irrigation district or Indian reservation, each district's or Indian reservation's assignment of the evaporation is calculated on Sheet H of the water balance tables (see appendix I), as the proportion of open-water area of the shared canal assigned to each district or Indian reservation times the monthly evaporation coefficients previously described for evaporation from the mainstream. The annual sum of the monthly evaporation from the shared canal is the annual evaporation from the shared canal assigned to each irrigation district and Indian reservation.

Evaporation from single user and shared major delivery canals totaled about 12,900 acre-feet in 2001, less than two tenths of one percent of the combined water use from agriculture and exports along the lower Colorado River from Hoover Dam to Mexico.

Domestic consumptive use (CU_d)

Domestic use, as described here, includes municipal use, industrial use, and household use. Domestic use does not include diversions by MWD and CAP (included in export flow), or vegetative water use on wildlife refuges (included in agricultural ET and phreatophyte ET).

Reclamation estimates domestic water use for this report 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 not available, 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. other method unique to the specific circumstances of an individual domestic diverter.

Chapter 8 provides a more detailed explanation of the domestic water use factors used in this report.

Reclamation estimates domestic water use from Hoover Dam to Mexico to be 79,194 acre-feet in calendar year 2001. After distribution of the residuals from the water balance in each reach, the final value of domestic water use (domestic consumptive use) increased by one acre-foot to 79,196 acre-feet. Domestic consumptive use accounts for about one percent of the consumptive use (agricultural, domestic, and export) along the lower Colorado River from Hoover Dam to Mexico.

Change in reservoir storage (ΔS_r)

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

Reclamation reports reservoir storage values monthly in reservoir elevations and contents tables provided by the Lower Colorado Dams Facilities Office. Reclamation calculates the change in reservoir storage values used in this report as the difference between storage calculated on the first day of each month. Table 2.8 shows the annual change in storage values used in this report.

Table 2.8 — Change in reservoir storage and reporting agency

Units: Annual acre-feet

Description	Station Number	Measured ΔS_r	Final ΔS_r After Distribution of Residual	% Change (Final - Measured÷ Measured)	Reporting Agency
Change in storage, Lake Mohave	09422500	46,000	45,975	-0.1%	Reclamation
Change in storage, Lake Havasu	09427500	4,500	4,495	-0.1%	Reclamation
Change in storage, Senator Wash	--	-4,475	-4,475	0.0%	Reclamation

Change in aquifer storage ()S_a)

Reclamation uses a change in aquifer storage value of zero in the water balances 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. Reclamation uses 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), derived from judgement, which 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 (1,364 acre-feet).

Residual (Q_{res})

The residual, which is primarily a summation of the error in all the measurements and estimates used in the water balance, is the difference between the summation of all inflows to the reach, and all outflows from the reach and water uses within the reach. The residual will be positive if inflows to a reach exceed outflows plus water uses. The residual will be negative if outflows plus water uses exceed inflows. The residual will only be zero in an ideal system, where the water balance includes all inflows, outflows, and water uses and each is without measurement or estimation error. The residual will never be zero in the real-world of the lower Colorado River, but can be small when compared to the inflow. Table 2.9 displays the residuals for each reach, along with the inflows, outflows, and water uses of the water balance.

Table 2.9 — 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})	10,209,400	10,567,500	7,699,400	6,148,954	10,209,400
Flow at the downstream boundary (Q_{ds})	10,567,500	7,699,400	6,148,954	1,782,987	1,782,987
Residual	-521,194	-281,241	391,250	98,223	-312,962
Residual as a percentage of the flow at the upstream boundary (Q_{us})	-5.11%	-2.66%	5.08%	1.60%	-3.07%
Difference between flow at the upstream and downstream boundaries (Q_{dif})	-358,100	2,868,100	1,550,446	4,365,967	8,426,413
Measured Tributary inflow (Trm)	0	5,357	0	6,954	12,311
Unmeasured Tributary inflow (Trum)	6,480	36,290	33,750	3,000	79,520
Exported flow (Q_{ex})	0	2,773,504	0	3,816,655	6,590,159
Evaporation (E)	122,083	118,011	66,724	9,027	315,845
Domestic consumptive use (CU_d)	757	40,968	4,220	33,249	79,194
Agricultural ET (ET_{ag})	0	76,193	761,725	344,201	1,182,119
Phreatophyte ET (ET_{pht})	734	177,812	364,752	74,566	617,864
Change in reservoir storage () S_r)	46,000	4,500	-4,475	0	46,025
Change in aquifer storage () S_a)	0	0	0	0	0

The residuals in calendar year 2001 vary from less than 2% to slightly more than 5% of the presumed standard error of estimate of the flow at the upstream reach boundaries. The overall residual from Hoover Dam to Mexico is slightly more than 3%. Reclamation considers these results to be acceptable for a large river system such as the lower Colorado River. Reclamation used the following standard error of estimate values for the upstream flows to each reach, 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.

Reclamation considers distributing the residual to be optional if the value of the residual is equal to or less than the presumed standard error of estimate of the mainstream inflow. Reclamation chooses to distribute the residual in all reaches for LCRAS Demonstration of Technology reports to demonstrate the mechanics of the distribution and the distribution's impact on consumptive use values.

Reclamation distributes the residual 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. Reclamation proportions the residual by dividing the variance of a term of the water balance by the sum of the variances for all terms of the water balance. Reclamation then subtracts this proportion of the residual (in acre-feet) 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.

Reclamation uses standard error of estimate and variance values based upon values recommended in Lane, W. L., 1998 in this report. Reclamation adjusts some of the recommended values based upon judgment. Sheet A of the water-balance tables in appendix I displays the standard error of estimate and variance values used in the water balance for calendar year 2001.

Interaction between Reaches

An inconsistency in the final value 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 final 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 the distributed value of the flow below Davis Dam is in the Davis Dam to Parker Dam reach. When the interaction between these reaches is considered, the result is a one final value of flow 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).

Reclamation resolves the interaction between reaches using a three-step process:

1. Temporarily fix the flow below Hoover Dam at the gaged value.
2. Calculate temporary adjusted flows 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}[13] from each reach.

3. Subtract the average of the difference between the gaged flows and the temporary adjusted flows, previously calculated in 2, from the temporary adjusted flows to yield the final adjusted flow below or at each dam and to Mexico.

Table 2.10 shows the calculations previously described applied to calendar year 2001 values, and the adjusted flows below Hoover, Davis, and Parker Dams, at Imperial Dam, and to Mexico.

[13] 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 2.10 — 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 [14]	Average
Gaged flow	10,209,400	10,567,500	7,699,400	6,148,954	1,782,987	
Amount of residual from the water balance of each reach below each dam apportioned to Q_{dif} .	-520,708	-270,039	371,318	80,302	N/A	
Temporary adjustments to flows (start with zero at most upstream dam and add cumulatively to most downstream flow)	0	-520,708	-790,747	-419,429	-339,127	-414,002
Temporary adjusted flows (gaged flow + temporary adjustment)	10,209,400	10,046,792	6,908,653	5,729,525	1,443,860	
Final flows (temporary adjusted flow - average of temporary adjustments)	10,623,402	10,460,794	7,322,655	6,143,528	1,857,863	
Final adjustments (final adjusted flow - gaged flow)	414,002	-106,706	-376,745	-5,426	74,876	
Final adjustments to gaged flows in percent	4.06%	-1.01%	-4.89%	-0.09%	4.20%	

By solving this boundary problem, Reclamation can create a table of adjusted values for the whole water balance which yields a residual of zero for all reaches of the lower Colorado River below Hoover Dam and calculate a distributed value of the underflow to Mexico. Table 2.11 shows the final values of the water balance.

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

Table 2.11 — 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})	10,623,402	10,460,794	7,322,655	6,143,528	10,623,402
Flow at the downstream boundary (Q_{ds})	10,460,794	7,322,655	6,143,528	1,857,863	1,857,863
Residual (Q_{res})	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	162,608	3,138,139	1,179,127	4,285,665	8,765,539
Measured tributary inflow (Trm)	0	5,378	0	6,952	12,330
Unmeasured tributary inflow (Trum)	6,506	36,677	32,727	2,993	78,903
Exported flow (Q_{ex})	0	2,763,462	0	3,831,008	6,594,470
Evaporation (E)	121,823	117,897	66,835	9,029	315,584
Domestic consumptive use (CU_d)	757	40,966	4,220	33,253	79,196
Agricultural consumptive use(CU_{ag})	0	76,146	776,204	346,767	1,199,117
Phreatophyte water use (CU_{pht})	734	177,554	368,072	74,686	621,046
Change in reservoir storage ()S_r)	45,975	4,495	-4,475	0	45,995
Change in aquifer storage ()S_a)	-175	-326	998	867	1,364

Sample Calculation

This sample calculation shows how agricultural consumptive use is calculated for a diverter. The Colorado River Indian Reservation in Arizona (CRIR) will serve as the sample diverter and the Parker Dam to Imperial Dam reach will serve as the sample reach..

The calculation for agricultural consumptive use has four major steps.

1. Calculate the agricultural ET for each diverter within a reach and sum these values to calculate agricultural 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 agricultural consumptive use for the reach by distributing the residual to agricultural 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 agricultural consumptive use for each diverter by apportioning the agricultural consumptive use for the reach to each diverter in the same proportion that agricultural ET for each diverter is to agricultural ET for the reach.

The following paragraphs describing agricultural ET and consumptive use at CRIR and within the Parker Dam to Imperial Dam reach present detailed explanations of each of the four steps previously described. 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.[15]

Calculate agricultural ET for each diverter within the reach

Agricultural ET for a reach is the sum of the agricultural ET for all of the diverters within a reach. The agricultural ET of a diverter is the sum of the ET of each crop grown, and an estimate of evaporation from open water areas within the diverter boundary and major delivery canals which serve the diverter. 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. Evaporation 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 sum of the number of acres of open water within the diverter boundary and the major delivery canals (or the portion of a shared canal assigned to the single diverter).

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

[15] Reclamation calculated the crop acreage data shown in this sample calculation using remote sensing/GIS processes; CRIR did not provide the crop acreage data shown in this sample calculation.

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 January 8, 2001. The area-specific reference ET for the Parker/Palo Verde Valleys is used to calculate ET for CRIR. Reclamation chose January 8th 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 2.12.

Table 2.12 — Reference ET values for January 8, 2001

	Reference ET for January 8, 2001 (Standardized Equation)	
AZMET/CIMIS Station Name	Millimeters	Inches
Parker AZMET station site	2.3	0.09
Blythe NE CIMIS station site	1.6	0.06
Ripley CIMIS station site	1.4	0.06
Area-Specific Reference ET	1.8	0.07

The following shows the area-specific reference ET calculation for January 8th:

$$\text{Area-Specific Reference ET} = (2.3+1.6+1.4) \div 3 \div 25.4 \text{ millimeters/inch}$$
$$= 0.07 \text{ inches (rounded)}$$

This sample calculation proceeds using alfalfa - perennial as the sample crop group, referred to hereafter simply as alfalfa. Note the following values for January 8th:

Area-Specific reference ET	=	0.07 (listed on Sheet D, inches)
ET Coefficient for alfalfa	=	1.104 (listed on page 2 of 2, Sheet E, dimensionless)
Precipitation	=	0.07 (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 dimensionless coefficient which varies by the month of the year (0.4 for January, from Sheet C). The following shows the daily ET rate calculation for alfalfa:

The following shows the daily ET rate[16] for alfalfa on January 8th:

Daily ET Rate$_{alfalfa}$ = Reference ET (0.07 inches from Sheet D) * ET coefficient for alfalfa (1.104 from Sheet E, page 2 of 2), - effective precipitation (0.07 inches, * 0.4 = 0.028 inches) rounded to 0.03 inches on Sheet C)

= 0.047 inches (round to 0.05 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. Irrigation must meet this loss of soil moisture.

The example continues with the calculation of ET (in acre-feet) for alfalfa for the month of January. The ET rate for alfalfa for the month of January is the summation of the daily ET rates for alfalfa calculated

[16] 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.

for all the days of January. (1.31 inches, from the Parker/Palo Verde ET-rate Table, Sheet E, page 1 of 2) and the acreage of alfalfa on CRIR listed for January 2001 (50,064 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 following shows the calculation of ET for alfalfa for the month of January:

$ET_{alfalfa}$ for January = 1.31 (inches) * 50064 (acres) ÷ 12 (inches/foot)

= 5,465 acre-feet (rounded to nearest acre-foot, Sheet O, Page 1 of 5).

Reclamation calculates evaporation from open water (including the open water of major delivery canals) much like ET for crops, except that Reclamation uses monthly calculations instead of daily calculations and Reclamation considers all precipitation to be effective in reducing evaporation (no calculation for effective precipitation is required). Appendix I, Part 2, 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),” shows the calculations of evaporation from open water of major delivery canals at CRIR. 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),” shows the results of calculations of evaporation from the open water of major delivery canals.

The following shows a sample calculation of evaporation from the open water of major delivery canals within CRIR for the month of January, 2001 (all values can be found on Sheet H).

Canal Evaporation for January = [+Reference ET (inches) * Evaporation Coefficient (dimensionless),- Precipitation (inches)] * Open Water Area In Canals (acres) ÷ 12 Inches/Foot

Canal Evaporation for January = [(2.28 inches *0.68) - 0.96 inches] * 279 acres ÷ 12 inches/foot = 14 acre-feet (rounded to nearest acre-foot)

The annual agricultural ET for CRIR is calculated by summing the monthly ET for each crop group and the evaporation from major delivery canals within CRIR. The agricultural ET for the reach used in the water balance is the annual sum of the ET for each crop and evaporation from open water (canals and ponds), 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 agricultural ET calculated for CRIR to derive the agricultural consumptive use for CRIR. The Parker Dam to Imperial Dam Water-Balance Table, Sheet A presents the values used in the water balance.

Reclamation performs the water balance between Parker and Imperial Dams on annual values. The water balance consists of many parts and each part used for calendar year 2001 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 is 7,699,400 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 is 33,750 acre-feet, as shown on Sheet C of the Parker Dam to Imperial Dam Water-Balance Table. The Geological Survey (page 46 of Owen-Joyce, Sandra J., and Raymond, Lee H., 1996) provided unmeasured tributary inflow value. 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, 6,148,954 acre-feet as shown on Sheet A, is the sum of four flows as shown on Sheet H of the Parker Dam to Imperial Dam Water-Balance Table. The four flows are,

1) Station 60 on the All-American Canal, 4,888,600 acre-feet,

2) Station 30 on the Gila Gravity Main Canal, 822,608 acre-feet,

3) the inflow to Mittry Lake, 10,426 acre-feet and,

4) the Colorado River Sluiceway, 427,320 acre-feet.

There are no exports from the system between Parker and Imperial Dams. Reclamation reports exports on sheet D when exports are present.

Evaporation

This evaporation calculation represents the evaporation from the open water of the mainstream, including reservoirs, and does not include evaporation from the open water of major delivery canals or ponds within an irrigation district or Indian reservation.

Reclamation calculates evaporation 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 is the evaporation for the Parker Dam to Imperial Dam reach. The following shows the evaporation calculation for January for river section 1.

Evaporation = [[January sum of daily reference ET (2.28 inches) * January evaporation coefficient (0.68)] - precipitation (0.96 inches)] * area of open water (4,008 acres) ÷ 12 (inches/foot)

= 197 acre-feet

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

Domestic consumptive use

Reclamation sums several users, as shown on Sheet E of the Parker Dam to Imperial Dam Water-Balance Table, to estimate domestic water use between Parker and Imperial Dams. Reclamation uses the methods described in the previous section entitled “Domestic Use (CU_d)” to develop these values. For example, Reclamation estimates Poston, with a population of approximately 389 (2000 census) to use 54 acre-feet annually (389 * 0.14). Reclamation calculates monthly values 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. Reclamation estimates domestic water use for Poston in the month of January to be 4.5 acre-feet [389 people * (0.14 ÷ 12)].

Change in reservoir storage

Senator Wash is the only reservoir between Parker and Imperial Dams. Reclamation calculates the change in reservoir storage 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, 2000, is 6,100 acre-feet and end-of-month storage, measured midnight January 31, 2001, is 6,601 acre-feet. The difference is an increase of 501 acre-feet. The annual change in reservoir storage is the difference between the January beginning-of-month storage and the December end-of-month storage (4,475 acre-foot loss in calendar year 2001).

The residual

Reclamation calculates the residual on Sheet A, page 1 of 2, of the Parker Dam to Imperial Dam Water-Balance Table. This result for calendar year 2001 is 391,250 acre-feet, or about 5.08 percent of the flow below Parker Dam. The following shows the residual calculation (see previous section entitled "Water Balance" for definitions of terms),

$$\text{Residual} = Q_{dif}\ (1{,}550{,}446) + Q_{Trum}\ (33{,}750) - S_r\ (-4{,}475) - CU_d\ (4{,}220) - ET_{ag}\ (761{,}725) - ET_{pht}\ (364{,}752) - E\ (66{,}724)$$

$$= 391{,}250 \text{ acre-feet}$$

Calculate agricultural consumptive use for the reach

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

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

Where:

Agricultural CU_{Reach}	=	Agricultural consumptive use between Parker and Imperial Dams
Agricultural ET_{Reach}	=	Agricultural ET between Parker and Imperial Dams
VAR_{ETag}	=	The variance of the agricultural 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

Reclamation presumes the SEE of the agricultural ET in the Parker Dam to Imperial Dam reach, 761,725 acre-feet, to be 5 percent yielding a variance of 1,450,543,396 acre-feet squared. The TVAR of the reach is 39,196,042,547 acre-feet squared, and the residual is 391,250 acre-feet. Sheet A of the Parker Dam to Imperial Dam Water-Balance Table shows all the values in the previous paragraph.

The following shows the result of substituting the previously mentioned values into the equation used to calculate Agricultural consumptive use for the Parker Dam to Imperial Dam reach:

$$\text{Agricultural } CU_{Reach} = 761{,}725 + [(1{,}450{,}543{,}396 \div 39{,}196{,}042{,}547) \times (391{,}250)]$$

$$\text{Agricultural } CU_{Reach} = 776{,}204 \text{ acre-feet}$$

Calculate the agricultural consumptive use for each diverter

Reclamation calculates the agricultural consumptive use for each diverter by apportioning the agricultural consumptive use for the reach to all the diverters in the same proportion that the agricultural ET of each diverter is to the total agricultural ET for the reach. The following shows the calculation of agricultural consumptive use for CRIR.

$$\text{Agricultural CU}_{CRIR} = \text{Agricultural ET}_{CRIR} \div \text{Agricultural ET}_{Reach} * \text{Agricultural CU}_{Reach})$$

Where:

$\text{Agricultural CU}_{CRIR}$ = Agricultural consumptive use for CRIR,
$\text{Agricultural ET}_{CRIR}$ = Agricultural ET for CRIR,
$\text{Agricultural ET}_{Reach}$ = Agricultural ET between Parker and Imperial Dams,
$\text{Agricultural CU}_{Reach}$ = Agricultural consumptive use between Parker and Imperial Dams.

Sheet O, page 1 of 5 or on Sheet A, page 2 of 2 shows the agricultural ET for CRIR Sheet A, page 1 of 2 shows values for the other variables previously defined for the Parker Dam to Imperial Dam Water-Balance Table. Substituting values into the equation described previously yields the agricultural consumptive use for CRIR:

$\text{Agricultural CU}_{CRIR}$ = 338,909 acre-feet ÷ 761,725 acre-feet * 776,204 acre-feet
$\text{Agricultural CU}_{CRIR}$ = 345,351 acre-feet [17]

Results

The tables and charts found on the following pages and in chapter 4 present the results of LCRAS for Calendar Year 2001. Table 2.13 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 consumptive use values reported by the decree accounting report and those calculated by LCRAS can be attributed to:

[17] Results shown in the example and those reported in appendix 1 sometimes differ due to rounding of values used in the calculations or rounding of results.

1. diverters which Reclamation reports in LCRAS but not in the decree accounting report.

2. the decree accounting report does not include unmeasured return flows in calculations of consumptive use for individual diverters. The decree accounting report subtracts the sum of unmeasured return flows for the whole basin from the sum of diverter consumptive use for the whole basin as a correction to derive the basin total consumptive use. The basin totals in LCRAS are simply the sum of the values for individual diverters.

3. Reclamation currently reports consumptive use in LCRAS for fields immediately adjacent to, but not within, irrigation district boundaries as charged to the State or other service within which the field actually resides. This reporting convention holds in LCRAS even if all of the fields are irrigated from the same diversion. The decree accounting report does not have the resolution of analysis needed to identify fields that are adjacent to but not within an irrigation district and therefore includes fields immediately adjacent to an irrigation district in estimates of district consumptive use unless the adjacent fields report a diversion separately from the irrigation district.

Table 2.13 — LCRAS Agricultural, Domestic, and Export Consumptive Use, Phreatophyte Water Use, and Consumptive Use from the Decree Accounting Report

Units: annual acre-feet.

LCRAS			**Decree Accounting Report**	
Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
Nevada				
Uses above Hoover Dam (from 2001 decree accounting report)		295,447	295,447	Uses above Hoover Dam
Uses below Hoover Dam	18,252	18,395	19,983	Uses below Hoover Dam
			1,492	Unmeasured return flow credit
Nevada Total	18,252	313,842	313,938	Nevada Total
California				
			5,254,722	Sum of individual diverters
			86,075	Unmeasured return flow credit
California Total	176,315	5,142,976	5,168,647	California Total
Arizona				
Subtotal (Below Hoover Dam, less Wellton-Mohawk IDD)	0	0	60,814	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (from the 2001 decree accounting report)		0	0	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (from 2001 decree accounting report)		0	153,216	Wellton-Mohawk IDD
			124	Pumped from South Gila wells (DPOCs): returns
			2,687,811	Unmeasured return flow credit
Arizona Total	0	0	-2,473,905	Arizona Total
Lower Colorado River Basin Total				
Total Use	194,567	5,456,818	3,008,681	Total Use

Figure 2.2 presents results for the states of California and Arizona. Chapter 4 displays results for each diverter, as well as state and basin totals.

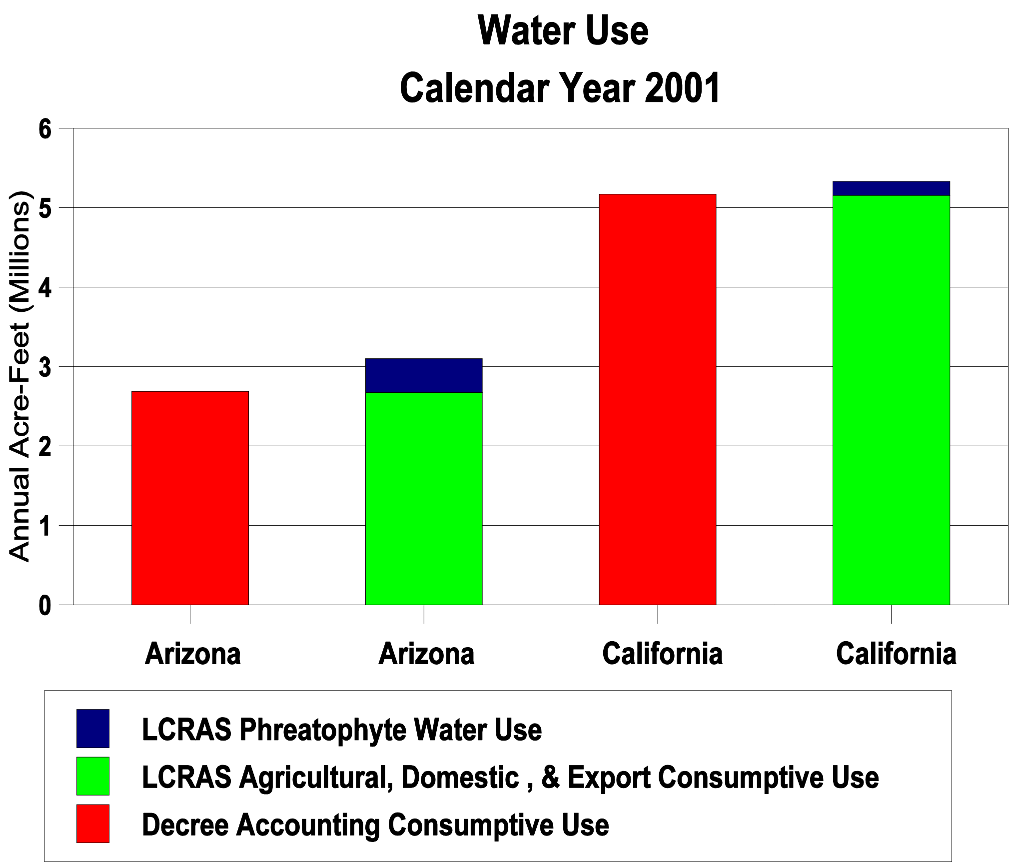


Figure 2.2 — State water use totals for Arizona and California (calendar year 2001).

LOWER COLORADO RIVER ACCOUNTING SYSTEM
MAP INDEX - CY 2001

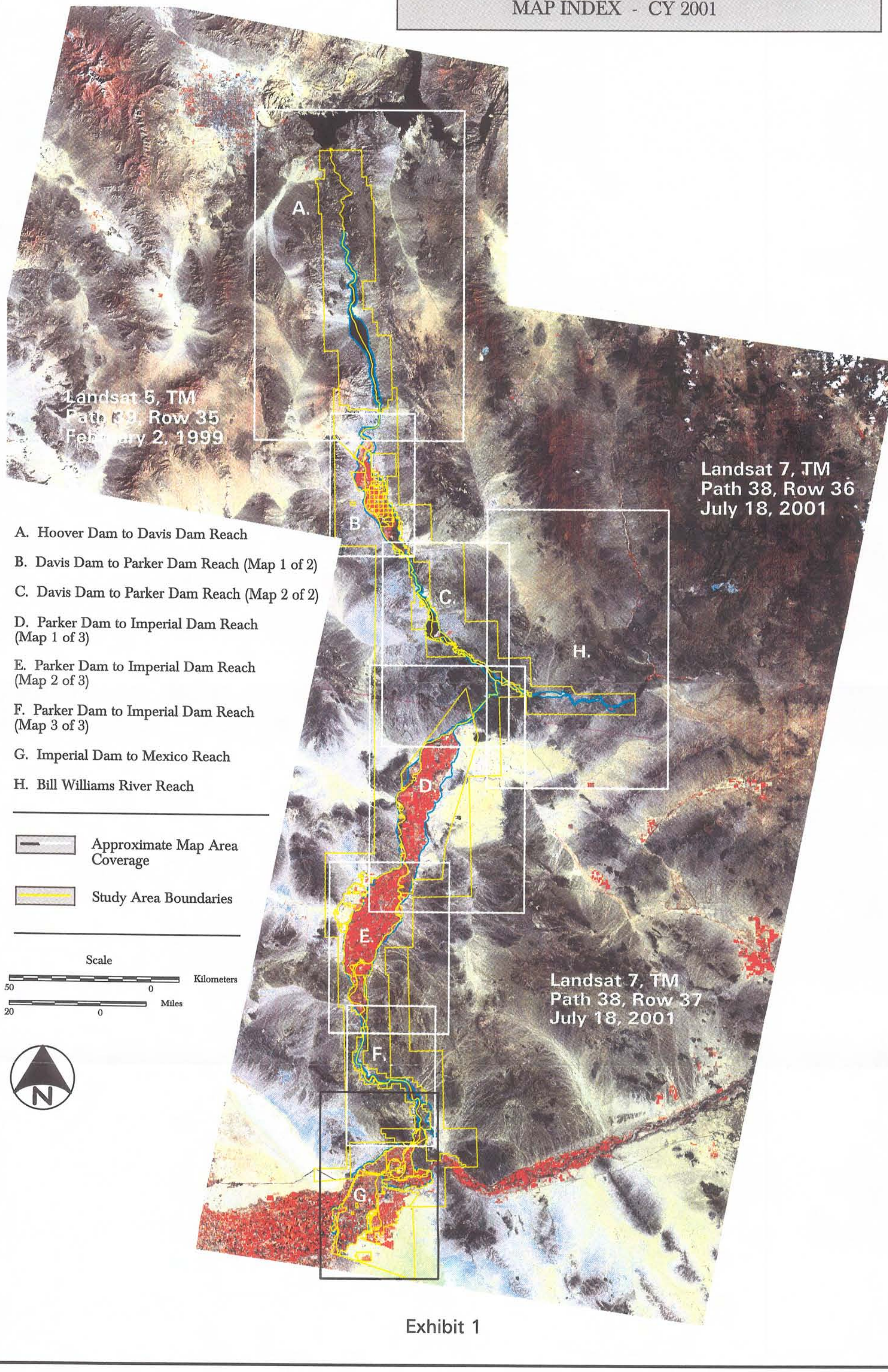
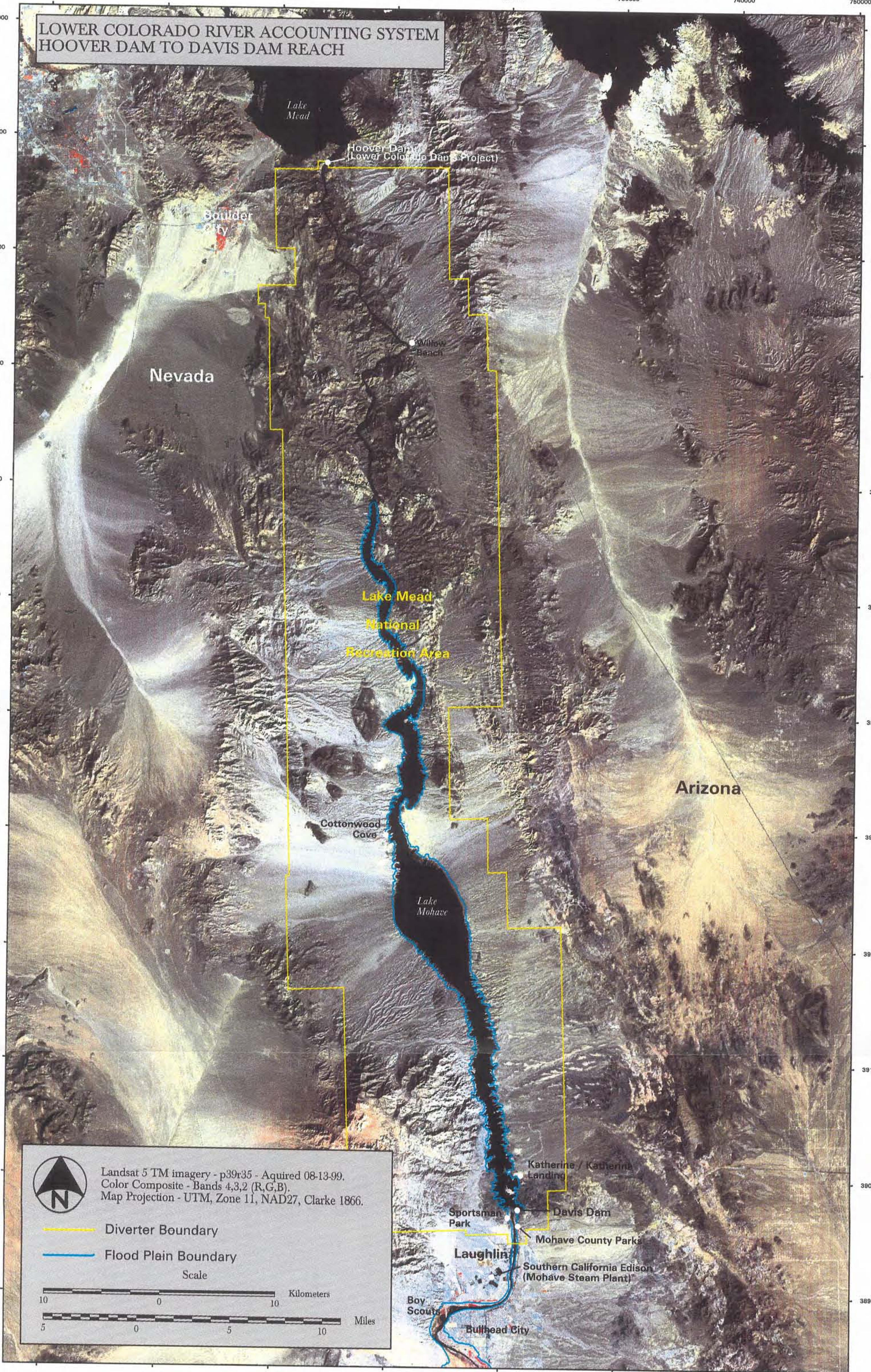
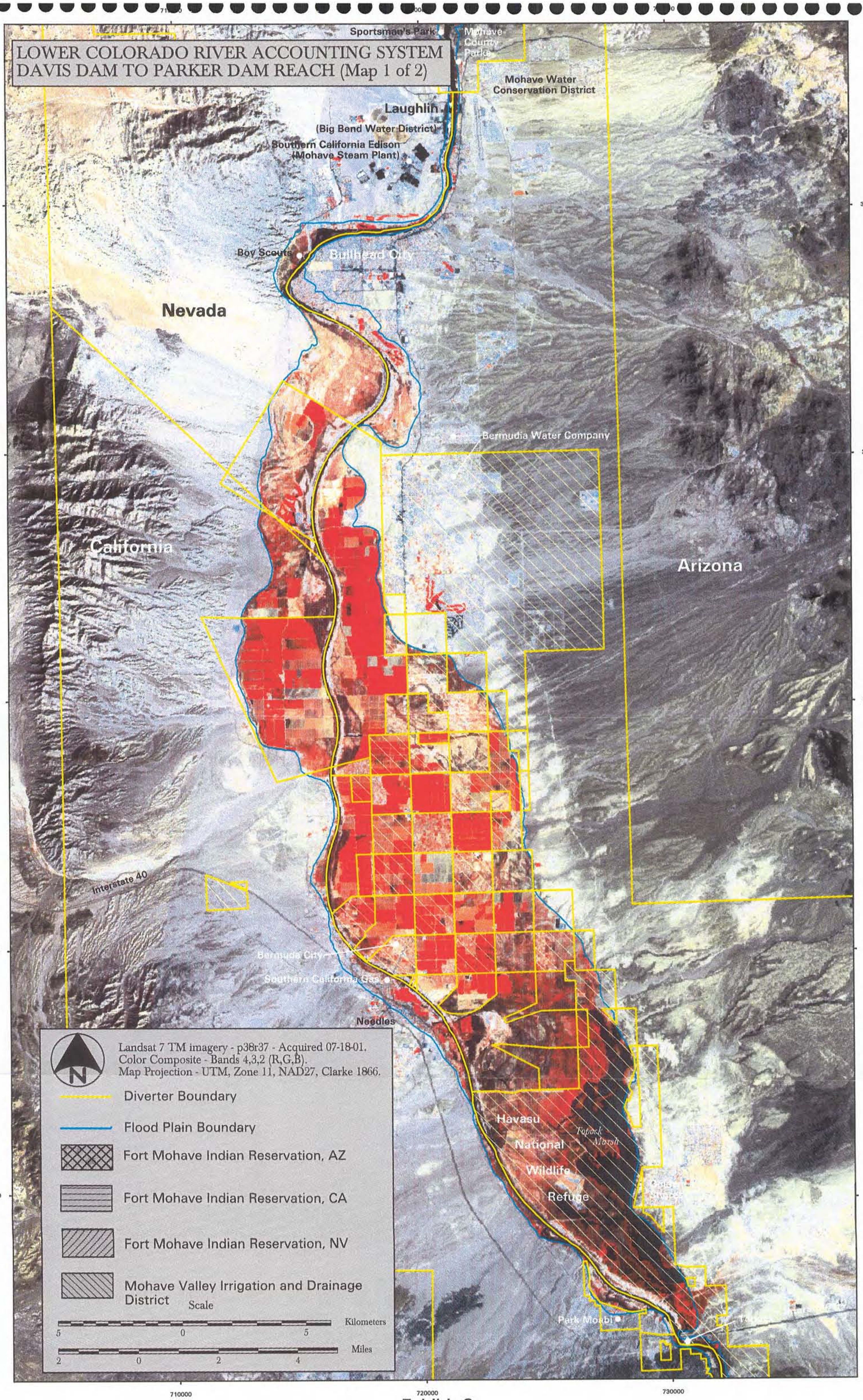


Exhibit 1



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

Exhibit 2



LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 1 of 2)
Sportsman's Park
Mohave County Parks
Mohave Water Conservation District
Laughlin
(Big Bend Water District)
Southern California Edison (Mohave Steam Plant)
Boy Scouts
Bullhead City
Nevada
Bermudia Water Company
California
Arizona
Interstate 40
Bermuda City
Southern California Gas
Needles
Havasu National Wildlife Refuge
Topock Marsh
Park Moabi
Landsat 7 TM imagery - p38r37 - Acquired 07-18-01.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
Diverter Boundary
Flood Plain Boundary
Fort Mohave Indian Reservation, AZ
Fort Mohave Indian Reservation, CA
Fort Mohave Indian Reservation, NV
Mohave Valley Irrigation and Drainage District
Scale
Kilometers
5 0 5
Miles
2 0 2 4
710000
720000
730000

Exhibit 3

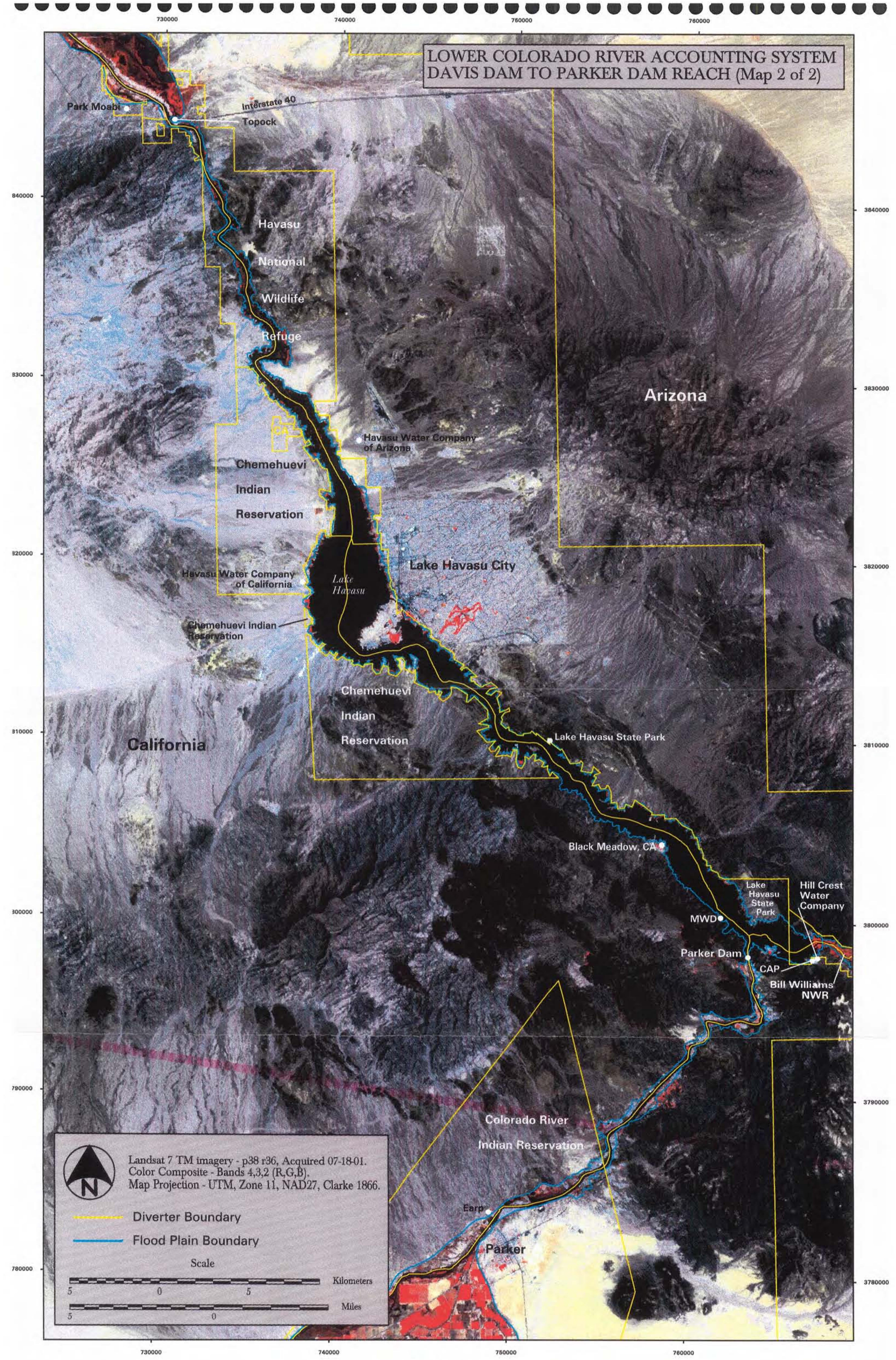
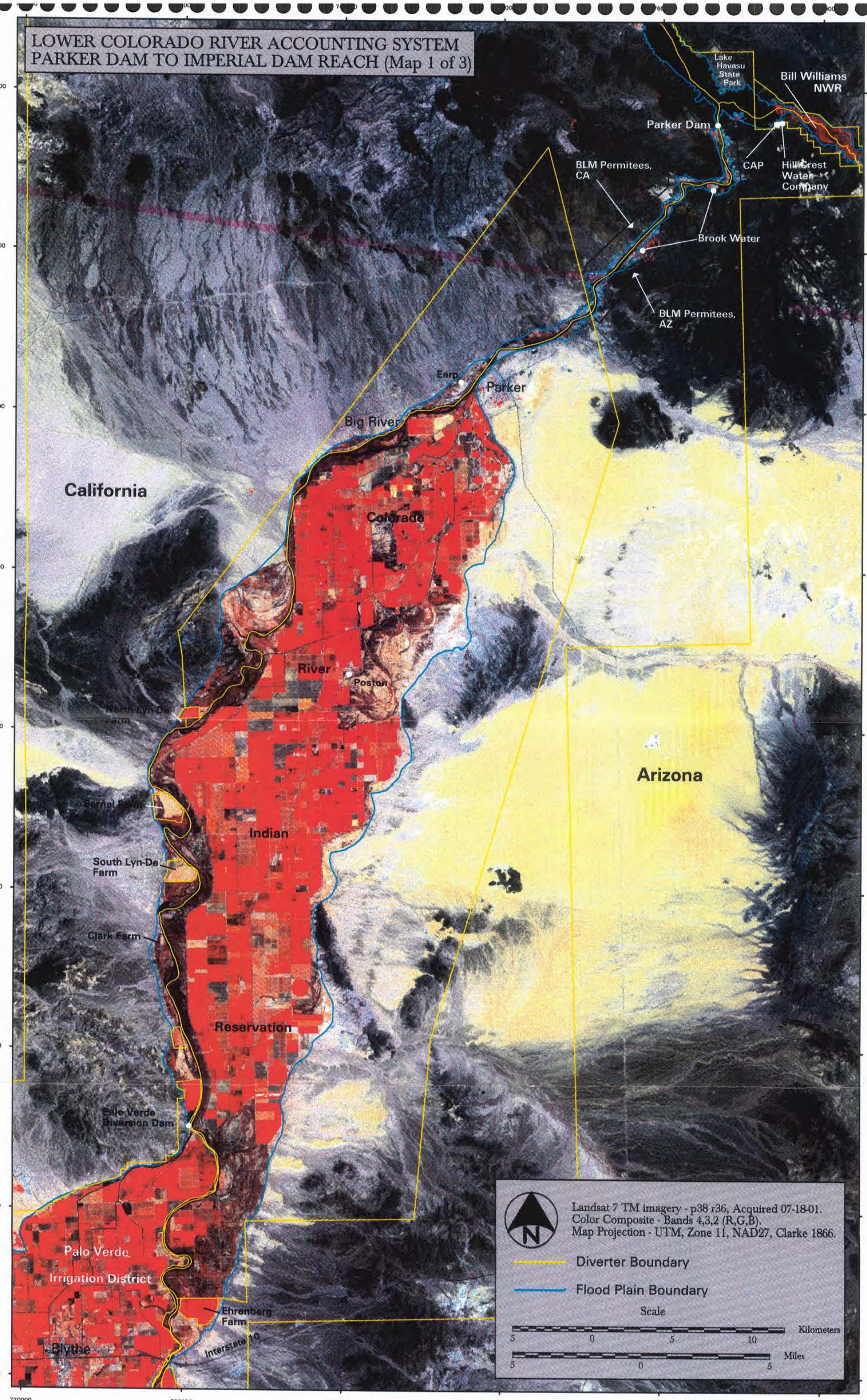

LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 2 of 2)
Park Moabi
Interstate 40
Topock
Havasu
National
Wildlife
Refuge
Arizona
Havasu Water Company of Arizona
Chemehuevi
Indian
Reservation
Lake Havasu City
Havasu Water Company of California
Lake Havasu
Chemehuevi Indian Reservation
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, Acquired 07-18-01.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
N
Diverter Boundary
Flood Plain Boundary
Scale
Kilometers
Miles
730000
740000
750000
760000
3840000
3830000
3820000
3810000
3800000
3790000
3780000

Exhibit 4



LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 1 of 3)
Lake Havasu State Park
Bill Williams NWR
Parker Dam
CAP
Hill Crest Water Company
BLM Permitees, CA
Brook Water
BLM Permitees, AZ
Earp
Parker
Big River
California
Colorado
River
Poston
Indian
Reservation
Arizona
South Lyn-De Farm
Clark Farm
Palo Verde Diversion Dam
Palo Verde
Irrigation District
Ehrenberg Farm
Blythe
Interstate 10
Landsat 7 TM imagery - p38 r36, Acquired 07-18-01.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
Diverter Boundary
Flood Plain Boundary
Scale
Kilometers
Miles
3800000
3790000
3780000
3770000
3760000
3750000
3740000
3730000
3720000
720000
730000
740000
750000
760000
770000

Exhibit 5

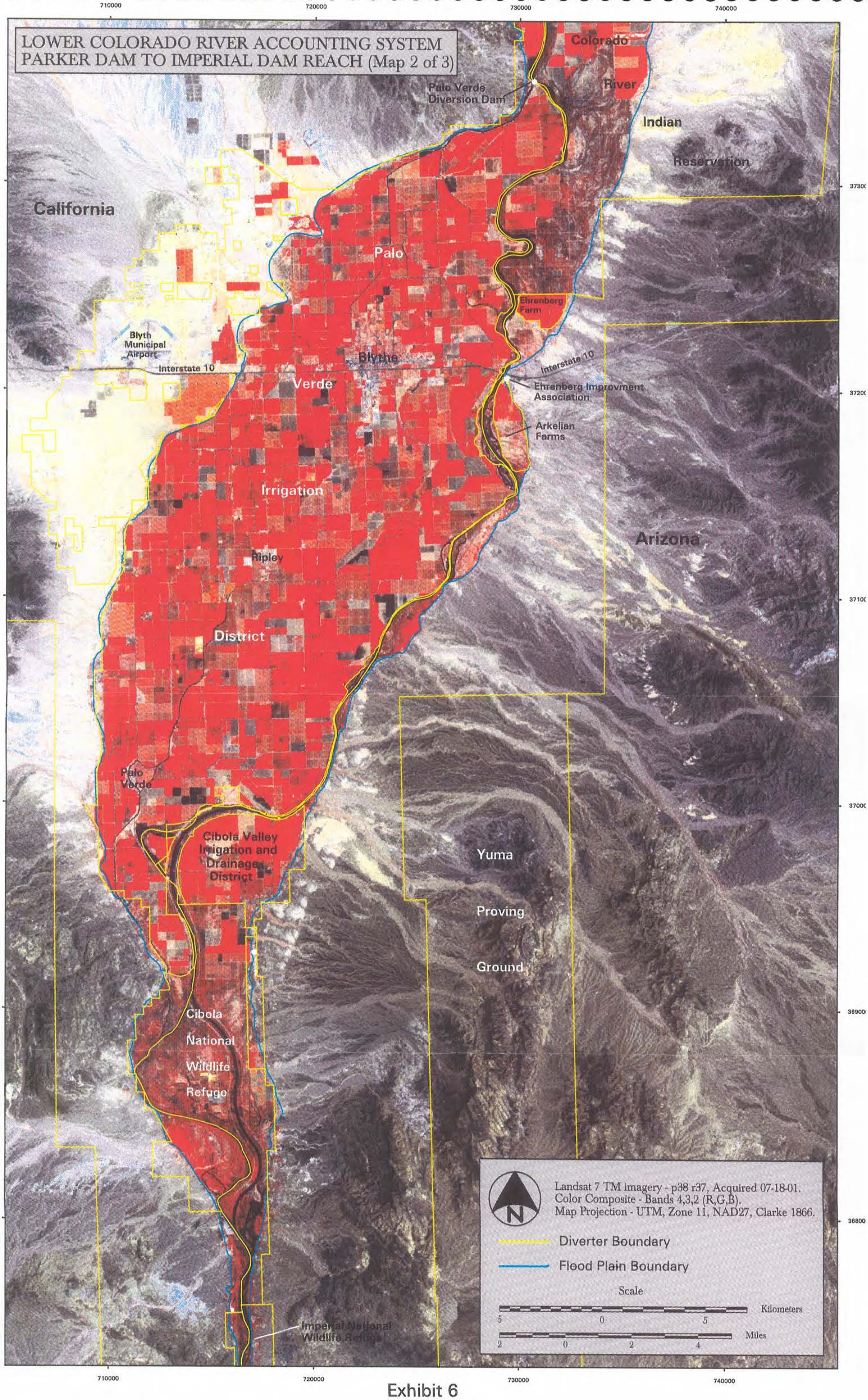
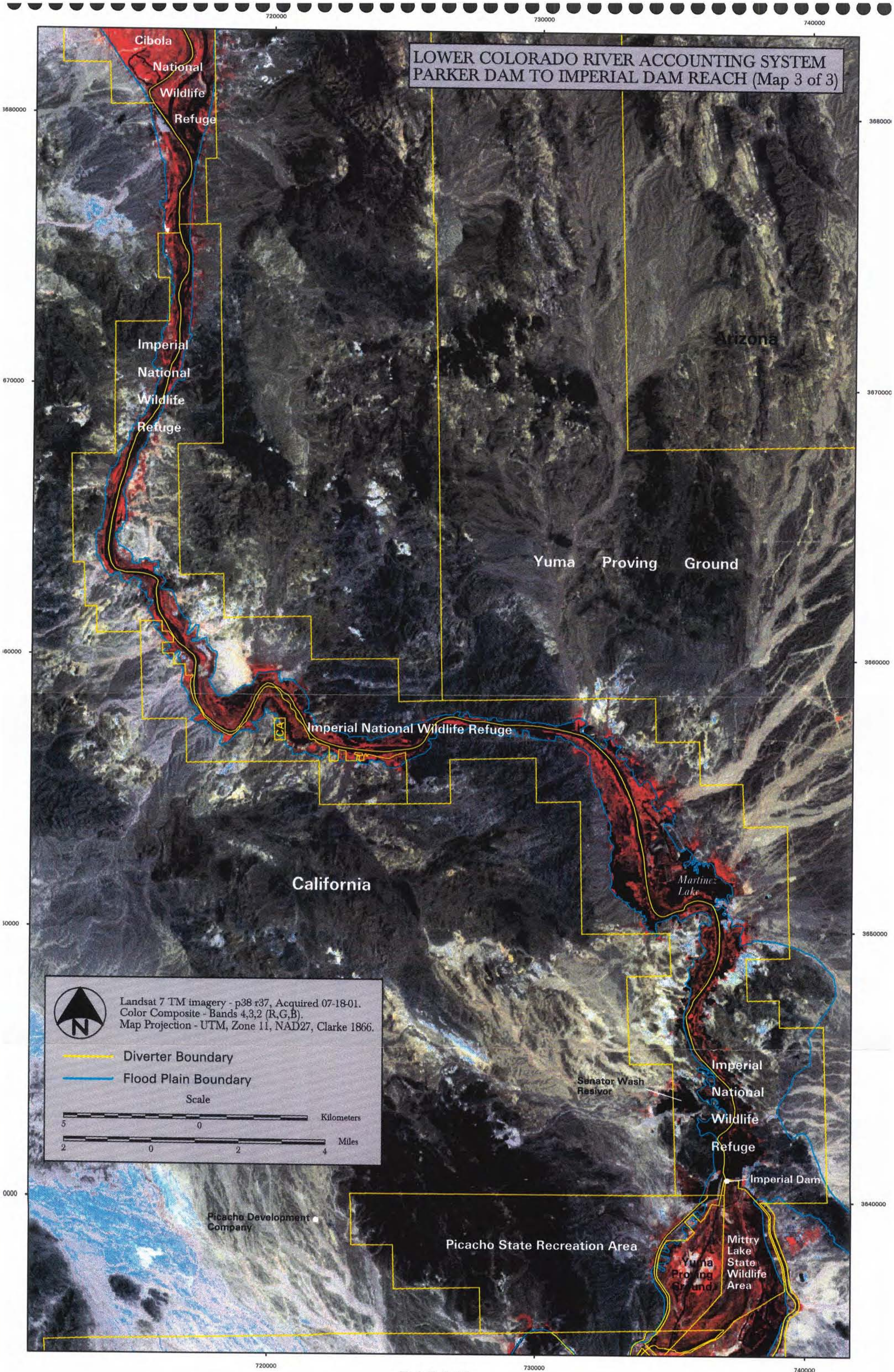

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 2 of 3)
710000
720000
730000
740000
3730000
3720000
3710000
3700000
3690000
3680000
Colorado
River
Indian
Reservation
Palo Verde
Diversion Dam
California
Palo
Verde
Irrigation
Ripley
District
Blythe
Blyth
Municipal
Airport
Interstate 10
Ehrenberg
Farm
Ehrenberg Improvment
Association
Arkelian
Farms
Arizona
Palo
Verde
Cibola Valley
Irrigation and
Drainage
District
Yuma
Proving
Ground
Cibola
National
Wildlife
Refuge
Imperial National
Wildlife Refuge
Landsat 7 TM imagery - p38 r37, Acquired 07-18-01.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
Diverter Boundary
Flood Plain Boundary
Scale
Kilometers
Miles

Exhibit 6



LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 3 of 3)
720000
730000
740000
3680000
3670000
3660000
3650000
3640000
Cibola National Wildlife Refuge
Imperial National Wildlife Refuge
Arizona
Yuma Proving Ground
Imperial National Wildlife Refuge
CA
California
Martinez Lake
Senator Wash Resivor
Imperial National Wildlife Refuge
Imperial Dam
Picacho Development Company
Picacho State Recreation Area
Yuma Proving Ground
Mittry Lake State Wildlife Area
N
Landsat 7 TM imagery - p38 r37, Acquired 07-18-01.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
Diverter Boundary
Flood Plain Boundary
Scale
5
0
Kilometers
2
0
2
4
Miles

Exhibit 7

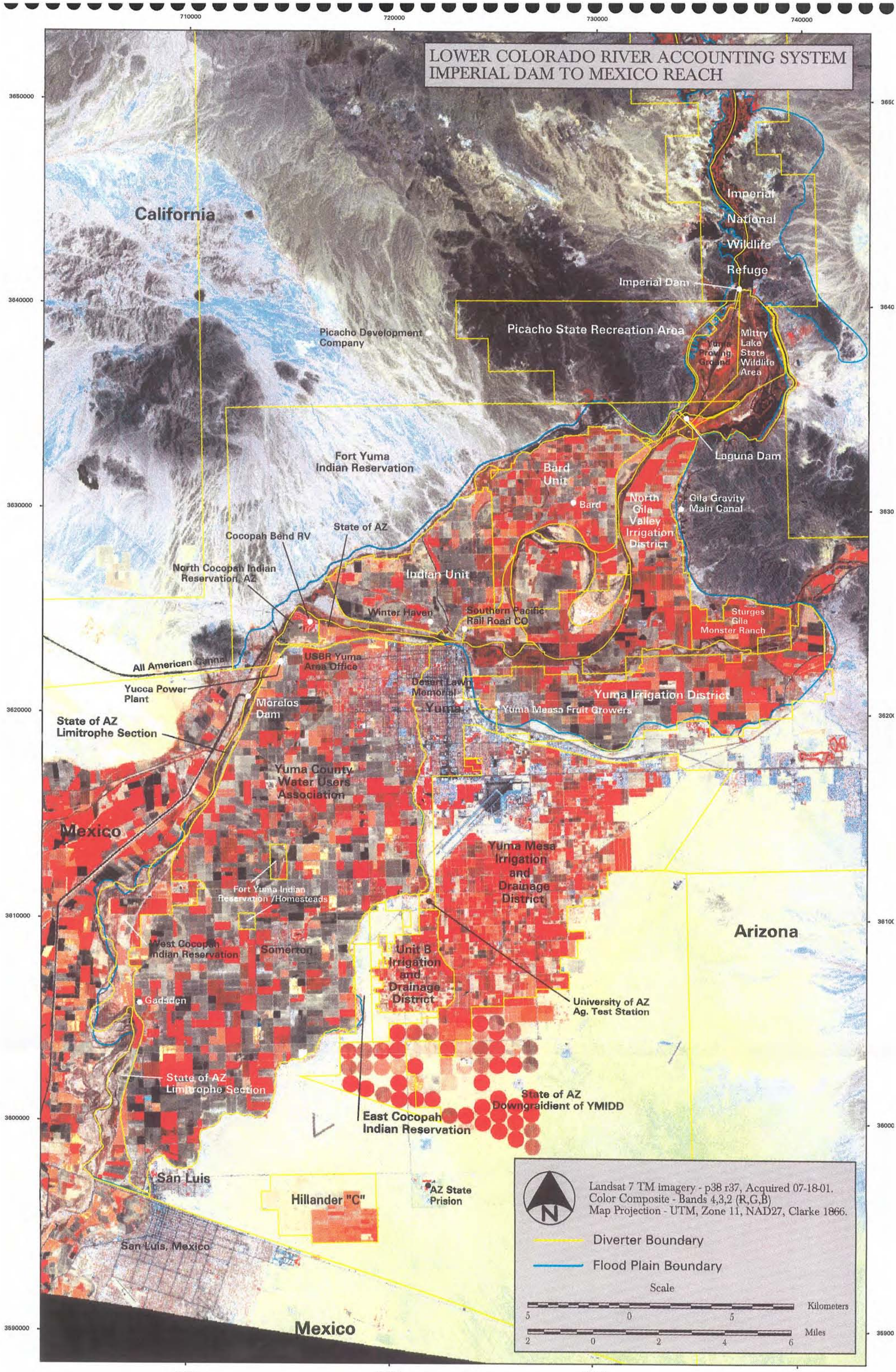

LOWER COLORADO RIVER ACCOUNTING SYSTEM
IMPERIAL DAM TO MEXICO REACH
California
Imperial National Wildlife Refuge
Imperial Dam
Picacho Development Company
Picacho State Recreation Area
Yuma Proving Ground
Mittry Lake State Wildlife Area
Laguna Dam
Fort Yuma Indian Reservation
Bard Unit
Bard
North Gila Valley Irrigation District
Gila Gravity Main Canal
Cocopah Bend RV
State of AZ
North Cocopah Indian Reservation, AZ
Indian Unit
Winter Haven
Southern Pacific Rail Road CO
Sturges Gila Monster Ranch
All American Canal
USBR Yuma Area Office
Yucca Power Plant
Desert Lawn Memorial
Morelos Dam
Yuma
Yuma Irrigation District
Yuma Mesa Fruit Growers
State of AZ Limitrophe Section
Yuma County Water Users Association
Mexico
Yuma Mesa Irrigation and Drainage District
Fort Yuma Indian Reservation /Homesteads
Arizona
West Cocopah Indian Reservation
Somerton
Unit B Irrigation and Drainage District
Gadsden
University of AZ Ag. Test Station
State of AZ Limitrophe Section
State of AZ Downgraident of YMIDD
East Cocopah Indian Reservation
San Luis
Hillander "C"
AZ State Prision
San Luis, Mexico
Mexico
Landsat 7 TM imagery - p38 r37, Acquired 07-18-01.
Color Composite - Bands 4,3,2 (R,G,B)
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
N
Diverter Boundary
Flood Plain 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

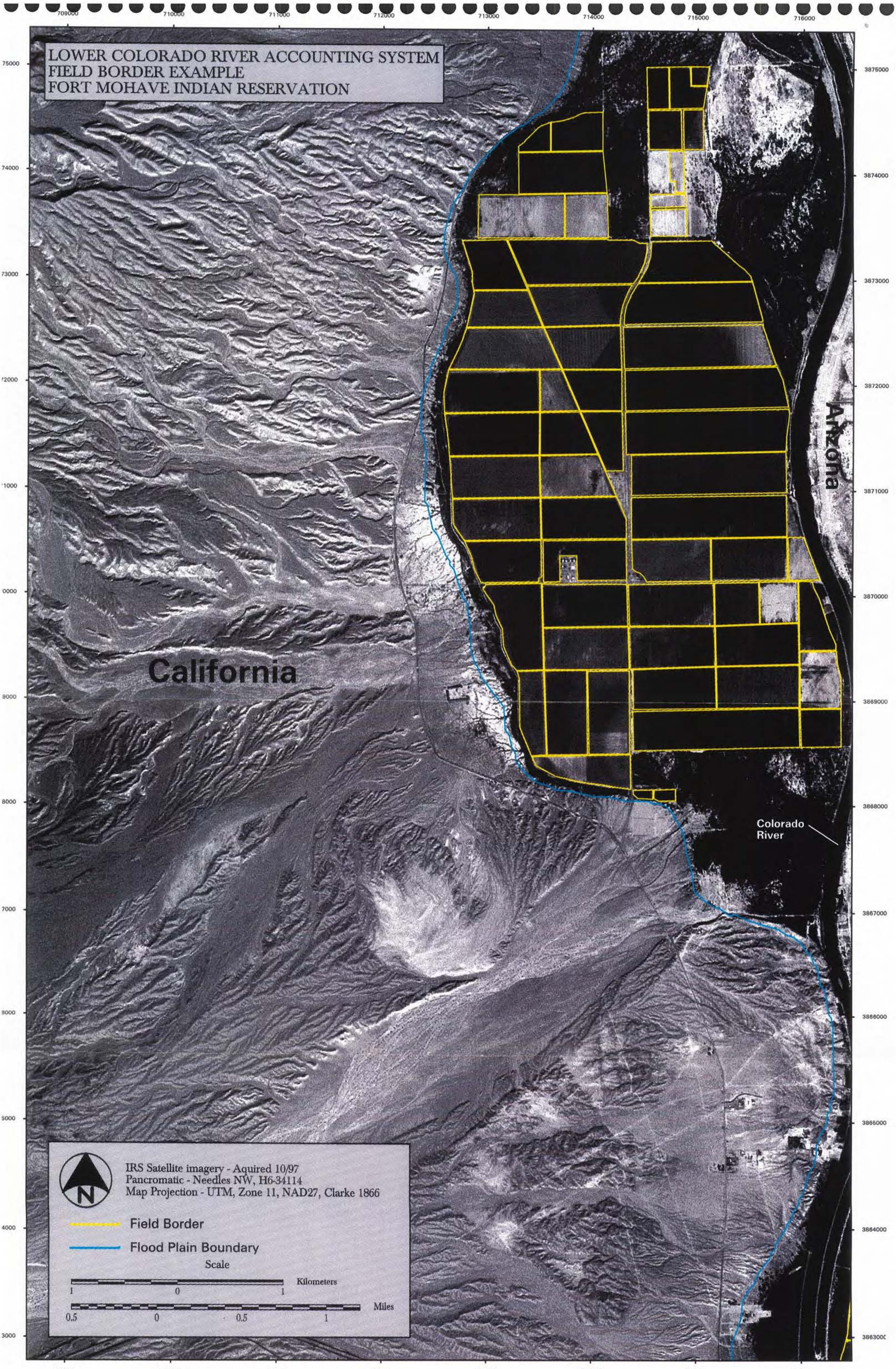

LOWER COLORADO RIVER ACCOUNTING SYSTEM
FIELD BORDER EXAMPLE
FORT MOHAVE INDIAN RESERVATION
California
Arizona
Colorado River
IRS Satellite imagery - Aquired 10/97
Pancromatic - Needles NW, H6-34114
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
N
Field Border
Flood Plain Boundary
Scale
Kilometers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

Exhibit 9

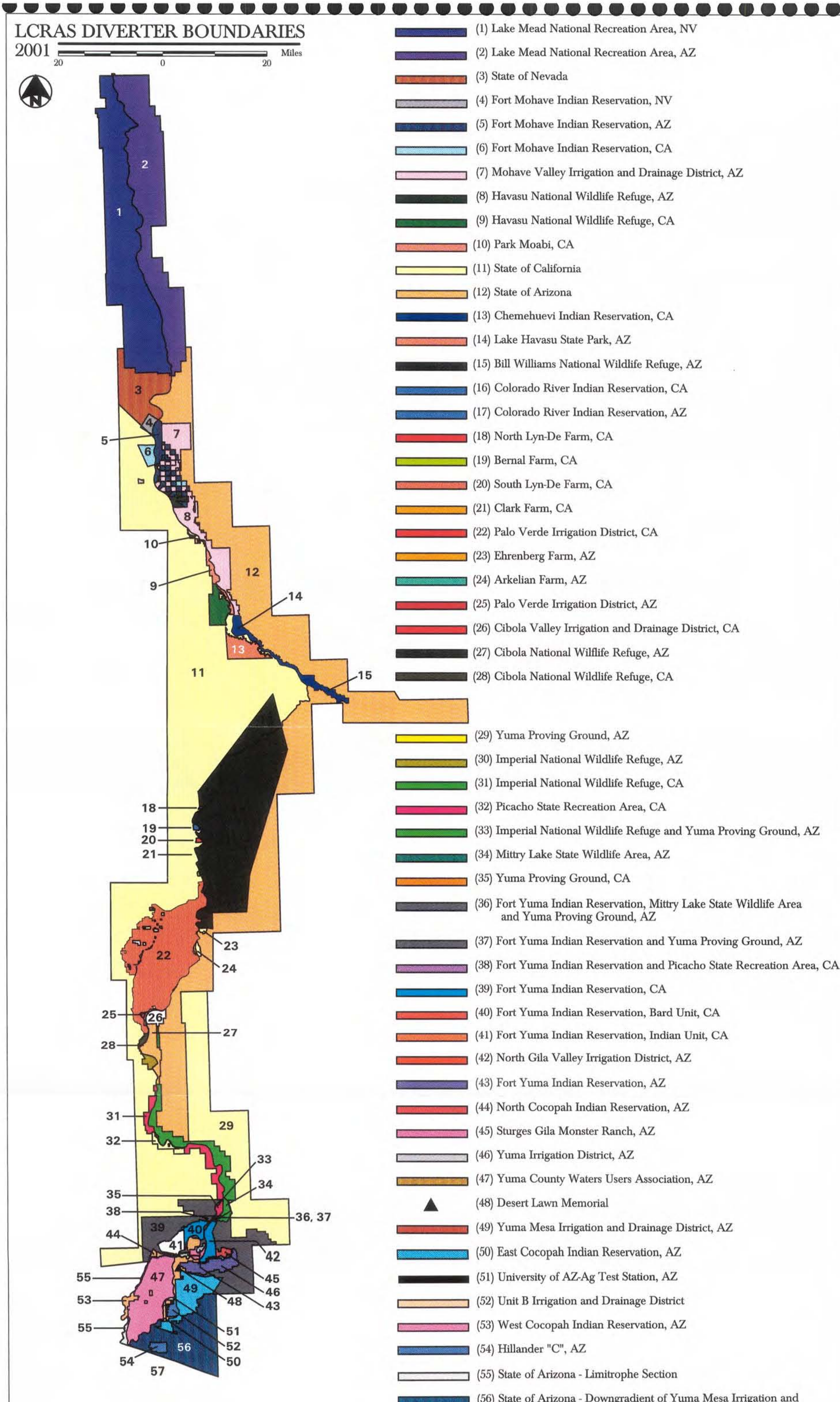

LCRAS DIVERTER BOUNDARIES
2001
20 0 20 Miles
N
(1) Lake Mead National Recreation Area, NV
(2) Lake Mead National Recreation Area, AZ
(3) State of Nevada
(4) Fort Mohave Indian Reservation, NV
(5) Fort Mohave Indian Reservation, AZ
(6) Fort Mohave Indian Reservation, CA
(7) Mohave Valley Irrigation and 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, Acquired 07-18-01.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD27, Clarke 1866.
N
Diverter Boundary
Flood Plain Boundary
Scale
Kilometers
10
0
10
Miles
5
0
5
770000
780000
790000
800000
810000
820000
3860000
3850000
3840000
3830000
3820000
3810000
3800000
3790000
3780000
3770000
3760000

Exhibit 11

Chapter 3 — LCRAS Improvements

Reclamation operates the LCRAS program in an environment of continuous process improvement. Reclamation reviews each application of LCRAS and incorporates lessons learned into subsequent reports. Reclamation also makes modifications to each application of LCRAS in response to information provided by water users and as modified processes become available after analysis of long-term questions and issues.

The following paragraphs describe improvements made since the issuance of the 2000 LCRAS Demonstration of Technology report, and potential improvements under active consideration during the past year. Reclamation does not repeat completed improvements, or potential improvements identified in the previous reports which Reclamation has assigned a low priority.

Agricultural ET/Consumptive Use

Reclamation has replaced the terms crop ET (ET_{crop}) and crop consumptive use with the terms agricultural ET (ET_{ag}) and agricultural consumptive use in this report. Agricultural ET is the sum of crop ET, evaporation from the open water in canals which serve a diverter, and evaporation from ponds maintained by a diverter. Agricultural consumptive use is the final value of agricultural ET after distribution of the residual from the water balance.

Crop Delineation and Acreage Summaries

Reclamation added a fifth satellite image (March 12, 2001) in the Yuma area to improve acreage estimates of Spring 2001 vegetables. In future years, a fifth image will be added as needed. The need for a fifth image will be dependent upon the crop planting calendars.

Phreatophyte Delineation and Acreage Summaries

Reclamation mapped additional acres of phreatophytes in calendar year 2001. These additional acres generally include areas away from the surface channel which had not been previously mapped. Typically, these areas represent relatively small stands of vegetation adjacent to relic stream meanders and backwaters (such as near the Bard Unit), and phreatophyte areas surrounded by agricultural production.

Crop and Phreatophyte Evapotranspiration, and Evaporation

Reclamation made four significant changes to crop and phreatophyte ET, and evaporation calculations.

1) Reclamation adjusted the ET and evaporation coefficients to more accurately calculate ET and evaporation using the ASCE-recommended Standardized Reference ET equation (on average the coefficients were increased by approximately 5.9 %),

2) revised the growing season (planting and harvesting dates) represented by the ET coefficients based upon Reclamation's observation during field data collection and input from irrigation districts,

3) created one new crop group (herbs) and two new phreatophyte groups (moist soil units and seasonal wetlands) to better represent observed field conditions, and

4) introduced precipitation data from the Blythe Airport NWS station into the average for the Parker/Palo Verde area and acknowledged the termination of the Palo Verde CIMIS station (The Palo Verde CIMIS station has recently been replaced by the Palo Verde II CIMIS station number 175 and will be considered in the next report).

ET coefficients were created for herbs, moist soil units and seasonal wetlands, based upon information provided by irrigation districts and refuge managers. Moist soil units and seasonal wetlands were identified mainly in the Cibola National Wildlife Refuge. Herbs were grown predominantly in the Yuma area.

Phreatophyte Evapotranspiration

Corrections

Upon review of the previous LCRAS report, Reclamation discovered errors in the delineation and quantification of phreatophytes in the Bill Williams River between Alamo Dam and Lake Havasu (Reclamation considers the water use of phreatophytes in the Bill Williams River in an analysis to derive the inflow to Lake Havasu from the releases at Alamo Dam). Reclamation corrected two errors for this report, 1) a data entry error where Reclamation mistakenly included only one of 2 identified phreatophyte groups in it's analysis and 2) a GIS processing error where Reclamation mistakenly clipped a portion of the coverage for the Bill Williams River, thereby excluding a portion of the Bill Williams River area from analysis. These errors caused the residual for the Davis Dam to Parker Dam reach to be reported about 9,600 acre-feet lower than it should have been in the LCRAS report for calendar year 2000. On a percentage basis the residual in calendar year 2000 for the Davis Dam to Parker Dam reach, reported as -2.48%, upon correction should have been reported as -2.57%.

Studies

Reclamation continues a cooperative study initiated in fiscal year 2001 with the Nevada District of the Geological Survey to improve phreatophyte evapotranspiration estimates used by LCRAS. The study's objective is to refine evapotranspiration estimates for the most common phreatophyte communities found along the lower Colorado River using parameters measured by three micro-meteorological stations placed above phreatophyte stands in Topock Marsh and possibly one station adjacent to the Bill Williams River below Alamo Dam. The micro-meteorological stations will collect data for a minimum of two years. To date, the Geological Survey has installed two micro-meteorological stations. The Geological Survey plans to install the remaining micro-meteorological station(s) by the end of fiscal year 2002.

The study plan includes producing phreatophyte evapotranspiration values as described in the previous paragraph, comparing them with phreatophyte evapotranspiration values calculated using evapotranspiration coefficients and reference ET currently used by LCRAS, and assessing adjustments that may be needed to the phreatophyte evapotranspiration coefficients.

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. Reclamation uses information gained through such consultations and other information that may become available to update diverter boundaries used by LCRAS. Such information sharing and gathering is an ongoing effort.

Reclamation made minor adjustments to the diverter boundaries for 2001. Changes were made when an updated field border encroached upon a diverter boundary. Diverter boundaries were moved as required to keep the entire field within the boundary of one diverter.

Open Water Acreage

Reclamation overlaid TM imagery acquired for July 18 and November 15th, 2001 on to the calendar year 2000 open water layer to identify significant (greater than 90 m^2) changes in open water acreage that may have occurred over the calendar year. This analysis identified changes required for Senator Wash (to include the west third of the reservoir inadvertently omitted from analysis for the previous report), and for the Colorado River below Parker Dam (to include of a portion of the river immediately south of and adjacent to Parker Dam, also inadvertently omitted from analysis for the previous report).

Reclamation also overlaid July 18th, 2001 30-m TM imagery onto the coverage of open water within delivery canals used for calendar year 2000 to look for needed changes and improvements that could be made. This analysis identified exposed pools of water adjacent to the Gila Gravity Main Canal and the All-American Canals. The area of pools along the Gila Gravity Main Canal were digitized and included in the open water area of the canals used to calculate canal evaporation.

Domestic Use

Reclamation included a report of domestic use for the Fort Mojave Indian Reservation in the state of Arizona in this 2001 report. The domestic use value was reported by the Tribe in their report on water use for Reclamation's annual Decree accounting report.

Canal Losses

A correction was made to the acreage of open water identified in Gila Gravity Main Canal, see previous section entitled, "Open Water Acreage.".

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 3.1 displays the water-balance residuals for each of the reaches used by LCRAS for calendar years

1995 through 2001.

Table 3.1 — 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%
2001	-521,194	-5.11%	-281,241	-2.66%	391,250	5.08%	98,223	1.60%	-312,962	-3.07%
Average	-152,665	-1.38%	-197,009	-1.98%	88,287	1.01%	82,452	1.29%	-178,935	-1.79%

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 3.2 displays the adjustments to the gaged flows at the reach boundaries for calendar years 1996[1] through 2001.

[1] Reclamation issued the 1995 LCRAS Demonstration of Technology report prior to adopting the current technique of adjusting the gaged flows at the reach boundaries.

Table 3.2 — Adjustments to Flows at the Reach Boundaries

Units: annual acre-feet.

	Below Hoover Dam		Below Davis Dam		Below Parker Dam		At Imperial Dam		Flow to Mexico	
Year	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%
2001	414,002	4.06%	-106,706	-1.01%	-376,745	-4.89%	-5,426	-0.09%	74,876	4.20%
Average	193,550	1.82%	-5,352	-0.03%	-166,620	-2.07%	-39,446	-0.61%	17,859	0.80%

Phreatophyte water use

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

Reclamation has undertaken a series of meetings in an effort to openly discuss this issue with 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. Therefore, agricultural consumptive values shown in this report should be considered minimum values, and phreatophyte water use is shown separately for each diverter.

Chapter 4 — Results in Tabular and Graphical Form

Table 4.1 — Results in tabular form.

Units: Annual acre-feet.

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Nevada				
Lake Mead National Recreation Area, NV.	299	0	308	Lake Mead National Recreation Area, diversion from Lake Mohave (Cottonwood). Reported as a diversion.
Cottonwood Cove (domestic consumptive use).		185		
Southern California Edison (domestic consumptive use).		12,967	12,968	Southern Nevada Water Authority (Southern California Edison), Sec 24 T32S R66E. Diversion = consumptive use.
Big Bend Water District (domestic consumptive use).		2,176	2,176	Big Bend Water District Diversion Sec 12 T32S R66E.
Sportsman's Park (domestic consumptive use).		10	10	Sportsman's Park.
Boy Scouts (domestic consumptive use).		0	0	Boy Scouts of America. Reported as a diversion.
Total Fort Mojave Indian Reservation, NV	7,144	3,057	4,521	Fort Mohave Indian Reservation (Avi), Hotel and Golf Course, 2 wells, sections 27 & 5. Reported as a diversion.
Fort Mojave Indian Reservation, NV.	7,144	2,099		
Fort Mojave Indian Reservation, NV (Avi) (domestic CU).		958		
State of Nevada[2].	10,809	0		Not reported.
Subtotal: Uses below Hoover Dam.	18,252	18,395	19,983	Subtotal: Uses below Hoover Dam.
Uses above Hoover Dam [3].		295,447	295,447	Uses above Hoover Dam.
			1,492	Unmeasured return flow credit to Nevada.
Nevada Totals.	18,252	313,842	313,938	Nevada Total[4].

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

[3] From the 2001 decree accounting report.

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

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
California				
Total, Fort Mojave Indian Reservation, CA.	4,992	13,020	18,512	Fort Mohave Indian Reservation, delivered by City of Needles, and pumped from river and wells. Reported as a diversion.
Fort Mohave Indian Reservation Agriculture	4,992	12,984		
Fort Mohave Indian Reservation domestic use		36		
Needles (domestic consumptive use).		2,133	2,132	City of Needles, Pumped from river and wells. Reported as a consumptive use.
Havasu Water Company.		35	59	Havasu Water Company. 1 well, T5N/R25E Sec31.
Metropolitan Water District of Southern California (Colorado River Aqueduct export).		1,245,885	1,250,502	Metropolitan Water District, diversion from Lake Havasu. Reported as a consumptive use.
Parker Dam and Government Camp (domestic consumptive use).		160	160	Parker Dam and Government Camp, diversion at Parker Dam. Reported as a consumptive use.
Total Colorado River Indian Reservation, CA[5].	37,920	1,738	4,296	Colorado River Indian Reservation, pumped from 11 pumps and wells, 4 pumps Big River. Reported as a diversion[6].
Colorado River Indian Reservation, CA.	36,513	0		
North Lyn-De Farm, CA[7].	1	835		
South Lyn-De Farm, CA.	3	282		
Bernal Farm, CA.	1,267	0		
Clark Farm, CA.	136	621		
Total Chemehuevi Indian Reservation, CA.	37	254	216	Chemehuevi Indian Reservation, pumped from river and wells (Reported as a diversion).
Chemehuevi Indian Reservation, CA.	37	206		

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

[6] 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.

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

Diverter Name	Phreatophyte Water Use		Agricultural, Domestic, and Export Consumptive Use		Consumptive Use	Diverter Name
LCRAS						**Decree Accounting Report**
Chemehuevi Indian Reservation, CA. (domestic use).			48			
Park Moabi, CA.		198		0		Not Reported.
Havasu National Wildlife Refuge, CA.		5,895		0		Not reported.
Total BLM Permittees (Lake Havasu and Yuma Field offices)		0		322	536	BLM Permittees (Multiple diversion points).
BLM-Black Meadow (Domestic Consumptive Use)			100			(Reported as a diversion)
BLM Permittees (Lake Havasu Field Office and Yuma Field Office), CA.			222			
Total Palo Verde Irrigation District, CA.		9,210		405,121	492,634	Palo Verde Irrigation District, diversion from Palo Verde Dam. Reported as a consumptive use.
Palo Verde Irrigation District, CA.	8,614		402,653			
Palo Verde Irrigation District, AZ.	596		680			
Blythe (city, domestic consumptive use).			1,702			
Ripley (domestic consumptive use).			53			
Palo Verde (domestic consumptive use).			33			
Cibola National Wildlife Refuge, CA.		19,884		0		Not reported.
Imperial National Wildlife Refuge, CA.		20,387		0		Not reported.
Fort Yuma Indian Reservation and Picacho State Recreation Area, CA.		4		0		Not reported.
Total Picacho State Recreation Area, CA.		4,795		0		Not reported.
Picacho State Recreation Area (Parker to Imperial)	4,665		0			
Picacho State Recreation Area (Imperial to Mexico)	130		0			
Lake Enterprises, CA (domestic consumptive use).				18	31	Lake Enterprises (Chemgold, Inc.). Reported as a diversion.

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use		Diverter Name
LCRAS			**Decree Accounting Report**		
All-American Canal below Pilot Knob[8].		3,425,195	3,415,009		Sum of IID and CVWD
				3,085,531	Imperial Irrigation District, diversion at Imperial Dam.
				329,478	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).		49	61		Southern Cal Gas 09N/23E-29DCA. Reported as a diversion.
Pacific Gas & Electric (domestic consumptive use).		0	0		Pacific Gas & Electric
Imperial National Wildlife Refuge and Yuma Proving Ground, CA.	51	0			Not reported.
Yuma Proving Ground, CA.	8,414	13			Not reported.
Fort Yuma Indian Reservation and Yuma Proving Ground, CA.	844	0			Not reported.

[8] Final value of export at USGS gauge number 09527500.

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Total Fort Yuma Indian Reservation, CA.	14,128	41,683	58,079	Total Fort Yuma Indian Reservation, CA
Fort Yuma Indian Reservation, Indian Unit, CA.	1,400	15,064	53,277	Sum Yuma Projects, Reservation Division (consumptive use).
			40,239	Yuma Projects, Res. Div., Indian Unit, div. at Imp. Dam (consumptive use).
Fort Yuma Indian Reservation, Bard Unit, CA.	847	22,570	45,678	Yuma Projects, Res. Div., Bard Unit, div. at Imp. Dam (consumptive use).
Bard (domestic consumptive use).		214	32,640	Yuma Project, Reservation Div. returns.
Winterhaven (domestic consumptive use).		80	132	Total Winterhaven (diversion).
			132	City of Winterhaven, 1 well, SE NE NE Sec 27 T16S R22E SBM.
				Town of Winterhaven, 1 well, 6S-22E 27DAA (Not Reported).
Fort Yuma Indian Reservation, CA.	11,881	3,755	480	Valdez, Mike, Sec 35 T15S R23E DDC.
			480	Living Earth Farm, Sec 02 T16S R23E BBC.
			1,070	MivCo Packing, (C-16-23) 9CCA.
			0	Valdez, Mike, Sec 22 T16S R23E BDD.
			2,400	Power, Pete, Sec 14 T16S R23E CCB.
			240	Unknown, I.D., 1 well, 16S-22E 29 DAD.
				(All wells reported as diversions)

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Total of Other Users, State Of California[9].	49,556	7,035	12,495	Total of Other State of California
Other Users, State of California (Davis to Parker)	19,339	1,495		Ida Cal, 11N/22W -31BAB (Not reported).
Other Users, State of California (Parker to Imperial)	27,788	931		Ida Cal, 11N/21E -36ADD (Not reported).
Other Users, State of California (Imperial to Mexico)	2,429	4,609		Ida Cal, 11N/21E -36CDA (Not reported).
				Previous wells irrigate lands north of Fort Mohave Irrigation District in CA.
			101	Lye, C.L., 1S/24E -16Gb.
			0	Harp, P. (R. Harp), (C-8-23) 13AAD.
			2,972	Horizon Farms, (C-8-22) 6CDA.
			225	Horizon Farms, (C-10-22) 7ABD.
			121	Horizon Farms, (C-8-22) 7BAB.
			225	Horizon Farms, (C-10-22) 6DCB.
			225	Horizon Farms, (C-8-22) 6BBD.
			500	Horizon Farms, (C-8-22) 6BCD.
			225	Horizon Farms, (C-10-22) 6CBB.
			199	Horizon Farms, (C-8-23) 1DCC.
			0	Horizon Farms, (C-8-23) 12CDB.
			1,378	Horizon Farms, (C-8-22) 6CBA.
			30	Horizon Farms, (C-8-23) 2ADC.
				Ed Wavers Farms, (C-8-22) 6BCD (Not Reported).
			428	Horizon Farms, (C-8-22) 1BBA.

[9] Agricultural consumptive uses and phreatophyte water uses not within known diverter boundaries.

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
			459	Ed Wavers Farms, (C-8-23) 1BAD.
			1,689	Horizon Farms (C-8-23) 12AAC
			0	Valdez, Mike, Sec T16S R23E SEC 30 ACC.
			0	Valdez, Mike, Sec T16S R23E SEC 30 ADD.
			1,382	Power, O.L., (C-8-23) 11 DCA.
			180	Harp, Robert, (C-8-23) 12 DAC.
			2,106	Dees, Alex, (C-8-23) 1 DAC.
			34	Wilson Farms, (C-8-23) 12 BBA.
			0	Land, K. H., (C-8-23) 2 DDA.
				Reclamation has not located the following wells, but presumes them to be within the State of CA polygons.
			5	Wetmore, Kenneth C.
			9	Wetmore, Mark M.
			1	Williams, Jerry.
			1	Sum of Lindeman, William H., Hazel D., Carney, Jerome D., and Phillips, Dorothy L. (3 wells).
			86,075	Unmeasured return flow credit to California.
California Totals.	176,315	5,142,976	5,168,647	California Total[10].

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

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Arizona				
Total Lake Mead National Recreation Area, AZ.	886	571	952	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).	538	0		
Lake Mead National Recreation Area, AZ (Davis Dam to Parker Dam).	348	0		
Katherine Landing and Willow Beach (domestic consumptive use).		571		
Lower Colorado Region Dams Project (domestic consumptive use).		0.4	0.5	Lower Colorado River Dams Project (Davis Dam), Diversion at Davis Dam. Reported as a consumptive use.
Bullhead City (domestic consumptive use).		4,859	8,098	Bullhead City, Pumped from wells. Reported as a diversion.
Mohave County Parks (domestic consumptive use).		62	104	Diversion at Davis Dam, Mohave Co. Parks. Reported as a diversion.
Mc Alister Housing Subdivision (domestic consumptive use)		1	1	Mc Alister, M. River Intake
Arizona State Parks (Windsor Beach)		13	22	Arizona State Parks (Windsor Beach).
Total Mohave Valley Irrigation and Drainage District	33,846	24,797	36,869	Total Mohave Valley Irrigation and Drainage District.
MVIDD (domestic consumptive use)[11].		2,804		36,869 Mohave Valley Irrigation and Drainage District. Reported as a diversion.
Mohave Valley Irrigation and Drainage District, AZ (includes no domestic use).	33,846	21,993		Domestic use. Reported as a diversion.

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

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use		Diverter Name
LCRAS			**Decree Accounting Report**		
Total Fort Mojave Indian Reservation, AZ.	34,737	41,220	63,451		Total: Fort Mohave Indian Reservation.
Fort Mojave Indian Reservation, AZ.	34,737	37,020		63,446	Fort Mohave Indian Reservation, 14 pumps and wells in flood plain. Reported as diversions.
Fort Mojave Indian Reservation, AZ. (domestic consumptive use)		4,200		5	Delivered by City of Needles
Golden Shores (domestic consumptive use).		320	534		Golden Shores Water Conservation District, pumped from wells. Reported as a diversion.
Topock (domestic consumptive use).		126			Not reported.
Crystal Beach Water Conservation District		54	90		Crystal Beach Water Conservation District, T4N/R20W Sec 7 Reported as a diversion
Havasu Water Company, AZ (domestic consumptive use).		392	653		Havasu Water Co. of AZ (Citizens Utilities). Reported as a diversion.
Mohave Water Conservation District (domestic consumptive use).		466	777		Mohave Water Conservation District; pumped from wells. Reported as a diversion.
Brook Water (domestic consumptive use).		244	407		Brook Water, pumped from river. Reported as a consumptive use.
Havasu National Wildlife Refuge, AZ[12].	52,602	349	21,481		Havasu National Wildlife Refuge, Inlet-NW NE NW Sec 33 T9N RSSW, well 8N/23E-15Aa (Topock Marsh). Reported as a consumptive use.
Lake Havasu City & MCWUA, AZ (domestic consumptive use).		9,037	15,063		Lake Havasu I.D.D. (City), pumped from wells. Reported as diversions.
Bill Williams National Wildlife Refuge (Lake Havasu).	571	0			Not reported.

[12] Reclamation estimates evaporation from Topock Marsh to be about 12,000 acre-feet. Reclamation does not assigned this evaporation to any diverter for this report.

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Central Arizona Project Canal (export).		1,517,577	1,523,092	Central Arizona Project; pumped from Lake Havasu. Reported as a diversion.
Town of Parker (domestic consumptive use).		539	900	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[13].	3,332	0		Not reported.
Poston (domestic consumptive use).		54		Not reported.
Total, Colorado River Indian Reservation	142,577	345,416	342,348	Colorado River Indian Reservation; diversion at Headgate Rock Dam, 1 pump from river (B-04-22) 14BBD & Town of Parker. Reported as a consumptive use.
Colorado River Indian Reservation, AZ.	142,577	345,351		
CRIR Domestic Use (Delivered by town of Parker)		65		
Ehrenburg Improvement Association (domestic consumptive use).		247	411	Ehrenburg Improvement Association, 1 pump SW Sec 3 T3N R22W G&SRM. Reported as a diversion.
Cibola (domestic consumptive use).		24		Not reported.
Ehrenberg Farm, AZ.	1	2,551	3,101	Total Jack Rayner at Ehrenberg Farm
				2,518 Jack Rayner (B-04-22) 34 DCC (CDD).
				583 Jack Rayner (B-04-22)34 DCC (DCD).
				Reported as diversions.
Arkelian Farms, AZ.	2,615	1,107	2,208	Total George Arkelian at Arkelian Farms (diversions)
				0 George Arkelian (B-03-22)16 DBD (DAD).
				2,208 George Arkelian (B-03-22)16 DBD (DAD).

[13] May need to modify to include a golf course.

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Total Bureau of Land Management permittees.	0	648	1,254	Bureau of Land Management permittees (LHFO & YFO). Reported as a diversion.
Bureau of Land Management permittees (Davis Dam to Parker Dam, domestic consumptive use).		121		
Bureau of Land Management permittees (Parker Dam to Imperial Dam, domestic consumptive use).		527		
Hillcrest Water Company (domestic consumptive use).		14	24	Hillcrest Water Co. Reported as a diversion.
Total Yuma Proving Ground.	382	525	875	Yuma Proving Ground, diversion at Imperial Dam, wells W,X,Y,Z. Reported as a consumptive use.
Yuma Proving Ground.	382	0		
Yuma Proving Ground (domestic consumptive use).		525		
Fort Yuma Indian Reservation, Mittry Lake State Wildlife Area and Yuma Proving Ground, AZ.	874	0		Not reported.
Fort Yuma Indian Reservation and Homesteads, AZ.	3,012	1,290	9,786	Total of wells reported as diversions within Fort Yuma Indian Reservation & Homesteads, AZ
				6,311 Dulin, A (C-8-22) 9 CCC.
				304 Dulin, A (C-8-22) 8 DAC.
				Glen Curtis Cit (C-8-22) 18 CBD.
				600 Glen Curtis Cit (C-8-22) 18 DDD.
				1,611 Glen Curtis Cit, (C-8-22) 7 CCD.
				960 Youmans, R., Sec 17 T08S R22W CBC.
				Reported as diversions.
Martinez Lake (domestic consumptive use).		1		Not reported.

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Cibola Valley Irrigation and Drainage District, AZ.[14]	6,380	14,561	26,302	Total: Cibola Valley Irrigation District.
				26,302 Cibola Valley Irrigation District, 3 pumps Sections 20, 21, and 26T1N R23W. Reported as a diversion.
Cibola National Wildlife Refuge, AZ.	49,370	6,635	11,025	Cibola National Wildlife Refuge, 4 pumps, Section 2 and 31 T1S R23W. Reported as a diversion.
Total Imperial National Wildlife Refuge, AZ.	32,697	56	8,000	Imperial National Wildlife Refuge, 2 wells, Sec 13 T5S R22W G&SRM. Reported as a diversion.
Imperial Wildlife Refuge (Parker to Imperial Reach)	27,011	0		
Imperial Wildlife Refuge (Imperial to Mexico Reach)	5,686	56		
Mittry Lake State Wildlife Area, AZ.	10,374	132	360	Pumper L. Pratt Sec 14 T7S R22W ABC.
Sturges Gila Monster Ranch, AZ.	817	6,126	12,474	Gila Monster Ranch, diversions at Imperial Dam (Warren Act). Reported as a consumptive use.
City of Yuma (domestic consumptive use).		17,805	17,732	City of Yuma, diversion at Imperial Dam (All-American Canal), diversion at Imperial Dam (Gila). Reported as a consumptive use.
Marine Corps Air Station [15] (domestic consumptive use).		1,384	2,307	Marine Corps Air Station (Yuma), diversion at Imperial Dam. Reported as a diversion.
Southern Pacific Company (domestic consumptive use).		29	48	Southern Pacific Company, diversion at Imperial Dam. Reported as a diversion.
Yuma Mesa Fruit Growers (domestic consumptive use).		7	12	Yuma Mesa Fruit Growers Association, diversion at Imperial Dam. Reported as a diversion.

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

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

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Total University of Arizona Agricultural Station.	0	218	1,038	University of Arizona, diversion at Imperial Dam (Warren Act). Reported as a diversion.
University of Arizona Agricultural Station Agricultural CU & Phreatophyte water use.	0	218		
Underflow to Mexico from the application of water by the U. of A.[16]	0	0		
Yuma Union High School (domestic consumptive use).		120	200	Yuma Union High School, diversion at Imperial Dam. Reported as a diversion.
Desert Lawn Memorial.	0	360	336	Desert Lawn Memorial, diversion at Imperial Dam. Reported as a diversion.
North Gila Valley Irrigation District, AZ.	2,023	19,273	19,275	North Gila Valley Irrigation District, diversion at Imperial Dam. Reported as a consumptive use.
Yuma Irrigation District, AZ.	1,204	30,414	51,325	Total for Yuma Irrigation and Drainage District
				49,171 Yuma Irrigation District, diversion at Imperial Dam and pumped from private wells. Reported as a consumptive use.
				488 Cameron Bros Sec 24 T08S R23W CCB.
				1,637 Cameron Bros Sec 24 T08S R23W CAD.
				22 Cameron Bros Sec 25 T08S R23W ACD.
				7 Judd T. Ott Sec 30 T08S R22W BAB.
				Decree accounting reports individual wells as diversions.

[16] 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	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Total for Yuma Mesa Irrigation and Drainage District, AZ	0	126,048	150,636	Yuma Mesa Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use[17].
Yuma Mesa Irrigation and Drainage District, AZ.	0	67,909		
Underflow to Mexico[18].		27,286		
State of AZ-Down Gradient from YMIDD (Consumptive use by down gradient users[19]).	0	25,903		
Hillander "C" Irrigation District, AZ .	0	4,938		
State Prison (domestic consumptive use).		12		

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

[18] See the following, "Distribution of Underflow To Mexico To Water Users Below The Northerly International Boundary".

[19] 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	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Total Yuma County Water Users Association, AZ.	4,682	152,396	238,636	Total Yuma County Water Users Association
Yuma County Water Users Association, AZ.	11	120,960	230,675	Yuma County Water Users Association, diversion at Imperial Dam and pumped from wells[20].
Underflow to Mexico[21].		25,852	300	Burrell, Sec 33 T08S R24W BAB.
State of Arizona - Limitrophe Section.	4,671	2,289	0	Farmland Management Sec 19 T09S R24W BAD.
City of Somerton (domestic use).		1,017	109	Farmland Management, Sec19 T09S R24W BDD.
City of Gadsden (domestic use).		133	90	Farmland Management, Sec19 T09S R24W BDA
City of San Luis (domestic use).		2,145	1,822	Waymon Farms, Sec 36 T09S R24W AAA.
			2,024	Waymon Farms Sec 31 T09S R24W BBB.
			1,234	J.W. Cumings, (C-10-25) 1BBA.
				State of Arizona Limitrophe Section:
			584	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.
			238	Earl Huges, (C-11-25) 3DAC.

[20] 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.

[21] See the following, "Distribution of Underflow To Mexico To Water Users Below The Northerly International Boundary."

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Total Unit B Irrigation and Drainage District, AZ.	0	45,746	15,996	Total Unit “B” Irrigation and Drainage District
Unit B Irrigation and Drainage District, AZ.	0	6,885	15,980	Unit "B" Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use[22].
Underflow to Mexico[23].		38,861	16	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).		849	850	Yuma Area Office, USBR diversion from Well No.8. Reported as a consumptive use.
Yucca Power Plant [24](domestic consumptive use).		804	804	Yucca Power Plant. Sec 36 T16S R21E CBA. Reported as a diversion.
Yuma County (domestic consumptive use).		7,779		Not reported.

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

[23] See the following, “Distribution of Underflow To Mexico To Water Users Below The Northerly International Boundary.”

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

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
Total Cocopah Indian Reservation	7,003	7,433	14,764	Total Cocopah Indian Reservation
Subtotal, West Cocopah Indian Reservation, AZ.	6,267	6,441	12,537	Subtotal, West Cocopah Indian Reservation
West Cocopah Indian Reservation, AZ.	6,267	5,751	9,957	Cocopah Indian Reservation, diversion at Imperial Dam. Pumped from wells, West Cocopah
Underflow to Mexico[25].		690	630	W. Brand, D. Donnely (C-9-25) 35 ABA.
			1,950	P. Sibley, (C-10-25) 2CDA.
				Wells reported as diversions.
Subtotal, North Cocopah Indian Reservation, AZ.	736	848	2,227	Subtotal, North Cocopah Indian Reservation
North Cocopah Indian Reservation, AZ.	736	644	532	Doug Mellon Farm 16S/22E-30CDA.
Cocopah Bend RV (domestic consumptive use)[26].		204	1,355	Doug Mellon Farm 16S/21E-25DAA.
			340	Cocopah Bend RV. 1 well, Sec 30 T16S R22E BDB.
				Reported as diversions.
East Cocopah Indian Reservation, AZ. (domestic consumptive use + bingo)		144		Not reported.

[25] See the following, "Distribution of Underflow To Mexico To Water Users Below The Northerly International Boundary"

[26] Located within North Cocopah Indian Reservation.

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS			**Decree Accounting Report**	
Total of Other Users, State of Arizona[27].	36,494	7,610	20,414	Total Other State of Arizona (reported as diversions)
Other Users, State of Arizona (Davis to Parker)	3,602	0	432	Hall, Ansil (Sec 36 T16S R21E BCB
Other Users, State of Arizona (Parker to Imperial)	20,368	0	110	Amigo Farms (Sec 28 T16S R22E CDA.
Other Users, State of Arizona (Imperial to Mexico)	12,524	7,610	168	Curry Family LTD (Sec 29 T16S R22E DAC
			2,850	R.E. & P. Power (Sec 29 T16S R22E BCC
			419	Ogram, George, Sec 24 T08S R23W DCC
			0	Ogram, George, Sec23 T08S R23W CDA (Indeterminate location)
			319	Peach, Sec 22 T08S R23W DCC
				Arizona State Parks, Lake Havasu S.P.
			9,835	State of Arizona (State Land Department)
			559	Ott, Judd T., (C-8-22) 19CCA
			330	Glen Curtis Cit (C-8-22) 24BDD
			4,353	Glen Curtis Cit (C-8-22) 24BDD
			559	Ott, Lee & Larry (Sec. 23 T8S R23W).
			480	Cibola Sportsman Sec. 31, T1S, R23W, CCB

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

Diverter Name	Phreatophyte Water Use	Agricultural, 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).	??	??	2,625,036	Arizona Subtotal (Below Hoover Dam, less Wellton-Mohawk Irrigation and Drainage District).
			60,814	Pumped from South Gila Wells (drainage pump outlet channels): Returns.
Arizona uses above Hoover Dam[28].		124	124	Arizona uses above Hoover Dam.
			104	Lake Mead Nat'l Recreation, AZ. Diversions from Lake Mead (Temple Bar).
			20	Marble Canyon Company.
Wellton-Mohawk Irrigation and Drainage District [27].		276,681	276,681	Wellton-Mohawk Irrigation and Drainage District.
			153,216	Unmeasured return flow credit to Arizona.
Arizona Totals.	ERR	ERR	2,687,811	Arizona Total[29].
Lower Basin Totals.	ERR	ERR	8,170,396	Total Lower Basin Use[28].

[28] From the 2001 decree accounting report.

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

Distribution of Underflow to Mexico Among US Water Users Below The Northerly International Boundary

Underflow to Mexico resulting from the application of Colorado River water diverted from the mainstream, either directly from the surface stream or through underground pumping, is diverted Colorado River water that is not available for consumptive use in the United States, nor is it available for satisfaction of the Mexican treaty obligation. Therefore, Reclamation must consider underflow to Mexico resulting from the application of Colorado River water (underflow) a consumptive use, and assign the consumptive use to those who diverted the water.

The worksheet presented in table 4.2 calculates,

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

   A. the adjustment to the flow to Mexico previously calculated in table 2.10,

   B. the final value of underflow from Sheet A of the Imperial Dam to Mexico water balance table and,

   C. the assumption that the ratio of the final value of underflow across the SIB and the Limitrophe Section is the same as the ratio of the estimates of these underflows used in the water balance and,

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

Table 4.2 — Distribution of Underflow to Mexico Among US Water Users Below The Northerly International Boundary

Estimate of Underflow Across SIB (acre-feet/year)	62,443	75.7%
Estimate of Underflow Across the Limitrophe section (acre-feet/year)	20,000	24.3%
Estimate of Total Underflow	82,443	100%
Final value of Total Underflow	109,226	
Final value of Underflow Across SIB (acre-feet/year)	82,684	75.7%
Final value of Underflow Across the Limitrophe section (acre-feet/year)	26,542	24.3%
Check Total	109,226	100%

Water User or Source of Underflow	Distribution of Underflow to Mexico Across SIB Among US Water Users (In Percent, See Chapter 7)	Distribution of Underflow to Mexico Across SIB Among US Water Users (Consumptive Use in Acre-Feet)
Unit B	47%	38,861
YMIDD & Yuma Mesa Canals	33%	27,286
YCWUA & Yuma Valley Canals	0%	0
YID	10%	8,268
River (Mor. - SIB)	7%	5,788
Other Sources	100%	82,684
Total Underflow Across SIB	197%	162,887

Water User	Acres of Crops (Including Double Cropping)	Percentage of Total	Distribution of Underflow to Mexico Across the Limitrophe Section Among US Water users (Consumptive Use in acre-feet)
Yuma County Water Users Association	75,007	97.4%	25,852
West Cocopah Indian Reservation	1,983	2.6%	690
Check Totals	76,990	100%	
Total Underflow - Limitrophe			26,542

Selected Results in Graphical Form

The following is a list of the bar charts with short interpretations of the information displayed upon them included on the following pages:

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 2001 by the decree accounting report, and the agricultural, domestic, and export 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 resolving the issue of the amount of phreatophyte water use, if any, that should be reported as part of a diverter's consumptive use[30].

The consumptive use totals for each state shown for the decree accounting report include unmeasured return flows calculated for diverters within the state, but credited to the basin as a whole on page 1 of the decree accounting report. The consumptive use values shown for individual diverters from the decree accounting report do not include unmeasured return flows calculated for diverters, but reported only as basin totals on page 1 and state totals in footnote 1 of page 1 in the decree accounting report.

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

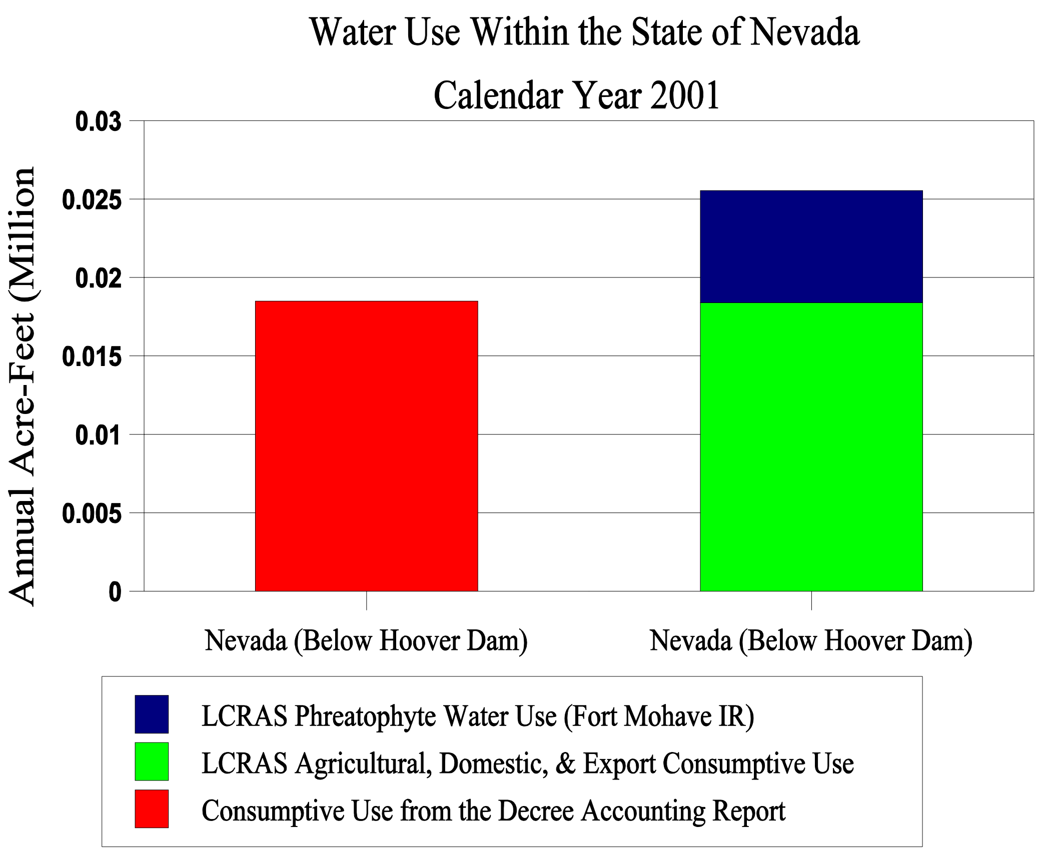


Figure 4.1 — Water use within the State of Nevada

Figure 4.1 compares the agricultural, domestic, and export 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). The amount of phreatophyte water use, if any, that should be added to the agricultural, domestic, and export use of a diverter to develop a complete value of consumptive use is unresolved at this time and remains an open question.

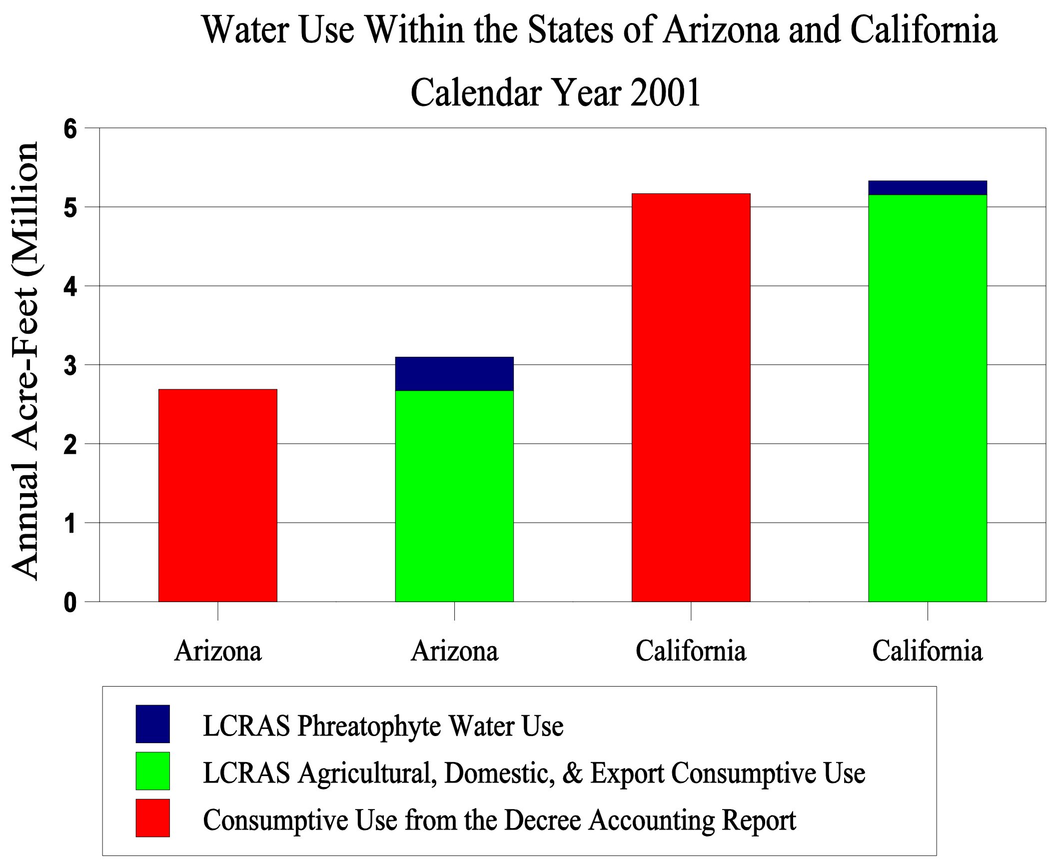


Figure 4.2 — Water use within the states of Arizona and California

Figure 4.2 compares the agricultural, domestic, and export 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). Figure 4.2 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 agricultural, domestic, and export consumptive use of a diverter to develop at a complete value of consumptive use is unresolved at this time and remains an open question.

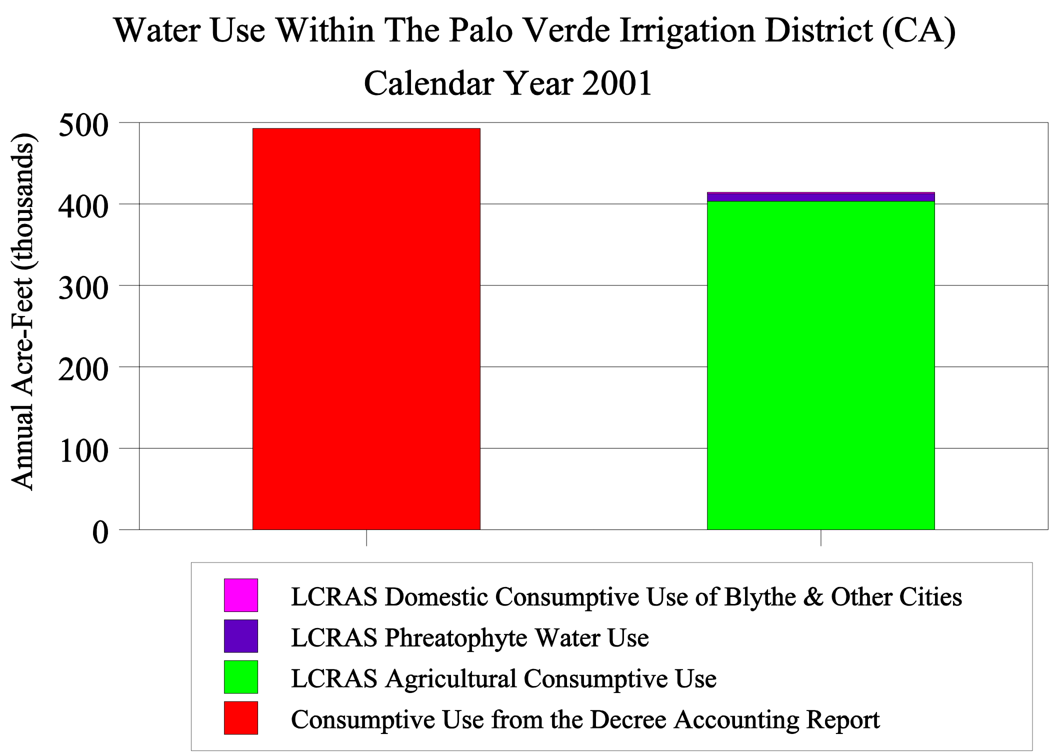


Figure 4.3 — Water use within the Palo Verde Irrigation District

The bar chart for the Palo Verde Irrigation District shows the sum of agricultural and domestic consumptive use, and phreatophyte water use identified by LCRAS 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.

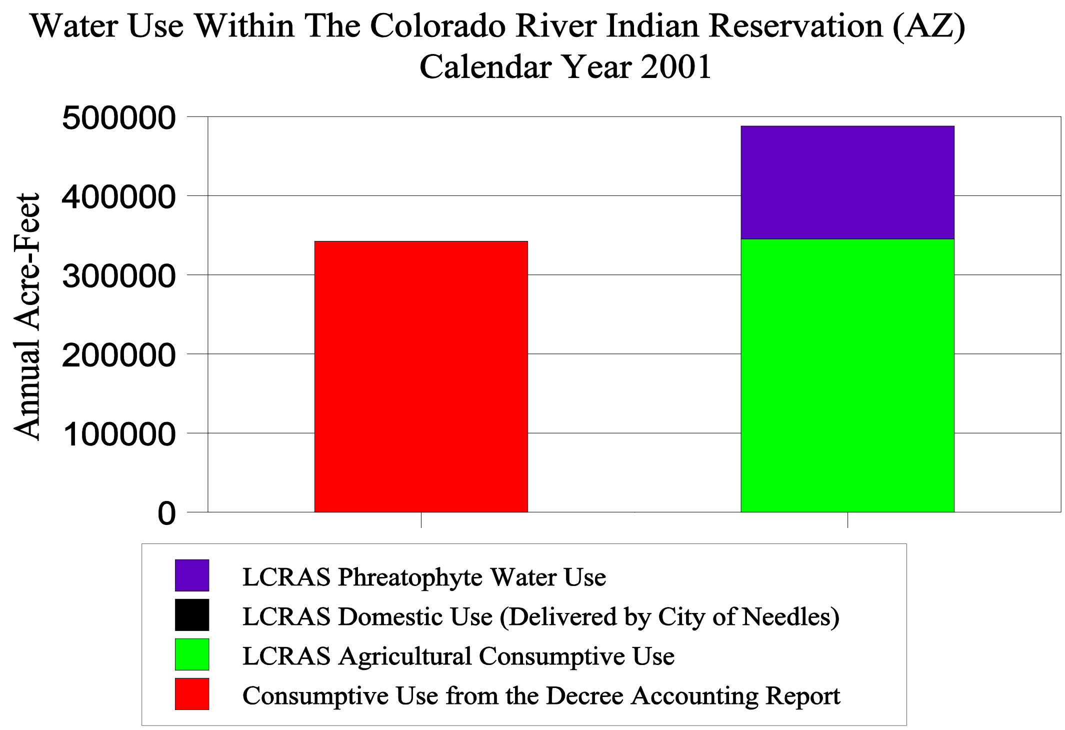


Figure 4.4 — Water use within the Colorado River Indian Reservation (AZ)

The bar chart for the Colorado River Indian Reservation (AZ) compares the agricultural and domestic consumptive use (delivered by City of Needles), 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 by 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.

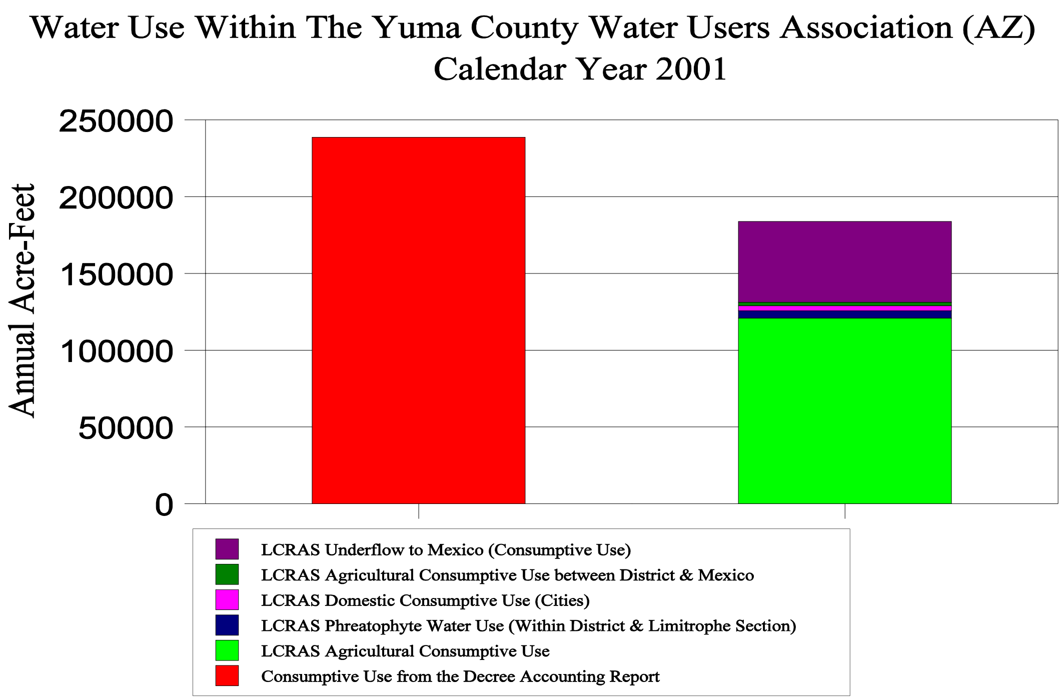


Figure 4.5 — Water use within the Yuma County Water Users Association (AZ)

The bar chart for the Yuma County Water Users Association (YCWUA) compares agricultural and domestic consumptive uses, phreatophyte water use, and the final value of the underflow to Mexico that results from the application of water within the district, plus agricultural 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.” Reclamation must consider the underflow to Mexico, the domestic consumptive use, the agricultural consumptive use, and the phreatophyte water use identified between the district boundary and Mexico consumptive use because these quantities represent diversions from the Colorado River that do not return to the Colorado River.

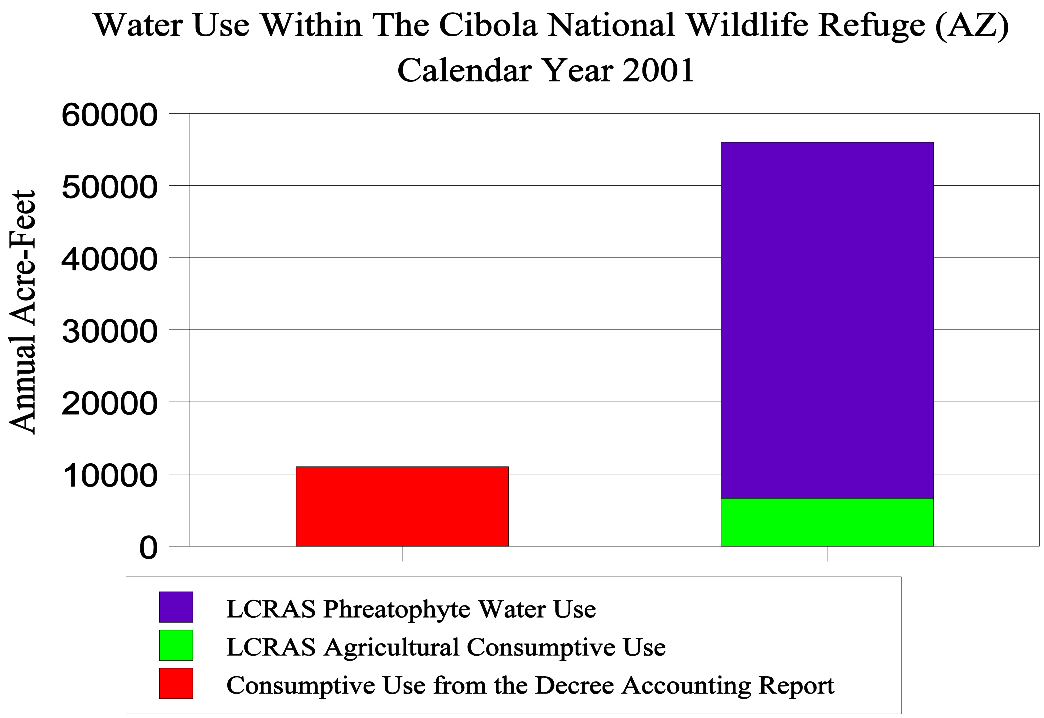


Figure 4.6 — Water use within the Cibola National Wildlife Refuge (AZ)

The bar chart for the Cibola National Wildlife Refuge compares the agricultural 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 reported for the Cibola National Wildlife Refuge by 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 to developing a complete value of consumptive use for the diverter.

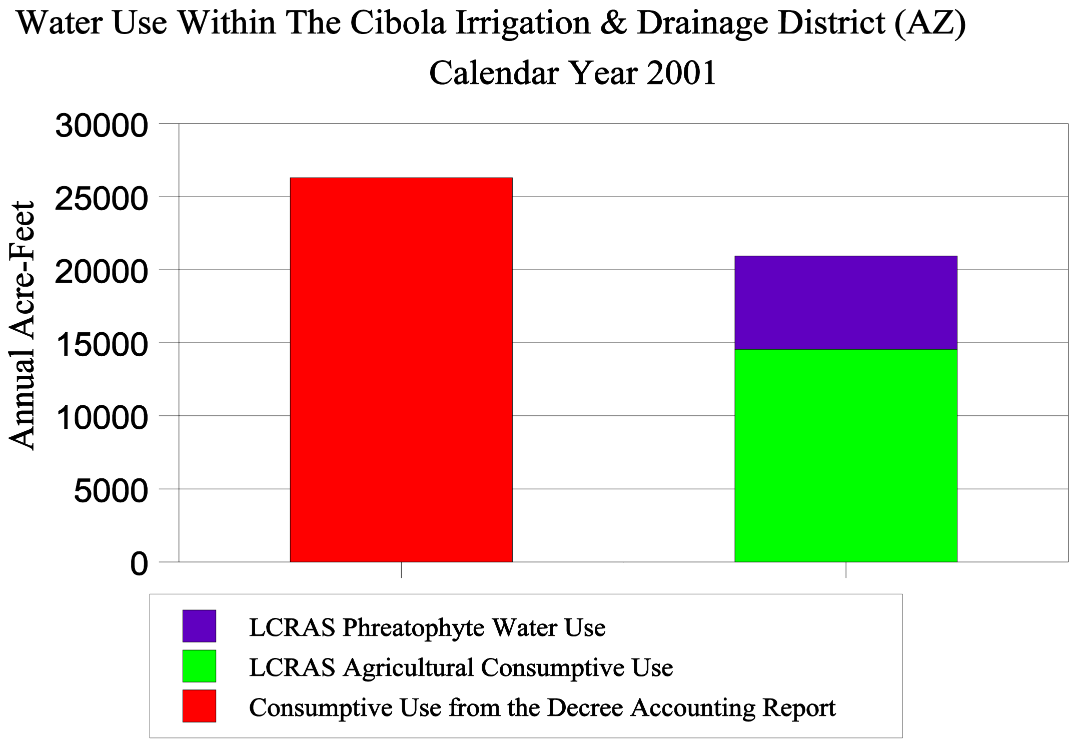


Figure 4.7 — Water use within the Cibola Irrigation and Drainage District (AZ)

The bar chart for the Cibola Irrigation and Drainage District compares the agricultural 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 to developing a complete value of consumptive use for the diverter.

Chapter 5 — Reference Evapotranspiration

Introduction

This chapter documents the reference evapotranspiration (reference ET) values produced for this report and how they differ from the reference ET values reported by the Arizona Meteorological Network (AZMET) and the California Irrigation Management Information System (CIMIS) stations sited along the lower Colorado River[1]. This chapter 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

Reclamation calculates ET values for LCRAS 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. Reclamation developed the area-specific reference ET values for the Palo Verde/Parker area 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. Reclamation developed the area-specific reference ET values for the Yuma area similarly, using data collected by the three AZMET stations sited in Yuma area (North Gila, Yuma Valley, and Yuma Mesa). Reclamation developed the reference ET for the Mohave Valley using the standardized equation and data collected by the single AZMET station sited in the Mohave Valley. Table 5.1 lists annual summations of the averaged daily reference ET values used in this report.

[1]The University of Arizona and the California Department of Water Resources operate the AZMET and CIMIS stations, respectively.

Table 5.1 — Annual Summation of Area-Specific Averaged Daily Reference ET Values Used in this Report

Units: inches

Year	Mohave	Palo Verde/Parker	Yuma	Average
2001	75.04	73.42	71.62	73.36

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. The AZMET stations reported average annual reference ET values approximately 18 percent higher than those reported by the CIMIS stations for the same period.

Table 5.2 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 2001 (the Palo Verde CIMIS station was taken out of service in December of 2000. It has been replaced by Palo Verde II, which will be used in the 2001 report.).

Table 5.2 — 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	Yuma Valley 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	92.04
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	89.20
1999	84.99	88.35	71.67	69.83	68.88	82.87	83.40	88.97
2000	86.78	87.78	68.41	68.24	65.72	82.97	78.97	86.03
2001	78.76	81.96	66.34	NA	67.51	75.00	79.31	81.29

The disparity in reference ET values reported by the AZMET and CIMIS networks indicated that a consistent set of reference ET values was not available for use by Reclamation. A consistent set of reference ET values is required to calculate agricultural and phreatophyte ET on both the California and Nevada, and Arizona sides of the Colorado River with a single set of ET coefficients for each crop and phreatophyte group. Reclamation discussed the requirement for a consistent set of reference ET values with representatives from the CIMIS and AZMET networks and Reclamation's consultant. This discussion resulted in a recommendation to develop an interim solution for use until a permanent solution could be developed.

Reclamation adopted the interim solution to calculate agricultural and phreatophyte ET using an average of the reference ET values reported by the CIMIS and AZMET networks within specific geographic areas (area-specific average reference ET). Reclamation also participated in an analysis of the reference ET values reported by the AZMET and CIMIS networks sited along the lower Colorado River to identify a permanent solution. The LCRAS public meeting in Henderson, Nevada, in October 1998 provided the forum for a thorough discussion of the use of area-specific average reference ET values. Reclamation used area-specific average reference ET values to prepared the LCRAS Demonstration of Technology Reports for calendar years 1997 and 1998.

Analysis of the reference ET values 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. differences in the equation used to calculate reference ET,
2. differences in crop conditions at the station sites,
3. differences in equipment maintenance and calibration procedures, 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 equation to calculate net radiation[2],
2. siting condition effects, including variations in crop conditions, at AZMET or CIMIS station sites is not fully known,
3. AZMET and CIMIS stations use very similar equipment, and maintenance and calibration procedures and,
4. 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.

[2]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.

Net radiation

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

AZMET and CIMIS stations use different cloud cover approximations to calculate net radiation. 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.

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

Station siting conditions

Siting conditions, including variations in crop conditions, at individual AZMET or CIMIS station sites most likely impact the accuracy of the calculated reference ET, however the magnitude of the impact of siting conditions is unknown. Reclamation is cooperating with the University of Arizona (operators of the AZMET network) in a study to identify the impact on reported reference ET values from siting conditions at individual stations. 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 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. Discussions with representatives from the AZMET and CIMIS networks concluded that differences in equipment type or maintenance and calibration do not contribute significantly to the disparity in the reference ET values reported by the AZMET and CIMIS networks.

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.

The standardized reference evapotranspiration equation solution

Representatives from the AZMET and CMIS networks and Reclamation's consultant recommended a permanent solution to the problem the disparity between the reference ET values presented to the LCRAS program. The recommended permanent 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, Dr. Paul Brown of AZMET has calculated reference ET using the standardized equation, for each AZMET and CIMIS station site, based upon the data collected by each station; and Reclamation has calculated area-specific reference ET values, as described at the beginning of this chapter, using reference ET values calculated by Dr. Paul Brown using the standardized equation.

The Standardized Equation

The development of the standardized reference ET equation is a response to 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."[4]

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

The TC evaluated equations preferred by the scientific/engineering community including the ASCE-Penman Monteith, FAO-56 Penman Monteith, 1982 Kimberly Penman, CIMIS Penman, NARCS Chapter 2 Penman Monteith, and the 1985 Hargreaves 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. Evaluations of the performance of the proposed equations used 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. The TC also compared 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 which uses constants (C_n and C_d) to represent a tall or short reference crop and the time step of the ET calculation (hourly or daily).

[4] 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 following shows the standardized equation used to calculate the reference ET values used in this report.

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

Where:

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

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

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

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

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

*e_s = mean saturation vapor pressure at 1.5 to 2.5 m height (kPa),

*e_a = mean actual vapor pressure at 1.5 to 2.5 m height (kPa),

*) = slope of the vapor pressure-temperature curve (kPa $°C^{-1}$),

(= 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. Table 5.3 shows annual summations of the daily reference ET values calculated for this report.

Table 5.3 — 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
2001	76.26	81.20	70.83	NA	70.21	70.92	71.74	75.57	73.82

Impact of using the standardized equation on ET coefficients

The standardized equation produced an annual summation of the daily reference ET which is 5.19% lower than the annual summation of the daily reference ET produced by the AZMET network and 4.68% higher than the annual summation of the daily reference ET produced by the CIMIS network in calendar year 2001.

Chapter 6 — Remote Sensing and GIS Procedures

Overview

Reclamation integrates remote sensing and geographic information system (GIS) technologies 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. Reclamation generates annual acreage summaries for each land-cover group by diverter boundary, river reach, and State. Reclamation performs accuracy assessment for crop and phreatophyte groups.

Field Border Database

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

Changes in field borders, noted during the acquisition of ground reference data throughout the year, serve as a data source for updates to the field-border database. 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. Reclamation routinely updates field borders when field staff observe changes during ground reference data collection. Reclamation completed a comprehensive field border update in 1998 using Fall 1997 Indian Remote Sensing (IRS) orthorectified 5-meter panchromatic imagery. Reclamation updates and incorporates field border updates every year based on ground reference information and new IRS imagery where needed.

Refer to table 6.1 for metadata on this field-border database. Five field-border databases cover the project area (figure 6.1). 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 Reclamation assigns by the spectral classification process. Reclamation populates "CROP-TYPE" with the name of a specific crop if the field is a ground reference field. Reclamation populates other attributes such as "AVG-HT," "GROWTH-

STAGE,” etc., for ground reference fields. Reclamation uses the code, “AA” to designate a field as a ground reference field reserved for accuracy assessment.

Table 6.2 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. Reclamation performed this comparison 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 6.1 — Metadata for Field Border Database - 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

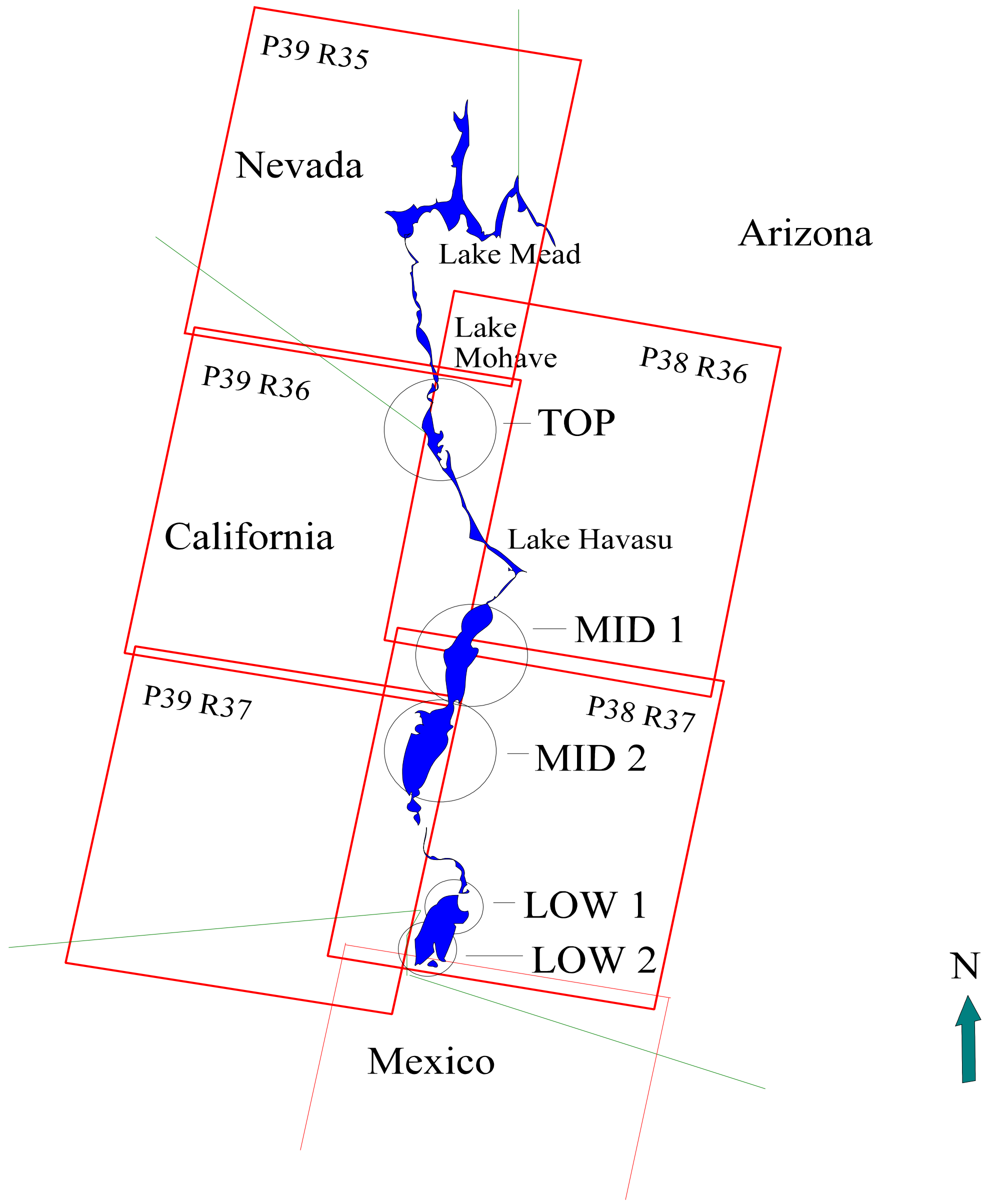


Figure 6.1 — Image Processing Areas and Landsat Scene Boundaries.

Table 6.2 — Field Acreage (SPOT Image Data & GPS Control Points)

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

COMMENTS:

1. Feeder ditch between road and crops account for discrepancy.

2. Satellite acquisition problems.

3. Digitizing problems; moved nodes, discrepancies resolved.

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>	

Other GIS coverages used in this process include Diverter, Floodplain, and River Reach boundaries. Reclamation continuously improves the diverter coverage 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

Reclamation classifies irrigated areas four times annually with the exception of the ‘TOP’ processing area (figure 6.1) which Reclamation classifies twice each year. Reclamation bases the number of classifications necessary and the classification dates on crop calendar information for the area. Reclamation does not classify orchards from spectral data, but updates their distribution based on field verification. The principle source of data for image classification is Landsat Thematic Mapper imagery (bands 1-5,7). 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. Reclamation collects ground reference data for training the spectral classifier during a 10-day period. Reclamation chooses this period based on the Landsat satellite flyover date and crop planting practices.

Reclamation chooses image classification processing areas 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. Reclamation uses a total of five processing areas for crop classification work (Figure 6.1).

Reclamation in conjunction with a private contractor, Pacific Meridian Resources, developed classification methods. Reclamation and Pacific Meridian Resources tested a variety of methods and improved them during the initial year of the project. Reclamation has continued to improve the methods. This chapter discusses significant methods and improvements.

Ground Reference Data Collection

Reclamation collects ground reference data 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). Reclamation chooses ground reference collection periods to coincide as closely as possible with the Landsat satellite fly-over dates.

Reclamation designed the data collection program 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. Reclamation samples approximately 15 percent of the fields in the project area. Reclamation originally chose ground reference fields using a random number generator and reviewed the chosen fields to ensure an adequate geographic distribution. Although Reclamation routinely visits these fields during data collection, Reclamation often samples additional fields to capture rare crops or other anomalous conditions important for the spectral classifier.

Reclamation provides each ground reference crew 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. Reclamation uniquely colors fields to be sampled (ground reference fields) for ease of identification, and colors indicate the crop observed at the previous ground reference visit, which often helps in identifying crop residue or any significant changes in planting practices. Reclamation collects data using a data collection program written for this project run on laptop computers. Table 6.3 lists ground-reference attributes collected. Table 6.4 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. The driver and coder quality check recorded Field id's and crop group codes to avoid data entry errors. The driver and coder once again quality check the data at the end of the day after field work is completed, and Reclamation performs an additional check of the field data upon returning to the office. After Reclamation performs a final check of the field data, Reclamation uses the data to "populate" items (Arc/Info data fields) in the field border database.

Table 6.3 — 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 6.4 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 6.2, 6.3, and 6.4, at the end of this chapter, are flow diagrams that summarize the crop classification procedures discussed in this section.

After Reclamation populates the field border database with ground reference data, Reclamation reserves about one third of the ground reference fields for an independent accuracy assessment set. Reclamation chooses accuracy assessment fields using a random stratified approach to ensure a statistically valid sample. Reclamation uses the remaining ground reference fields for spectral signature development.

Automated Signature Generation

Initially, Reclamation created a single spectral training site 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.

Reclamation created a process to automatically extract training signatures for spectral classification, utilizing spectral "region-growing" algorithms (Woodcock, et. al., 1992), ERDAS Imagine software, Arc/Info software (ESRI, 1994), and Image Processing Workbench (IPW) software (Frew, 1990). Reclamation reselects ground reference fields from the field border database and buffers 25 meters to the inside. Reclamation then uses these fields to mask a Landsat image consisting of bands 3, 4, and 5.

Reclamation then converts the resulting image of ground reference fields into IPW format and uses region-growing algorithms 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.).

Reclamation tested a number of Landsat band combinations and region-growing spectral and spatial thresholds to determine the best combination for this application. Figure 6.5 shows ground reference fields partitioned into spectral regions.

Reclamation then converts the spectral region coverage of ground reference fields to Arc/Info vector format. Reclamation uses the spectral region coverage as an Area of Interest (AOI) file in ERDAS Imagine and "overlays" the spectral region coverage with the original six-band Landsat TM image to generate spectral training site statistics for each spectral region. Reclamation then relates the ground reference data from the field border database to the resulting ERDAS signature file to include crop group attributes collected in the field in the ERDAS signature file with each spectral training signature.

Table 6.4 — Crop Group and Name List used for Calendar Year 2001

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		Turnip & Rutabaga
	Timothy Grass	Herbs	Thyme, dill, basil, rosemary, tarragon, oregano
Citrus	Young, 1-2 Meter		
	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

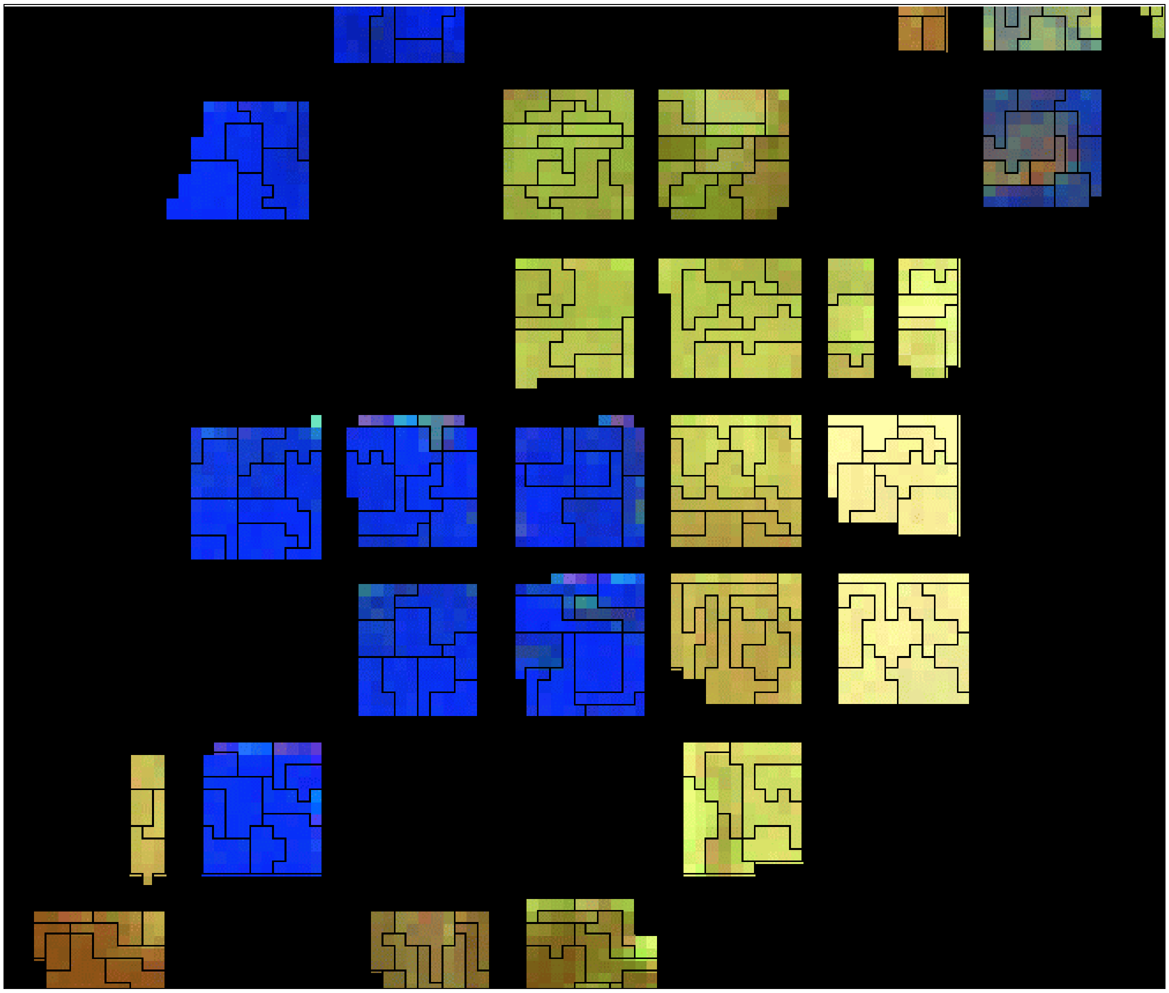


Figure 6.5 — Ground Reference Fields - masked and partitioned into spectral regions for signature generation. Black lines denote spectral regions plotted on Landsat bands 4, 3, 2.

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 with a standard deviation value of less than or equal to three, in all six bands. Reclamation chose standard deviation cutoffs based on classification results; however, this cutoff can vary dependent on spectral properties of individual crop groups. Reclamation also visually inspects the signature set 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, Reclamation performs a supervised maximum likelihood classification in ERDAS Imagine to classify all fields. Reclamation then "overlays" the resulting pixel classification with the field border database and gives each field a single crop group label based on the distribution of classified pixels within that field. Reclamation uses a simple plurality rule (the field label is given to the group that has the most classified pixels within that field). Reclamation evaluates this initial classification by creating a frequency table that compares labels derived from ground observations to labels derived from the classifier. Reclamation includes only those fields used for spectral training sites in the frequency table. This table is a measure of how well the classification process classified the training fields. Reclamation assumes that the accuracy based on the independent accuracy assessment fields will be less than 90 percent if the overall accuracy based on this frequency is less than 90 percent. Reclamation employs an iterative classification procedure to improve the classification.

Reclamation identifies training signatures that may be responsible for causing a field to be mislabeled by generating a summary table of the pixel classification for mislabeled training fields. This table shows the signatures responsible for classifying each pixel within a field. If necessary, Reclamation performs cluster analysis to evaluate spectrally similar signatures that may represent different crop groups. Once Reclamation identifies problem signatures and refines the signature set, Reclamation performs a second classification and evaluates the classification as previously described. Four, and sometimes more, classification iterations may be necessary to achieve an overall accuracy of 90 percent within the training fields.

Accuracy Assessment

Reclamation generates accuracy assessment error matrices for all final crop classifications. These matrices report errors of omission and commission based on crop group acreage and number of fields correct. Reclamation reserves about one third of the ground reference fields as an independent sample for accuracy assessment purposes for each classification time.

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. Undersampled crop groups generally represent crops grown either in such a minor amount that an adequate sample is not possible, or crops 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.

Reclamation is currently working with an independent statistician to review and improve the ground reference field sampling design used for spectral classification and accuracy assessment. Reclamation plans to implement these improvements for CY2002 and CY2003.

Accuracy assessment matrices

Reclamation considers error matrices based on the number of acres correctly classified and matrices based on the number of fields correctly classified to be useful. Reclamation includes in this report only accuracy figures reported on an acreage basis, the most useful for relating crop classification error to consumptive-use calculations. Reclamation analysts use accuracy figures reported on the number of fields correct to help define the crop groups being confused in the classifier, and determine ways of improving the classification process and the annual crop group summaries.

Tables 6.5, 6.6, 6.7, and 6.8 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 the irrigated field actually belongs (reported in the columns of the error matrix). A commission error occurs when an area is included into a group to which the area 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. Reclamation adjusts some reported accuracy percentages for expected spectral confusion between any crop group and a fallow condition.

The crown closure of most crops is not great enough to spectrally differentiate them from a fallow field when at an immature growth stage. Of important note is 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 6.5 — February 2001 Accuracy Assessment Error Matrix - by Acreage

Ground Reference Fields

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Legume/ Solanum Vegetables	Crucifers	Fallow	Dates	Safflower	Deciduous Orchards	Small Vegetables	Root Vegetables	Perennial Vegetables	**TOTALS**	%correct	% correct with
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		(commission)	fallow correction
Alfalfa	**1**	**7431.00**		153.5		54.5								129.1				27			**7795.10**	95.33%	96.99%
Cotton	**2**		**0**																		**0.00**		
Small Grain	**4**			**1895.6**		109.1							19	110.7				2.5			**2136.90**	88.71%	93.89%
Corn	**5**				**0**																**0.00**		
Lettuce	**6**					**1758.4**							73.9	110.1				48.8			**1991.20**	88.31%	93.84%
Melons	**7**						**0**														**0.00**		
Bermuda Grass	**8**							**578**													**578.00**	100.00%	100.00%
Citrus	**9**								**750**												**750.00**	100.00%	100.00%
Tomatoes	**10**									**0**											**0.00**		
Sudan Grass	**11**										**0**							152.9			**152.90**	0.00%	0.00%
Legume/Solanum Vegetables	**12**											**0**									**0.00**		
Crucifers	**13**			34.1									**698.1**								**732.20**	95.34%	95.34%
Fallow	**14**	49.20		61.8		36.7	26.01					17.9	17.23	**5812.3**							**6021.14**	96.53%	100.00%
Dates	**15**														**163**						**163.00**	100.00%	100.00%
Safflower	**16**															**0**					**0.00**		
Deciduous Orchards	**17**																**54.8**				**54.80**	100.00%	100.00%
Small Vegetables	**18**																	**226.2**			**226.20**	100.00%	100.00%
Root Vegetables	**19**																		**0**		**0.00**		
Perennial Vegetables	**20**																			**0**	**0.00**		
TOTALS		**7480.20**	**0.00**	**2145.00**	**0.00**	**1958.70**	**26.01**	**578.00**	**750.00**	**0.00**	**0.00**	**17.90**	**808.23**	**6162.20**	**163.00**	**0.00**	**54.80**	**457.40**	**0.00**	**0.00**	**20601.44**	Total Samples	
%correct by crop		99%		88%		90%	0%	100%	100%			0%	86%	94%	100%		100%	49%			**19367.40**	Total Correct	
																					94%	**% correct**	
total with fallow correction		7480.20	0.00	1957.40	0.00	1795.10	26.01	578.00	750.00	0.00	0.00	17.90	715.33	5812.30	163.00	0.00	54.80	226.20	0.00	0.00	19576.24		
% correct with fallow correction		100%		91%		92%	100%	100%	100%			100%	89%	94%	100%		100%	49%			**95%**		

Table 6.6 — April 2001 Accuracy Assessment Error Matrix - by Acreage

Ground Reference Fields

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Legume/ Solanum Vegetables	Crucifers	Fallow	Dates	Safflower	Deciduous Orchards	Small Vegetables	Root Vegetables	Perennial Vegetables	**TOTALS**	%correct	% correct with
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		(commission)	fallow correction
Alfalfa	**1**	**9546.60**		44.6			121				625										**10337.20**	92.35%	92.35%
Cotton	**2**		**0**																		**0.00**		
Small Grain	**4**	38.20		**2428.7**														13.3			**2480.20**	97.92%	97.92%
Corn	**5**				**198.7**																**198.70**	100.00%	100.00%
Lettuce	**6**					**0**															**0.00**		
Melons	**7**	16.70			36.6		**352.1**				34.3	11.2				17.7		17.7			**486.30**	72.40%	72.40%
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**	159.80	75.1				61.2				**627.8**										**923.90**		
Legume/Solanum Vegetables	**12**			75.4								**284**									**359.40**	79.02%	79.02%
Crucifers	**13**												**0**			36.7					**36.70**	0.00%	0.00%
Fallow	**14**	612.60	5435	106.6	257.2		493.6				935.6	47.2		**3611**							**11498.80**	31.40%	100.00%
Dates	**15**														**163**						**163.00**	100.00%	100.00%
Safflower	**16**		17.7	58.3									47.3			**28.9**					**152.20**		
Deciduous Orchards	**17**																**56**				**56.00**	100.00%	100.00%
Small Vegetables	**18**																	**0**			**0.00**		
Root Vegetables	**19**																		**0**		**0.00**		
Perennial Vegetables	**20**																			**0**	**0.00**		
TOTALS		**10373.90**	**5527.80**	**2713.60**	**492.50**	**0.00**	**1027.90**	**600.00**	**750.00**	**0.00**	**2222.70**	**342.40**	**47.30**	**3611.00**	**163.00**	**83.30**	**56.00**	**31.00**	**0.00**	**0.00**	**28042.40**	Total Samples	
%correct by crop		92%	0%	90%	40%		34%	100%	100%		28%	83%	0%	100%	100%	35%	100%	0%			**18646.80**	Total Correct	
																					66%	**% correct**	
total with fallow correction		10159.20	5435.00	2535.30	455.90	0.00	845.70	600.00	750.00	0.00	1563.40	331.20	0.00	3611.00	163.00	28.90	56.00	0.00	0.00	0.00	26534.60		
% correct with fallow correction		98%	98%	93%	93%		82%	100%	100%		70%	97%	0%	100%	100%	35%	100%	0%			**95%**		

Table 6.7 — July 2001 Accuracy Assessment Error Matrix - by Acreage

Ground Reference Fields

MAP LABEL		Alfalfa 1	Cotton 2	Small Grain 4	Corn 4	Lettuce 6	Melons 7	Bermuda Grass 8	Citrus 9	Tomatoes 10	Sudan Grass 11	Legume/ Solanum Vegetables 12	Crucifers 13	Fallow 14	Dates 15	Safflower 16	Deciduous Orchards 17	Small Vegetables 18	Root Vegetables 19	Perennial Vegetables 20	TOTALS	%correct (commission)	% correct with fallow correction
Alfalfa	**1**	**8740.50**	88.3	51.6	18.6						418.6	20.7									**9338.30**	93.60%	93.60%
Cotton	**2**	584.60	**5546.5**								219										**6350.10**	87.35%	87.35%
Small Grain	**4**			**38.2**																	**38.20**	100.00%	100.00%
Corn	**5**		53.2		**251.5**							41.5		39.1							**385.30**	65.27%	75.42%
Lettuce	**6**					**0**															**0.00**		
Melons	**7**	154.50					**177**							78.2							**409.70**	43.20%	62.29%
Bermuda Grass	**8**							**650**													**650.00**	100.00%	100.00%
Citrus	**9**								**750**												**750.00**	100.00%	100.00%
Tomatoes	**10**									**0**											**0.00**		
Sudan Grass	**11**	386.40	68.9								**1391.5**	11.3		54.2				4.4			**1916.70**	72.60%	75.43%
Legume/Solanum Vegetables	**12**	46.20	7.9									**84.1**		15.6							**153.80**	54.68%	64.82%
Crucifers	**13**												**0**								**0.00**		
Fallow	**14**	4.10	2.5	287							145.3			**6786.1**				6.3			**7231.30**	93.84%	100.00%
Dates	**15**														**166**						**166.00**	100.00%	100.00%
Safflower	**16**				9.3											**37.1**					**46.40**	79.96%	79.96%
Deciduous Orchards	**17**																**55**				**55.00**	100.00%	100.00%
Small Vegetables	**18**																	**7**			**7.00**	100.00%	100.00%
Root Vegetables	**19**																				**0.00**		
Perennial Vegetables	**20**																				**0.00**		
TOTALS		**9916.30**	**5767.30**	**376.80**	**279.40**	**0.00**	**177.00**	**650.00**	**750.00**	**0.00**	**2174.40**	**157.60**	**0.00**	**6973.20**	**166.00**	**37.10**	**55.00**	**17.70**	**0.00**	**0.00**	**27497.80**	Total Samples	
%correct by crop		88%	96%	10%	90%		100%	100%	100%		64%	53%		97%	100%	100%	100%	40%			**24680.50**	Total Correct	
																					90%	**% correct**	
total with fallow correction		8744.60	5549.00	325.20	251.50	0.00	177.00	650.00	750.00	0.00	1536.80	84.10	0.00	6786.10	166.00	37.10	55.00	13.30	0.00	0.00	25125.70		
% correct with fallow correction		88%	96%	86%	90%		100%	100%	100%		71%	53%		97%	100%	100%	100%	75%			**91%**		

Table 6.8 — November 2001 Accuracy Assessment Error Matrix - by Acreage

Ground Reference Fields

		Alfalfa	Cotton	Small Grain	Corn	Lettuce	Melons	Bermuda Grass	Citrus	Tomatoes	Sudan Grass	Legume/ Solanum Vegetables	Crucifers	Fallow	Dates	Safflower	Deciduous Orchards	Small Vegetables	Root Vegetables	Perennial Vegetables	**TOTALS**	%correct	% correct with
MAP LABEL		**1**	**2**	**4**	**4**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		(commission)	fallow correction
Alfalfa	**1**	**8026.10**	237.1			174.7					33.8		94.2	398				63.2			**9027.10**	88.91%	93.32%
Cotton	**2**		**766.7**																		**766.70**	100.00%	100.00%
Small Grain	**4**			**0**																	**0.00**		
Corn	**5**				**0**																**0.00**		
Lettuce	**6**	7.30				**1741.9**					10.5	4.7	237.6					18.7			**2020.70**	86.20%	86.20%
Melons	**7**						**0**														**0.00**		
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**										**0**										**0.00**		
Legume/Solanum Vegetables	**12**											**0**									**0.00**		
Crucifers	**13**	70.20				127.2							**404.6**								**602.00**	67.21%	67.21%
Fallow	**14**	1438.75	275.3	35		1268.1					66.6		259.1	**6367.1**				5.8			**9715.75**	65.53%	100.00%
Dates	**15**														**172**						**172.00**	100.00%	100.00%
Safflower	**16**															**0**					**0.00**		
Deciduous Orchards	**17**																**55**				**55.00**	100.00%	100.00%
Small Vegetables	**18**												16.3					**96.1**			**112.40**	85.50%	85.50%
Root Vegetables	**19**																		**0**		**0.00**		
Perennial Vegetables	**20**																			**0**	**0.00**		
TOTALS		**9542.35**	**1279.10**	**35.00**	**0.00**	**3311.90**	**0.00**	**600.00**	**750.00**	**0.00**	**110.90**	**4.70**	**1011.80**	**6765.10**	**172.00**	**0.00**	**55.00**	**183.80**	**0.00**	**0.00**	**23821.65**	Total Samples	
%correct by crop		84%	60%	0%		53%		100%	100%		0%	0%	40%	94%	100%		100%	52%			**18979.50**	Total Correct	
																					80%	**% correct**	
total with fallow correction		9464.85	1042.00	35.00	0.00	3010.00	0.00	600.00	750.00	0.00	66.60	0.00	663.70	6367.10	172.00	0.00	55.00	101.90	0.00	0.00	22328.15		
% correct with fallow correction		99%	81%	100%		91%		100%	100%		60%	0%	66%	94%	100%		100%	55%			**94%**		

Results

Accuracy assessment tables indicate that Reclamation can achieve overall accuracies of over 90 percent after accounting for expected confusion at the growth stages previously discussed. Multiple classifications per year ensure the correct classification of immature crops as they mature. Of important note is that the crop groups (at a particular classification time) which represent the majority of the acreage tend to be the most accurately classified. 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 (little to no acreage planted in the crop during the classification period).

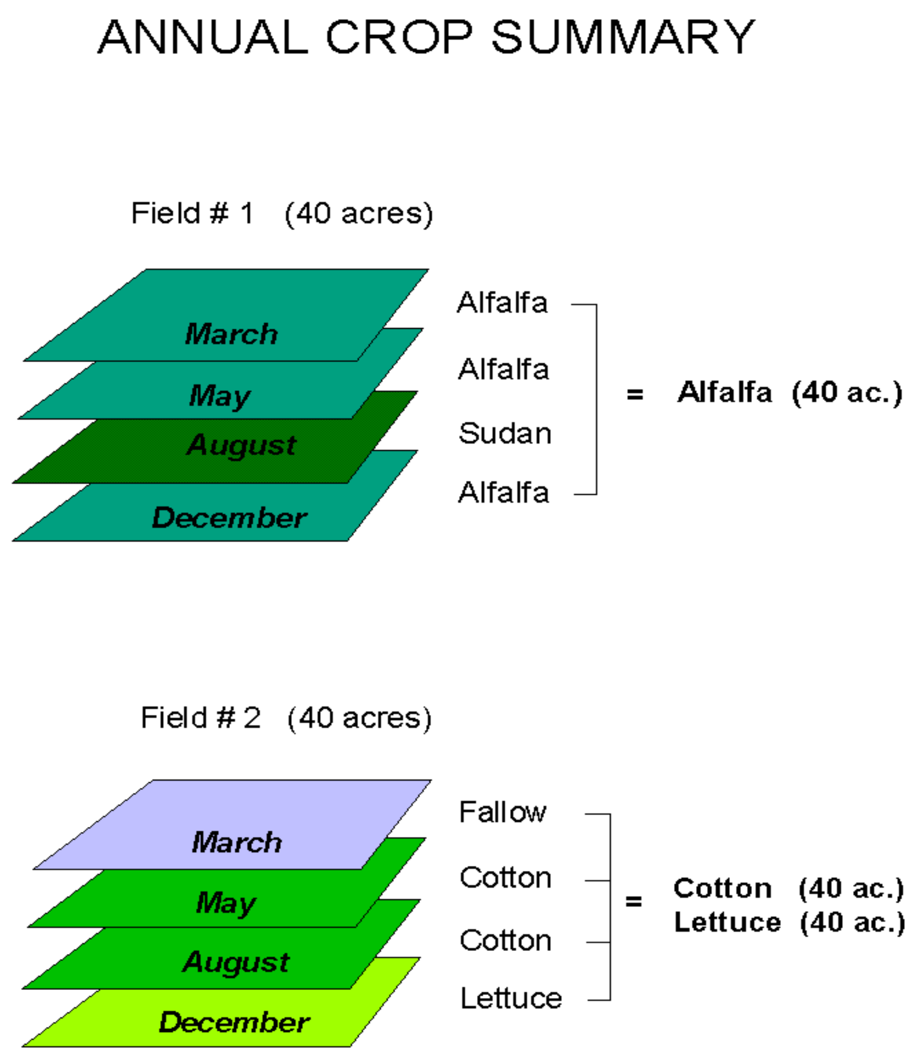
To assess the meaning of classification error, one must understand the intended use of the crop classification. The goal of LCRAS is to calculate the consumptive use of water. Classification error only has meaning in terms of the impact the classification error has on the resultant consumptive use value. Classification error resulting from the misidentification of crop groups with similar water demands, or which represent a very small portion of the irrigated acreage within a diverter boundary, negligibly impact the resultant value of consumptive use within the diverter boundary.

Annual Crop Group Summary

Reclamation generates annual acreage figures for each crop group and summarizes acreage for each crop group by diverter boundaries, river reach boundaries, and State boundaries. This summary is based on all four crop classification periods. Reclamation creates an Arc/Info “regions” coverage 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.

Reclamation uses a computer program for crop group acreage calculations 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 2001) and assigns acreage of crop group(s) for each field. Figure 6.6 is a graphic example of how this program functions. In Figure 6.6, field #1 is assigned 40 acres of alfalfa for the year (alfalfa is generally an annual crop), yet the August classification classified the crop in field #1 as Sudan. Accuracy assessment data indicate some confusion between Alfalfa and Sudan in the August classification. Because the crop in field #1 classified as Alfalfa for all classification dates except August, Reclamation assumes the August Sudan label to be classification error. Reclamation can account for and correct other similar types of error between two crops 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 Reclamation expects this combination from observed crop planting practices. Reclamation extensively reviews the results of the annual summary program for error and edits the results where necessary.

Figure 6.6 — Annual Crop Group Summary.



Classification of Phreatophyte Areas

Introduction

Reclamation initially classified phreatophyte areas in 1994 using Landsat Thematic Mapper imagery (bands 1-5,7) as the principle source data. Reclamation routinely used available aerial photography as an ancillary data set to help in spectral classification processes and editing. Reclamation chose image classification processing areas 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.

Reclamation accomplishes annual phreatophyte updates using change detection methodologies. This procedure identifies spectral difference between image dates (i.e. July 2000 and July 2001) and focuses remapping efforts in areas of spectral change.

Ground Reference Data Collection

Reclamation collects ground reference data for training the spectral classifier in a manner similar to that done for the crop classification. Reclamation collects data throughout the project area to adequately sample the variety of phreatophytes being mapped and to ensure a good geographic distribution of ground reference data. Reclamation staff fills out field forms at each ground reference site and uses GPS units 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. Reclamation provides plots with image backdrops 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). Reclamation often generates unsupervised classifications consisting of unlabeled spectral groups before field work, and Reclamation staff takes plots of these unlabeled spectral groups 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, Reclamation must collect field data and satellite data during the same season. After Reclamation collects ground reference data, Reclamation generates a digital coverage of data collection sites from the GPS data and uses the digital coverage in the classification process.

Classification Strategies

Reclamation explored a number of image band combinations to determine the optimum combination for phreatophyte classification purposes. Reclamation evaluated the following combinations:

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.

Reclamation classifies each image using both supervised and unsupervised algorithms. Reclamation merges and analyzes signature files from the classifications 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. The initial phreatophyte classification used a May 1994 TM 6-band image. Further work to determine 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

Reclamation masks imagery to isolate general phreatophyte areas, and creates NDVI images 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

Reclamation creates supervised spectral signatures using the GPS locations from field data and the “SEED” function in ERDAS Imagine software. Reclamation also generates unsupervised groups (or signatures) using “ISODATA” in ERDAS Imagine. Reclamation merges both sets of spectral statistics and then analyzes them using clustering algorithms. This analysis helps identify “informationally” unique spectral signatures (spectral signatures which always represent the same phreatophyte group in the landscape), spectrally similar signatures which represent different phreatophyte groups in the landscape (spectrally confused groups), and spectral signatures (from ISODATA) significantly different from all supervised signatures indicating that the analysis has not accounted for all of the spectral variability in the area of interest.

Reclamation also uses other diagnostic tools to assess the signature sets such as divergence measures (Transformed Divergence [TD] and Jeffries-Matusita [JM]) 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 the signature set is classifying the training sites (training sites used to generate signatures should be grouped correctly unless another signature is causing confusion and misclassifying the site). Reclamation typically refines classifications and signature sets 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, Reclamation uses these data to label spectrally derived polygons.

Polygon generation and labeling

Reclamation spectrally derives polygons with a minimum mapping unit of 2.5 acres for the phreatophyte groups using Landsat bands 3 and 4 and a texture band generated from band 4 (Ryherd and Woodcock, 1990) and image segmentation algorithms (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.

Reclamation labels polygons by overlaying polygon boundaries with any corresponding digital thematic data layer. In this case, Reclamation "overlays" polygon boundaries with the phreatophyte pixel classification, and generates a histogram showing the distribution of phreatophyte pixel groups within each polygon. Reclamation then applies labeling rules specific to the classification system based on the relative percentages of phreatophyte pixel groups within each polygon.

Editing

Once Reclamation labels the polygons, Reclamation edits the polygon phreatophyte map 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

Reclamation updates phreatophyte coverages annually using change detection methodologies and Landsat imagery for image-to-image comparison to identify spectral change from year to year.

Coregistration and image normalization

Reclamation first coregisters images from each date to reduce apparent change due to misregistration between the two image dates. Reclamation then radiometrically calibrates images 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, Reclamation performs various image subtraction tests using different band combinations to determine the optimum band combinations for this application. Reclamation analyzes image subtraction test results by examining the image subtraction outputs in combination with imagery, field notes, maps, and aerial photography, and chooses an image subtraction based on these results.

Reclamation then categorizes the image difference layer subtraction into five groups based on all available ancillary data. This five-group map of change focuses on changes in the distribution of phreatophyte groups 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

Reclamation makes field visits to areas of change 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

Reclamation verifies the final map change, and identifies and remaps areas of significant change with respect to phreatophyte groups using classification processes previously described for phreatophytes, or manual photo interpretation techniques. Reclamation then incorporates remapped areas 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).

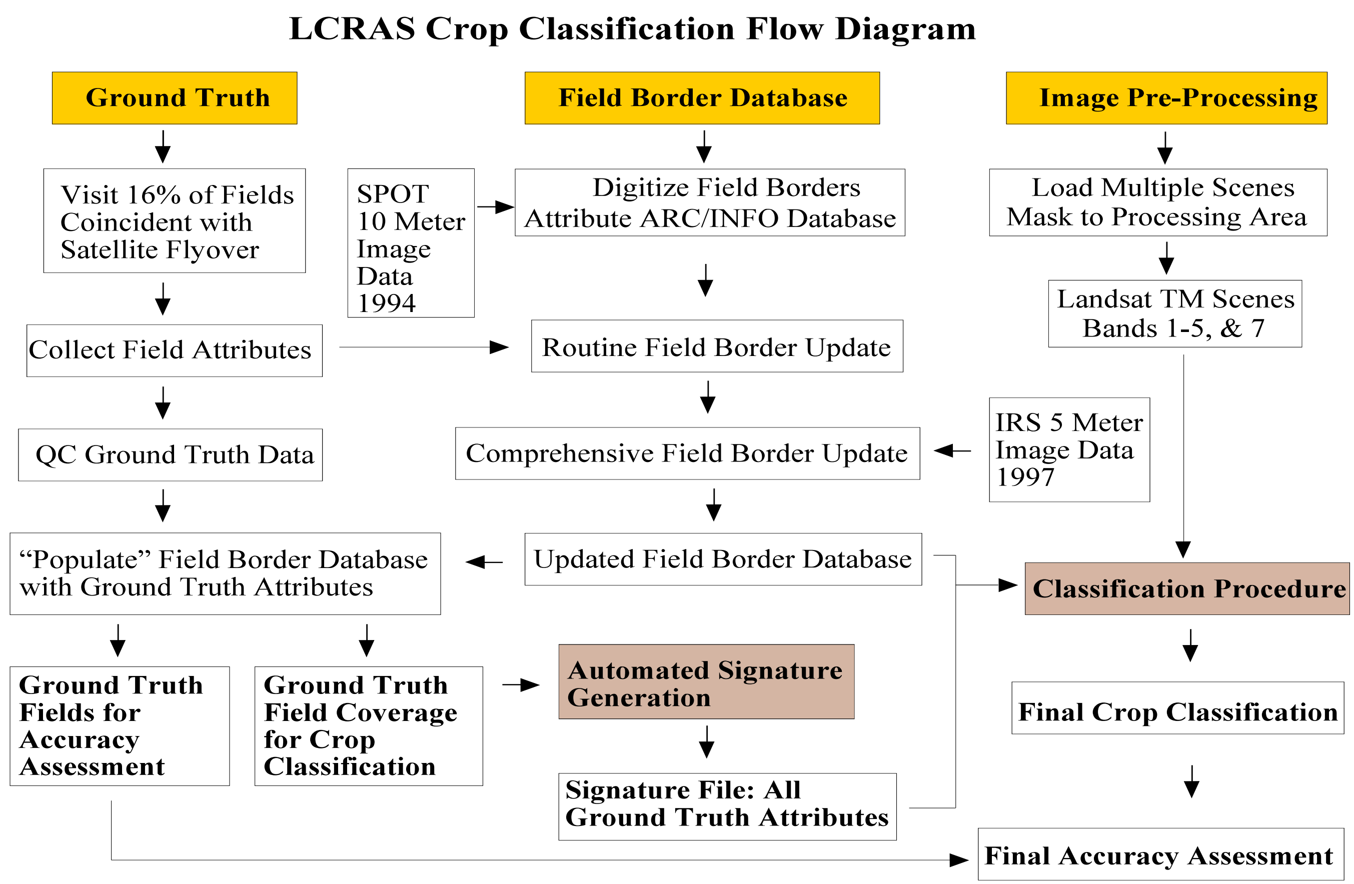


Figure 6.2 — LCRAS Crop Classification Flow Diagram.

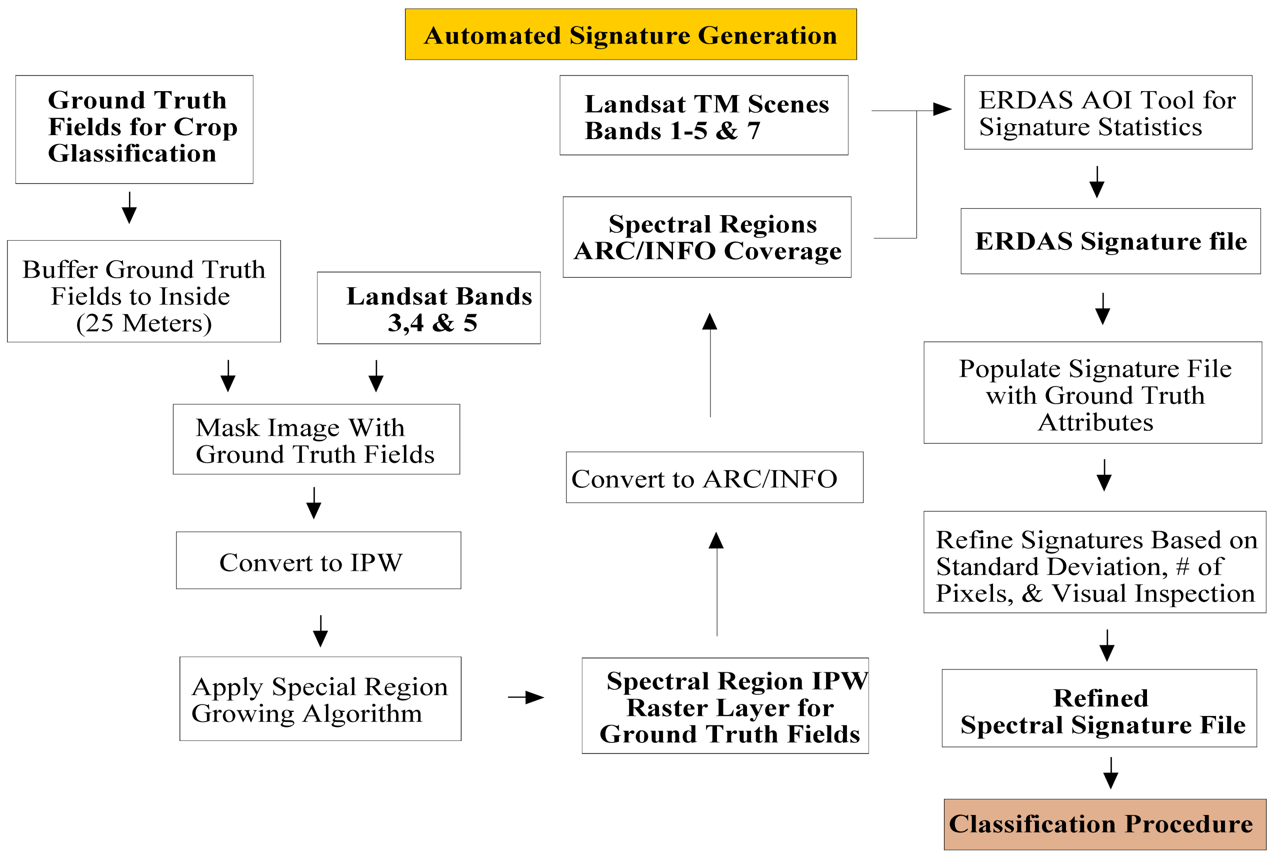


Figure 6.3 — Automated Signature Generation.

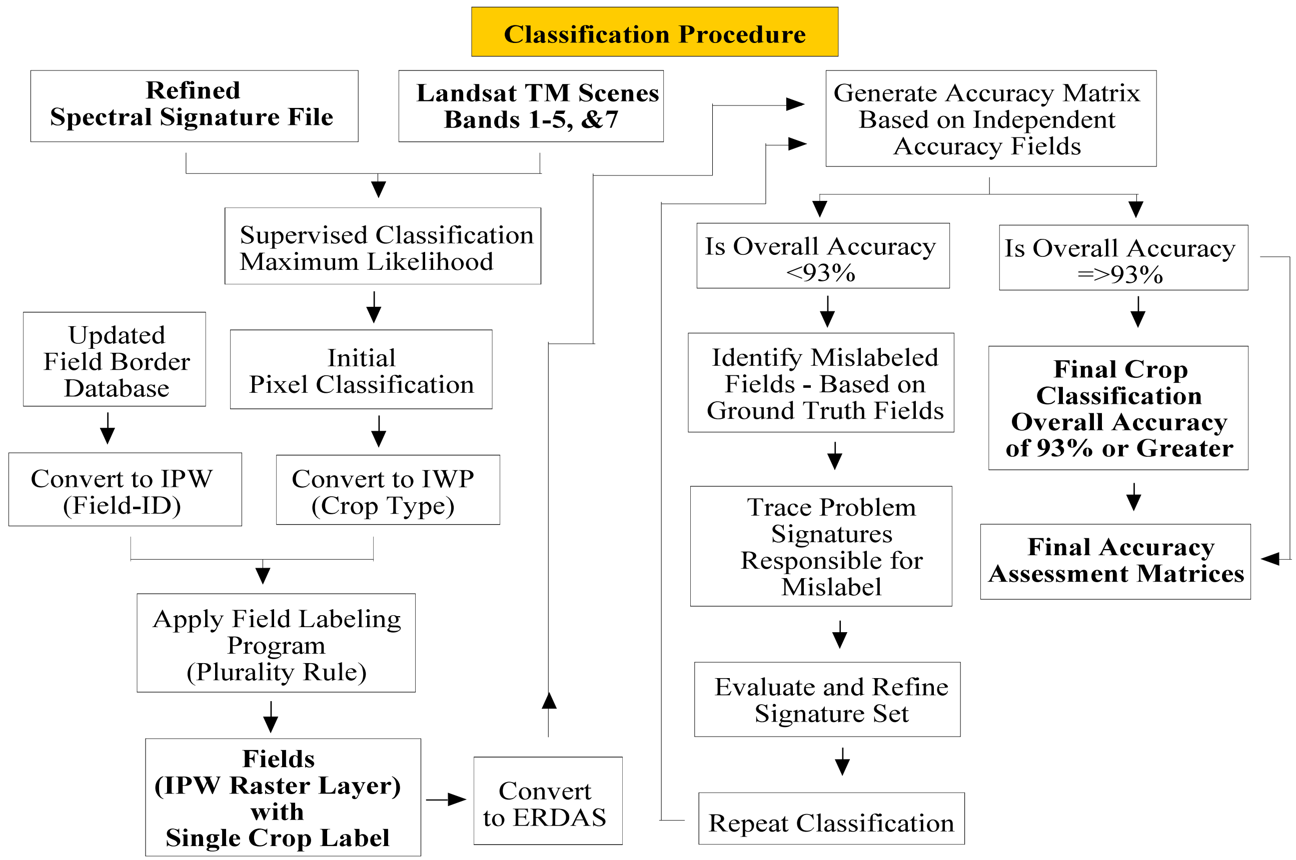


Figure 6.4 — Classification Procedure.

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Chapter 7

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 Agricultural and Domestic Water Use to Calculate Consumptive Use in the Lower Colorado River Accounting System

Introduction

This chapter documents the derivation of contribution fractions, in percent, which each irrigation district or other diverter near Yuma, Arizona contributes to the underflow into Mexico across Southerly International Boundary (SIB). This underflow is a consequence of the application of water diverted from the Colorado River which percolates to the groundwater table. Reclamation derives the contribution fractions from the results of a particle tracking study performed by the Yuma Area Office. The particle tracking 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).

The Lower Colorado River Accounting System (LCRAS) is a water budget tool currently being tested for application to the decree accounting report[1] calculations of consumptive use of Colorado River water from Hoover Dam to SIB. Reclamation performs calculations of consumptive use for LCRAS 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 States or to Mexico in accordance with treaty[2], Reclamation must account for this underflow to Mexico as a consumptive use. Reclamation must charge the underflow to Mexico, sometimes referred to as loss to Mexico, as a consumptive use to the entitlement of the district which diverted the water from the Colorado River.

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[1] 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.

[2] Treaty Series 994, Utilization of the Colorado and Tijuana Rivers and of the Rio Grand, Treaty Between the United States of America and Mexico, Signed at Washington February 3, 1944.

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 water diverted directly from the surface stream of the Colorado River. This pumped groundwater is excess irrigation from up-gradient applications of water diverted directly from the surface stream of the Colorado River.

The problem that Reclamation must solve 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. This chapter will refer to these fractions as independent components.

The following process 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 composed of fractions of the other identified components of the underflow at SIB. This chapter will refer to Hillander "C" and the south Yuma Mesa 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. Tables 9, 15, 16, and 17 of particle tracking study provide the data used in this analysis.

For this assessment, Reclamation considers the most appropriate value of flow for each component 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 following process description refers to tables shown at the end of this chapter.

To begin;

1. Observe the components of the underflow across SIB listed with their respective acre-foot volumes in table 7.1,
2. Set the flow of the dependent components of the underflow to Mexico across SIB (Hillander "C" and the south Yuma Mesa) to zero (table 7.1),
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 table 7.1),
4. Observe the components of the water pumped by Hillander "C" and the south Yuma Mesa listed with their respective acre-foot volumes (tables 7.2 and 7.3),
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 (tables 7.2 and 7.3),
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 tables 7.2 and 7.3),
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 tables 7.2 and 7.3),
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 contributes to the previously calculated totals in 7 and,

B. applying these percentages to the contribution Hillander "C" and the South Yuma Mesa 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 table 7.2 and table 7.3),

9. Transfer the acre-foot volumes previously calculated in 8 to table 7.1 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 table 7.1),

11. Calculate the "best fit" acre-foot volumes for the independent components of the underflow to Mexico at SIB by adjusting the values previously calculated in 10, in proportion to their magnitude, to equal the assumed volume of underflow to Mexico at SIB (column labeled "Average Adjusted to Equal 62,443 on table 7.1).

The process described previously has identified the independent components of the underflow to Mexico at SIB and the approximate fraction each independent component represents of the total underflow to Mexico at SIB. Table 7.4 lists the independent components, their respective acre-foot volumes, and the percent fraction each represents of the total underflow (columns labeled "Adjusted Acre-Feet" and "Percentage" respectively). The column labeled "Revised Value" on table 7.4 is simply a tool to distribute a value of underflow to Mexico at SIB different from 62,443 acre-feet. The water balance for the Imperial Dam to Mexico reach of LCRAS calculates a revised value by adding a portion of the residual from the water balance to the 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 Reclamation must credit to the diverters of the water as consumptive use. This assessment recognizes that, even if irrigation ceased in the Yuma area south of Morelos Dam, some water would continue to underflow to Mexico as part of the natural system.

While this assessment presents a rational way to estimate the fractions of the "loss of water to Mexico" across SIB, at this time Reclamation chooses not to use the particle tracking study to address the underflow to Mexico across the Limitrophe section. This conclusion is based upon a conclusion of the particle tracking study itself that, while the results for underflow across SIB are reliable, the results for the underflow across the Limitrophe section are not reliable.

Table 7.1 — Contributions to Underflow at SIB							
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.							
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 Irrigation and Drainage District	83	83	83	1,617	99	1,799	1,665
Yuma Mesa Irrigation and Drainage District	24,952	26,750	25,851	2,340	1,707	29,898	27,665
Yuma Mesa Irrigation and Drainage District Canals	1,670	1,701	1,686	82		1,768	1,636
Yuma County Water Users Association	5,978	17,486	11,732	1,446	0	13,178	12,194
Yuma Valley (Yuma County Water Users Association) Canals	6,169	10,804	8,487	856		9,343	8,645
Yuma Irrigation Dist. (YID)	0	0	0	0	0	0	0
Hillander "C" Irrigation District (HC) [3]	Included in others	Included in others					0
South Yuma Mesa [2]	Included in others	Included in others					0
River (Mor. - SIB)	5,570	7,547	6,559	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

[3] Reclamation does not consider deep percolation from irrigation water applied in these areas is to be a source because deep percolation from irrigation water applied in these areas is pumped water derived from other sources in this list, see the following breakouts.

Table 7.2 — Underflow to Mexico Contributed by Hillander "C"

Hillander "C" well 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 Irrigation and Drainage District	3,892	3,892	3,892	4,549	25.5%	1,617	
Yuma Mesa Irrigation and Drainage District	5,387	5,887	5,637	6,589	36.9%	2,340	
Yuma Mesa Irrigation and Drainage District Canals	190	196	193	226	1.3%	82	
Yuma County Water Users Association	2,806	4,164	3,485	4,074	22.8%	1,446	
Yuma Valley (Yuma County Water Users Association) Canals	1,733	2,380	2,057	2,404	13.5%	856	
Yuma Irrigation Dististrict (YID)	0	0	0	0	0.0%	0	
Hillander "C" Irrigation District (HC)[4]	Included in others	Included in others					
South Yuma Mesa [3]	Included in others	Included in others					
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%	6,341	
						6,341	Check Total

[4] Reclamation does not consider deep percolation from irrigation water applied in these areas to be a source because deep percolation from irrigation water applied in these areas is pumped water derived from other sources in this list, see the following breakout.

Table 7.3 — Underflow to Mexico Contributed by Irrigation from Wells South of the Yuma Mesa							
US Well pumping south of the Yuma Mesa 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 Irrigation and Drainage District	1,765	1,765	1,765	1,938	5.5%	99	
Yuma Mesa Irrigation and Drainage District	30,259	30,259	30,259	33,231	94.5%	1,707	
Yuma County Water Users Association	0	0	0	0	0.0%	0	
Yuma Irrigation District (YID)	0	0	0	0	0.0%	0	
Hillander "C" Irrigation District (HC)[5]	Included in others	Included in others					
South Yuma Mesa[4]	Included in others	Included in others					
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

[5] Reclamation does not consider deep percolation from irrigation water applied in these areas to be a source because deep percolation from irrigation water applied in these areas is pumped water derived from other sources in this list.

Table 7.4 — Sources of Underflow to Mexico Across SIB					
Source of Water	Adjusted Acre-Feet	Percentage	Rounded Percentage	Revised Value From Rounded percentage	
Unit B Irrigation and Drainage District	1,665	2.7%	3.0%	1,873	
Yuma Mesa Irrigation and Drainage District and Yuma Mesa Irrigation and Drainage District Canals	29,301	46.9%	47.0%	29,348	
Yuma County Water Users Association and Yuma Valley (Yuma County Water Users Association) Canals	20,839	33.4%	33.0%	20,606	
Yuma Irrigation District	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%	62,442	
				62,443	Check Value

Chapter 8 — Calculation of Domestic Consumptive Use

Introduction and Summary

This chapter'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). Reclamation calculates domestic consumptive use with one of the following four methods for use in LCRAS,

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, Reclamation will use an annual per-capita use factor of 0.3 acre-feet per capita, or Reclamation will add an estimate of the evapotranspiration by the vegetation which makes up the landscape to the domestic use calculated as the population times an annual per-capita domestic use factor of 0.14 acre-feet per capita,
4. Or other method unique to the specific circumstances of an individual domestic diverter.

Domestic Consumptive Use Factor

The domestic consumptive use factor is a ratio of consumptive use to diversion. Reclamation derived the domestic consumptive use factor of 0.6 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 along the lower Colorado River below Hoover Dam; Boulder City, Nevada[1], Laughlin, Nevada (Big Bend Water District), Needles[2], California; and Yuma, Arizona. Table 8.1 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. Reclamation added the use from the Robert B. Griffith Water Project (Las Vegas Valley, Henderson, and Boulder City, Nevada, combined) to Table 8.1 as a check value.

Table 8.1 — Domestic Consumptive Use Factors for Cities with Measured Returns

(Data from 1995 Decree Accounting Report[3] unless otherwise noted)

Units: acre-feet unless otherwise noted

City	Diversion	Wastewater or Return Flow	Domestic Consumptive use	Domestic Consumptive Use Factor[4]
Boulder City, NV[5]	5,430	1,368	4,062	0.75
Boulder City, NV (Household Use Only[6])	3,133	1,280	1,853	0.59
Laughlin, NV[7]	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

1 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.

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

3 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.

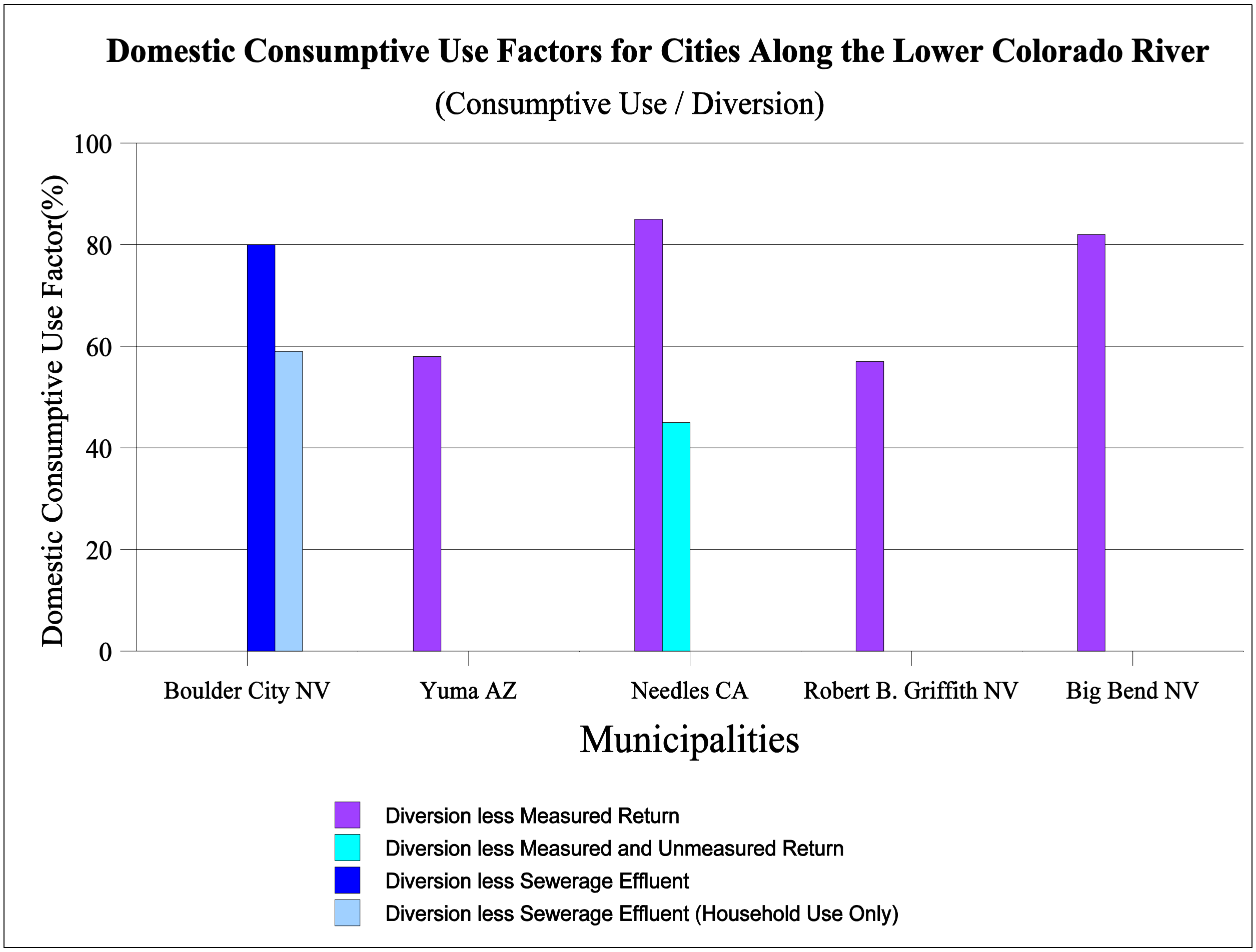
4 Domestic Consumptive Use ÷ Diversion for Domestic Use (dimensionless).

5 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.

6 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). Reclamation also removed the delivery for municipal landscape irrigation.

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

Figure 8.1 is a bar graph showing the domestic consumptive use factors, from Table 8.1, for each of the



cities previously mentioned 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 8.1 — Domestic Consumptive Use Factors for Cities with Measured Returns

Per-Capita Consumptive Use

Reclamation derived per-capita consumptive use factors for use in LCRAS 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 municipal supplies from a direct diversion from the surface stream of the Colorado River water (no private wells), and all the domestic water is returned to a sewerage system (no septic tanks). Also, the population of Boulder City is not impacted by large seasonal visitation as is the population of many cities along the lower Colorado River. Given this setting and the availability of measurements of water delivered and wastewater generated for the entire community, Reclamation calculated consumptive use and per-capita consumptive use with confidence.

Reclamation compiled records of Boulder City's population (see table 8.2), 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 Reclamation performed this study (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, Reclamation calculated per-capita domestic consumptive use 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 previously described, 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 8.2). 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.

Reclamation calculated total domestic consumptive use 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). Reclamation calculated the total per-capita domestic consumptive use by dividing the total domestic consumptive use by the population of the city.

Table 8.2 — 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

Reclamation also estimated the annual household per-capita consumptive use of water in Boulder City, which minimized the influence of domestic landscape irrigation, 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. 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 along the lower Colorado River for use in LCRAS 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. Tables 8.3 and 8.4, on the following pages shoe the delivery, wastewater, and municipal landscape irrigation data used in this analysis.

Table 8.3 — 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 8.4 — 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 8.5 shows the procedure Reclamation used to estimate 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 8.3 and table 8.4),

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 8.3),

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 8.2.

Table 8.5 — 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:	274.7	
Less Average January Municipal Landscape Use:	14.1	
Less Average January Waste Water:	110.5	
Equals Average January Household Consumptive Use:	150.1	(283.7 - 22.6 - 106.7)
Extrapolated Annual Household Consumptive Use Based Upon Average January Household Consumptive Use:	1801.2	(154.4 x 12)
Average Annual Diversion for Household Consumptive use:	3127.2	((283.7 - 22.6) x 12)
Average Annual Consumptive Use Factor for Household Use (dimensionless):	0.58	(1,852.8 ÷ 3,133.2)
Average Annual Per-Capita Household Consumptive Use (acre-feet per capita):	0.14	(1,852.8 ÷ 12,815)

Chapter 9 — 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. Reclamation initially projected the resolution of this question 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 2002 and future years until the question concerning the amount of phreatophyte water use that should be included in the calculation of consumptive use for diverters 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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