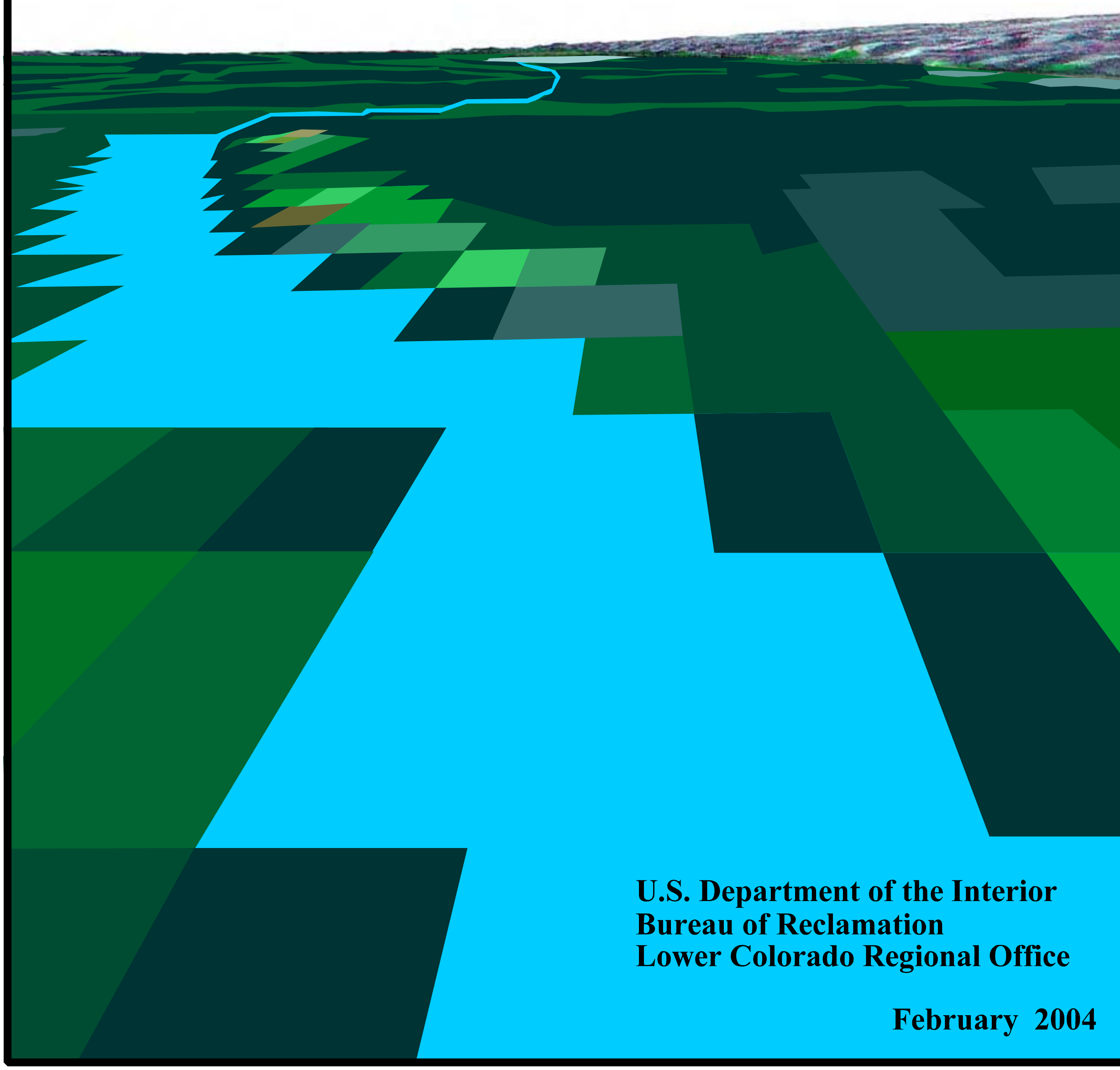
Lower Colorado River Accounting System
Demonstration of Technology

Calendar Year 2002



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

February 2004

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

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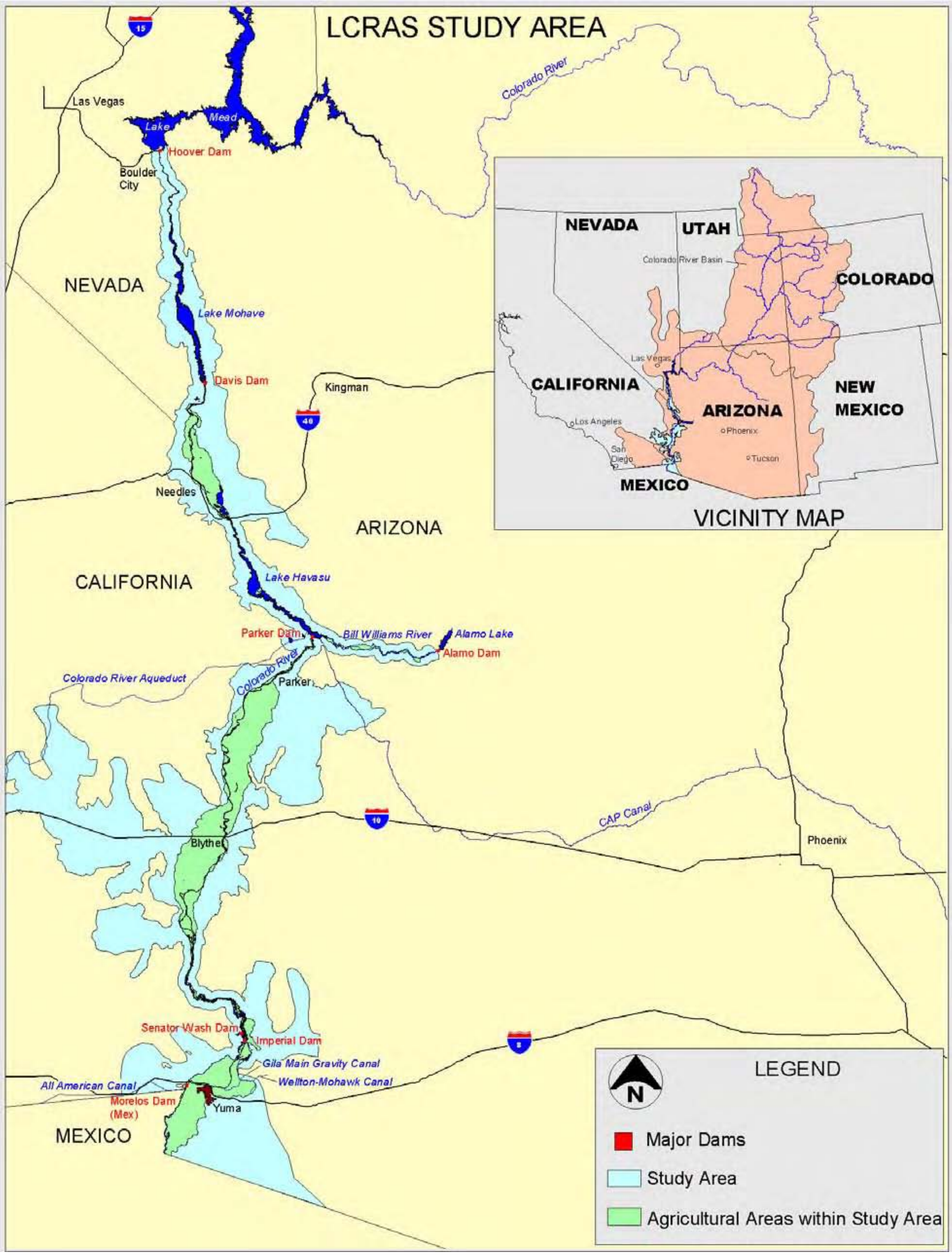

LCRAS STUDY AREA
Las Vegas
Lake Mead
Hoover Dam
Boulder City
Colorado River
NEVADA
Lake Mohave
Davis Dam
Kingman
Needles
ARIZONA
CALIFORNIA
Lake Havasu
Parker Dam
Bill Williams River
Alamo Lake
Alamo Dam
Colorado River Aqueduct
Parker
Blythe
CAP Canal
Phoenix
Senator Wash Dam
Imperial Dam
Gila Main Gravity Canal
Wellton-Mohawk Canal
All American Canal
Morelos Dam (Mex)
Yuma
MEXICO
VICINITY MAP
NEVADA
UTAH
Colorado River Basin
COLORADO
CALIFORNIA
Las Vegas
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), in addition to other requirements, requires the Secretary of the Interior (Secretary) to provide detailed and accurate records of diversions, return flows, and consumptive use of water diverted from the mainstream of the Colorado River below Lee Ferry (lower Colorado River) "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 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) document and present for evaluation, improved methods of quantifying the consumptive use of Colorado River water from Hoover Dam to Mexico that can be utilized in preparing the decree accounting report.

Background

In 1984, Reclamation joined with the U.S. Geological Survey; the lower Basin States of Arizona, California, and Nevada; 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 flows which return to the river through the groundwater system (unmeasured return flows) in addition to those measured as surface flows in calculating consumptive use. At that time, calculations of consumptive use in the decree accounting report did not include estimates 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 include measured and unmeasured return flows in calculations of consumptive use. The USGS completed its development of LCRAS in the late 1980s, but did not publish a final report until 1996 (Owen-Joyce and Raymond, 1996). In 1990, Reclamation assumed responsibility for the continued development of

LCRAS. Reclamation has modified LCRAS and issued reports that document its applications of LCRAS for calendar years 1995, 1996, 1997, 1998, 1999, 2000, and 2001 (Reclamation 1997, 1998, 1999, 2000, 2000a, 2001, 2002). This report documents Reclamation's application of LCRAS for calendar year 2002, including improvements Reclamation has made to LCRAS since issuing the previous report.

What is LCRAS?

LCRAS is a water balance of the lower Colorado River from Hoover Dam to Mexico. That is, LCRAS balances inflows, outflows, and water uses between the major dams and delivery points, called reaches[1]. The inflows, outflows, and water uses include agricultural and domestic water uses, and exports of water from the reach. Reclamation considers agricultural and domestic water uses and exports from the reach to be 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 sum of all flows entering the reach (inflows) and the sum of all flows leaving the reach (outflows) plus the sum of all water uses within the reach (water uses):

Residual = Sum of Inflows - (Sum of Outflows + Sum of Water Uses)

The residual is primarily the sum 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 (the square of the presumed standard error of estimate) (Lane, 1998), modifying each value. After 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. Because 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.

To calculate the water use of crops, natural vegetation (phreatophytes), canals, and open water bodies, Reclamation first estimates their rates of evapotranspiration[2] and evaporation. Using remote sensing and geographic information system (GIS) technologies, Reclamation determines the location and number of

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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.

[2] Evapotranspiration is the amount of water required by a plant in it's growth cycle.

acres of each crop group grown by each agricultural diverter, the type and acres of each phreatophyte group, and the acres of open water within each known service area or ownership boundary.

LCRAS calculates three categories of consumptive use: agricultural consumptive use, domestic consumptive use, and export consumptive use. Agricultural consumptive use is the final value of agricultural ET (agricultural ET plus a portion of the residual). The minimum agricultural ET is crop ET plus evaporation from canals that serve a diverter and bodies of open water maintained by a diverter. The amount of phreatophyte ET that should be added to the minimum agricultural ET to develop a complete ET value for agriculture is unresolved 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 (the final value of phreatophyte ET) separately for each diverter.

Domestic consumptive use is the final value of domestic water use after distribution of the residual of the water balance. Reclamation estimates domestic water use by (1) subtracting a measured return from a measured diversion; (2) applying water use coefficients to measured diversions; (3) applying per-capita consumptive use factors to the population of a town, city, or other municipal environment; or (4) using other methods unique to a specific domestic diverter. Reclamation chooses the appropriate method to estimate domestic water use based on the circumstances and type of data available for each domestic diverter.

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

Results of Key LCRAS Components

The following sections present qualitative and quantitative assessments of the results for the major components of LCRAS.

Image Classification of Crop, Phreatophyte, and Open Water Areas

Image classification is the process of using digital image processing procedures to identify features or land cover types in digital satellite imagery. Reclamation uses these techniques along with GIS technologies to determine the location and number of acres of crop groups, phreatophyte groups, and open water along the lower Colorado River from Hoover Dam to Mexico. This procedure is also referred to as 'mapping' in this report.

Image classification procedures using images from the Landsat 5 and Landsat 7 satellites provides excellent and reliable determinations of the location and number of acres of crop groups. Post-classification accuracy assessment shows that, overall, the crop groups can be mapped with an average accuracy of greater than 90 percent. To assess the meaning of image classification error, one must understand the intended use of the crop classification. The goal of LCRAS is to calculate the consumptive use of water. Image classification error only has meaning in terms of the effect the classification error has on the resultant consumptive use value. Classification error resulting from the misidentification of crop groups with similar water demands, or that represent a very small portion of the irrigated acreage within a diverter boundary, negligibly affect the resultant value of consumptive use within the diverter boundary.

Reclamation initially mapped phreatophytes along the lower Colorado River in 1994. Post-classification accuracy assessment of phreatophyte groups in this map indicate an overall accuracy of 87 percent. Reclamation updates the phreatophyte map each year by comparing the current year satellite images to the previous year's images (change detection methods) and field verifies major changes, which are usually due to fire or development. Reclamation also uses image classification and GIS processes to quantify open water areas. The classification results for Lakes Mohave and Havasu was found to be within 3 percent of the values published in elevation/capacity/area tables in 1995. This report does not repeat this comparison.

Calculating the Water Balance

Reclamation evaluates the water balance closure[3] by comparing the value of the residual to the presumed measurement error of the mainstream inflow to each reach. Reclamation considers distribution of the residual to be optional if the value of the residual is about equal to or less than the presumed standard error of measurement of the mainstream flow entering the reach. Reclamation has chosen to distribute the residual of all reaches in LCRAS Demonstration of Technology reports to demonstrate the impact distributing the residual has on 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.

[3] Water balance closure is an assessment of the magnitude of the residual relative to the magnitude of major inflows, outflows, or water uses.

Table ES-1 presents the values used in the water balance and shows the closure of the water balance for each reach for calendar year 2002.

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})	10,447,200	10,819,800	7,565,400	6,181,777	10,447,200
Flow at the downstream boundary (Q_{ds})	10,819,800	7,565,400	6,181,777	1,705,424	1,705,424
Residual (Q_{res})	-526,949	44,413	178,564	16,132	-287,840
Residual as a percentage of flow at the upstream boundary (Q_{us})	-5.04%	0.41%	2.36%	0.26%	-2.76%
Difference between flow at the upstream and downstream boundaries (Q_{dif})	-372,600	3,254,400	1,383,623	4,476,353	8,741,776
Measured tributary inflow (Trm)	0	5,702	0	13,173	18,875
Unmeasured tributary inflow (Trum)	6,480	36,290	33,750	3,000	79,520
Exported flow (Q_{ex})	0	2,819,589	0	3,965,573	6,785,162
Evaporation (E)	135,404	128,784	72,472	9,842	346,502
Domestic consumptive use (CU_d)	383	44,364	6,442	33,223	84,412
Agricultural ET (ET_{ag})	0	76,715	806,132	389,939	1,272,786
Phreatophyte ET (ET_{pht})	742	187,727	353,420	77,817	619,706
Change in reservoir storage (ΔS_r)	24,300	-5,200	343	0	19,443
Change in aquifer storage (ΔS_a)	0	0	0	0	0

Comparing Consumptive Use Results in LCRAS and Decree Accounting Reports

Table ES-2 compares State totals of agricultural, domestic, and export consumptive use, and phreatophyte water use developed by LCRAS, to consumptive use as compiled in the decree accounting report for calendar year 2002.

Table ES-2.— LCRAS agricultural, domestic, and export consumptive use, and LCRAS phreatophyte water use compared to decree accounting report consumptive use

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)		307,238	307,238	Uses above Hoover Dam
Uses below Hoover Dam	18,298	17,799	19,480	Uses below Hoover Dam
			1,491	Unmeasured return flow credit
Nevada Total	18,298	325,037	325,227	Nevada Total
California				
			5,365,608	Sum of individual diverters
			90,002	Unmeasured return flow credit
California Total	177,250	5,215,255	5,275,606	California Total
Arizona				
Subtotal (below Hoover Dam, less Wellton-Mohawk IDD)	425,671	2,517,054	2,743,682	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)		148	148	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (decree accounting report)		285,755	285,755	Wellton-Mohawk IDD
			60,354	Pumped from South Gila wells (drainage pump outlet channels [DPOCs]).
			163,244	Unmeasured return flow credit
Arizona Total	425,671	2,802,957	2,805,987	Arizona Total
Lower Colorado River Basin Total				
Lower Basin Total	621,219	8,343,249	8,406,820	Lower Basin Total

Table ES-3 shows the final adjusted values of all the water balance components after distributing the residual and after adjusting flows at the major dams and the flow to Mexico as described in Lane (1998) for calendar year 2002.

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})	10,772,734	10,618,913	7,407,132	6,192,078	10,772,734
Flow at the downstream boundary (Q_{ds})	10,618,913	7,407,132	6,192,078	1,728,743	1,728,743
Residual (Q_{res})	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	153,821	3,211,781	1,215,054	4,463,335	9,043,991
Measured Tributary inflow (Trm)	0	5,700	0	13,172	18,872
Unmeasured Tributary inflow (Trum)	6,505	36,230	33,274	2,999	79,008
Exported flow (Q_{ex})	0	2,821,196	0	3,967,992	6,789,188
Evaporation (E)	135,095	128,805	72,533	9,842	346,275
Domestic consumptive use (CU_d)	383	44,364	6,442	33,224	84,413
Agricultural consumptive use (CU_{ag})	0	76,722	813,676	390,470	1,280,868
Phreatophyte water use (CU_{pht})	742	187,772	354,870	77,838	621,222
Change in reservoir storage ()S_r)	24,275	-5,199	343	0	19,419
Change in aquifer storage ()S_a)	-169	51	464	140	486

Conclusion and Future of LCRAS

Reclamation believes that the LCRAS Demonstration of Technology Reports have shown that the technology used in LCRAS performs as intended, and is useful in assessing and solving water management issues. This is the last LCRAS Demonstration of Technology Report. Reclamation's future plans are to use the ET values for crop groups and phreatophyte groups that are generated by LCRAS for at least two primary purposes: First, as a tool in assessments of beneficial use for water management purposes, and second, as a tool in assessments of water use by phreatophyte groups in support of environmental activities along the lower Colorado River. Reclamation will produce a smaller, less detailed, LCRAS report beginning in 2004.

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Document Overview

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 2002. Chapter 1 provides general background information, including the Supreme Court Decree requirement to calculate consumptive use along the lower Colorado River. Chapter 2 describes the major activities required to calculate consumptive use with LCRAS and assesses their success in calendar year 2002, including identifying and mapping crop groups, phreatophyte groups, and open water. Chapter 2 also shows how to calculate agricultural consumptive use for a sample diverter.

Chapter 3 describes improvements made since the issuance of the 2001 LCRAS Demonstration of Technology report and potential improvements under active consideration during the past year. Chapter 4 uses tables and graphs to compare consumptive use values developed by LCRAS to consumptive use values compiled for the decree accounting report. Chapter 5 presents a detailed account of the disparity between the reference evapotranspiration values reported by two networks along the Colorado River and Reclamation's cooperative efforts with the networks to resolve the disparity.

Chapter 6 provides an in-depth discussion of using remote sensing and geographic information system (GIS) technologies to identify and map crop groups, phreatophyte groups, and open water. Chapter 7 documents the fractions of the underflow that cross the Southerly International Boundary with Mexico, which Reclamation must include in the agricultural and domestic consumptive use of diverters located downstream of the Northerly International Boundary with Mexico. Chapter 8 provides a more detailed explanation of the domestic water use factors used in this report.

Chapter 1 — Introduction

Chapter 1 briefly highlights the importance of the lower Colorado River; describes the Law of the River, which governs the river's operations and the aspects of this body of law that require an accounting of consumptive use; and then discusses how the existing decree accounting report and how the Lower Colorado River Accounting System (LCRAS) calculate consumptive use of Colorado River water apportioned to Arizona, California, and Nevada.

Lower Colorado River is Important to the Southwestern United States

The lower Colorado River (the Colorado River below Lee Ferry[4]) is critical to the environment and the economy of the Southwest. Extensive development of the lower Colorado River and its tributaries 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 that receive water from the lower Colorado River include Las Vegas, Nevada; Phoenix, Arizona; and Los Angeles and San Diego, California. 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 on 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" Governs Lower Colorado River Operations

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 (Reclamation), the Secretary contracts for all water released for diversion 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 sections briefly describe the four major components of the "Law of the River" as they relate to accounting for the consumptive use of Colorado River water apportioned to Arizona, California, and Nevada.

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

Colorado River Compact Provides Cornerstone of the "Law of the River"

The seven Colorado River Basin States (Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming) and the Federal Government negotiated the Colorado River Compact in 1922, considered the cornerstone of the "Law of the River." 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 of "doctrine of prior appropriation," deprive them of their ability to use the river's flows in the future. Among other things, the Colorado River Compact accomplished the following:

- Divided the Colorado River Basin into an Upper Basin (those parts of the States of the Upper Division that naturally drain into the Colorado River system above Lee Ferry) and a Lower Basin (those parts of the States of the Lower Division that naturally drain into the Colorado River system below Lee Ferry).

- Defined the relationship between the States in the Upper Basin (Colorado, New Mexico, Utah, and Wyoming)—the source of most of the river's water—and the States in the Lower Basin (Arizona, California, and Nevada)—the location of most of the water development.

- Apportioned to the Upper Basin and to the Lower Basin, respectively, the exclusive beneficial consumptive use of 7,500,000 acre-feet of water from the Colorado River system each year, for a total of 15 million acre-feet.

Boulder Canyon Project Act of 1928 Intended to Protect and Develop the Lower Basin

The Colorado River Compact set the stage for the Boulder Canyon Project Act, which set in place the management framework to develop and protect Colorado River resources in Arizona, California, and Nevada. Among other things, the Boulder Canyon Project Act of 1928 accomplished the following:

- Ratified the Colorado River Compact.

- Limited the beneficial consumptive use of water from the Colorado River by the State of California to 4,400,000 acre-feet a year.

- Authorized Arizona, California, and Nevada to enter into an agreement that of the 7,500,000 acre-feet of exclusive beneficial consumptive use apportioned to the Lower Basin each year by paragraph (a) of Article III of the Colorado River Compact, Arizona would be apportioned 2,800,000 acre-feet and Nevada would be apportioned 300,000 acre-feet.

Mexican Water Treaty of 1944 Established Relationship Between U.S. and Mexico Use of Colorado River Water

The Mexican Water Treaty of 1944 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.

Among other things, the Mexican Water Treaty accomplished the following:

- Committed 1.5 million acre-feet of the Colorado River's annual flow to Mexico.
- 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 Opinion and Decree Settled Longstanding Dispute

In 1963, the U.S. Supreme Court rendered an opinion and issued a decree to settle a 25-year-old dispute between Arizona and California regarding water supplies and the definition of Colorado River water. Among other things, the opinion accomplished the following:

- Concluded that Congress, in passing the Boulder Canyon Project Act, created a scheme to apportion the Lower Basin’s 7.5 million acre-feet of beneficial consumptive use of mainstream Colorado River water among Arizona (2,800,000 acre feet), California (4,400,000 acre feet), and Nevada (300,000 acre feet).
- Concluded that Congress gave the Secretary adequate authority to accomplish this apportionment 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.
- 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) set forth the following:

- Enjoined the Secretary from delivering water outside the framework of apportionments defined by the Boulder Canyon Project Act
- Mandated charging consumptive use of water against the State within which the consumptive use takes place.
- Required the Secretary to develop an annual report documenting all diversion and consumptive uses of Colorado River water in Arizona, California, and Nevada.

How Does The Decree Accounting Report Calculate Consumptive Use?

To comply with the Supreme Court Decree requirement to develop an annual report documenting all diversions and consumptive uses of Colorado River in Arizona, California, and Nevada, Reclamation each year prepares "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 manner in which consumptive use is calculated. Article I(A) of the Supreme Court Decree defines consumptive use as follows:

> "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.

Consequently, beginning in 1964, Reclamation calculated consumptive use primarily as measured diversions from the mainstream, less measured return flows to the mainstream. Then, 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 (task force) in 1970. In 1984, after extensive discussion and trials of other methods, the task force accepted a proposal to develop and study a water balance method for the lower Colorado River, named the Lower Colorado River Accounting System (LCRAS), to improve the calculation of consumptive use of Colorado River water in Arizona, California, and Nevada. (Bureau of Reclamation [1997] provides a more detailed history of events leading to the development of LCRAS.)

Since 1991, in parallel with the continued development of LCRAS, Reclamation has augmented its calculation of consumptive use in the annual decree accounting report with estimates of *unmeasured* return flow. Reclamation currently compiles the decree accounting report using estimates of unmeasured return flow based primarily on comparisons between measured diversions less measured return flows and (1) other estimates of consumptive use from 1991 Arizona Department of Water Resources studies[5], (2) a crop evapotranspiration study performed by Reclamation's Water Management Branch of the Operations and Maintenance Division in Boulder City, Nevada[6], and (3) exchanges of information between Reclamation staff and staff of the Colorado River Board of California.

In an attempt to estimate unmeasured return flow, Reclamation, for a single year in the early 1990s, developed unmeasured return flow factors for large agricultural diverters and selected domestic diverters along the lower Colorado River. The return flow factors were calculated by dividing estimates of unmeasured return flow (from the studies mentioned previously) by the reported diversions from the mainstream.

Since developing the unmeasured return flow factors, Reclamation has applied them to most diverters from the mainstream of the lower Colorado River based on similarity of conditions between diverters identified in the previously mentioned studies and other diverters from the mainstream. The decree accounting report provides a sum of the unmeasured return flows estimated for all users in Arizona, California, and Nevada. It does not provide estimated unmeasured return flow in reported values of consumptive use for individual diverters.

Some concerns exist about estimates of unmeasured return flows and the way they are presented in the decree accounting report, including the following:

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[5] 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.

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

- Reporting a single conglomerate value of unmeasured return flow as a correction to the sum of consumptive uses in Arizona, California, and Nevada and not for individual diverters.
- The unproven presumption that the relationship between diversion and unmeasured return flow is constant from year to year.
- The absence of a unique unmeasured return flow factor for each diverter.
- The absence of documentation for the underlying assumptions used to develop some of the unmeasured return flow factors.
- The absence of documentation for the assumptions, techniques, and decisions used to include or exclude water use by natural vegetation (phreatophytes) in developing the unmeasured return flow factors.

Reclamation, the Lower Basin States, and the Bureau of Indian Affairs Join to Improve Methods for Estimating and Distributing Consumptive Use

In 1984, Reclamation joined with the U.S. Geological Survey; Arizona, California, and Nevada; 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 calculating consumptive use. At that time, calculations of consumptive use in the decree accounting report did not account for 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 request from Arizona, California, and Nevada to account for measured and unmeasured return flows in calculations of consumptive use. USGS completed its development of LCRAS in the late 1980s, but did not publish a final report until 1996 (Owen-Joyce and Raymond, 1996). In 1990, Reclamation assumed responsibility for the continued development of LCRAS. Reclamation has modified LCRAS and issued reports that document its applications of LCRAS for calendar years 1995, 1996, 1997, 1998, 1999, 2000, and 2001 (Reclamation 1997, 1998, 1999, 2000, 2000a, 2001, 2002). This report documents Reclamation's application of LCRAS for calendar year 2002, including changes Reclamation has made to LCRAS since issuing the previous report.

How Does LCRAS Calculate Consumptive Use?

LCRAS addresses the previously mentioned weaknesses of the current methods used to calculate consumptive use in the decree accounting report. LCRAS (1) has no need of a correction to the sum of consumptive uses in Arizona, California, and Nevada for unmeasured return flows, (2) has no need to rely on, or hold constant, relationships between diversion, return flow, and consumptive use from previous years or previous studies, (3) provides a unique estimate of consumptive use (and phreatophyte water use) values for each individual diverter for each year, and (4) provides documentation for all methods used.

This report uses the following unique definitions for water use and consumptive use:

> **Water use**. The consumption of Colorado River water by plants, for domestic purposes, by export from the system, evaporation, and any other activity that removes water from the system.
>
> **Consumptive use**. That water use considered to be part of the apportionments of Colorado River water confirmed by the U.S. Supreme Court to be available to Arizona, California, and Nevada for beneficial consumptive use.

As mentioned previously, LCRAS is a water balance of the lower Colorado River. That is, it balances inflows, outflows, and water uses (as defined previously) between the major dams and delivery points, called reaches,[7] from Hoover Dam to Mexico.[8] Each reach is balanced independently of the other reaches. Reclamation considers some water uses in the water balance to be part of the apportioned 7.5 MAF of beneficial consumptive use of Colorado River water available to Arizona, California, and Nevada and considers some water uses to not be part of the apportionment.

The water balance is used to calculate a residual, which is primarily a sum of the error in all the measurements and estimates used in the water balance. The residual equals the difference between the sum of all flows entering the reach, less the sum of all flows leaving the reach and the sum of all water uses within the reach, as shown in the following equation:

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7 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.

8 LCRAS has no impact on diversions and consumptive uses upstream of Hoover Dam.

Residual = Sum of Inflows - (Sum of Outflows + Sum of Water Uses)

Reclamation refines the water balance by distributing the residual, that is subtracting a fraction of the residual from all measurements and estimates of inflows and adding a fraction of the residual to all measurements and estimates of outflows and water uses, in proportion to the product of their magnitude and variance[9] (Lane, 1998). After the residual is distributed, the refined values in the water balance sum to a residual of zero. Reclamation terms the refined inflow, outflow, and water use values as final values. Because the residual can be either a positive or a negative value, the final values can be either larger or smaller 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 following sections define these categories of consumptive use. This report quantifies the amount of phreatophyte water use that occurs within delineated service areas or ownership boundaries; however the amount of phreatophyte water use that should be added to the other consumptive uses to develop a complete value of consumptive use for individual diverters remains unresolved. Therefore, this report presents estimates of agricultural, domestic, and export consumptive use and phreatophyte water use separately for each delineated service area or ownership boundary. Assuming diverters report all diversions from and measured returns to the mainstream, consumptive use calculated by LCRAS should never exceed the measured diversion less the measured return flow for individual diverters. After resolving the issue about the amount of phreatophyte water use to include in consumptive use, Reclamation would be able to prepare a single complete value of consumptive use for individual diverters.

How Does LCRAS Calculate Agricultural Consumptive Use and Phreatophyte Water Use?

Agricultural consumptive use is the final value of agricultural evapotranspiration (ET)[10] after distributing the residual from the water balance. Since the residual can be either a positive or a negative number, agricultural consumptive use can be either slightly larger or slightly smaller than agricultural ET. Agricultural ET becomes, at minimum, crop ET plus evaporation from canals that serve a diverter and

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[9] The variance is the square of the presumed standard error of estimate.

[10] Evapotranspiration is the amount of water required by a plant in it’s growth cycle.

bodies of open water maintained by a diverter.

Reclamation calculates evapotranspiration and evaporation using the following information:

- Reference evapotranspiration values for short grass calculated from data provided by the California Irrigation Management Information System (CIMIS) and Arizona Meteorological Network (AZMET) stations located in irrigated areas along the Colorado River from Hoover Dam to Mexico (reference ET).
- Evapotranspiration coefficients for each crop and phreatophyte group (ET coefficients) and evaporation coefficients.
- 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.

Reclamation uses remote sensing and GIS technologies to determine the location and number of acres of each crop group grown by each agricultural diverter, the acres of each phreatophyte group, and the acres of open water within each known service area or ownership boundary.

How Does LCRAS Calculate Domestic Consumptive Use?

Domestic consumptive use is the final value of domestic water use after distributing the residual from the water balance. Since the residual can be either a positive or a negative number, domestic consumptive use can be either slightly larger or slightly smaller than the estimate of domestic water use used in the water balance. Reclamation estimates domestic water use[11] for LCRAS as follows:

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

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

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 another method unique to the specific circumstances of an individual domestic diverter.

Chapter 8 provides details of the derivation of the domestic use factors mentioned in 1 through 3 above.

How Does LCRAS Calculate Export Consumptive Use?

Export consumptive use is the final value of export water use after distributing 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. Since the residual can be either a positive or a negative number, export consumptive use can be either slightly larger or slightly smaller than the estimate of export water use used in the water balance.

Conclusion and Future Activities

Reclamation believes that the LCRAS Demonstration of Technology Reports have shown that the technology used in LCRAS performs as intended, and is useful in assessing and solving water management issues. This is the last LCRAS Demonstration of Technology Report. Reclamation's future plans are to use the ET values for crop groups and phreatophyte groups that are generated by LCRAS for at least two primary purposes: First, as a tool in assessments of beneficial use for water management purposes, and second, as a tool in assessments of water use by phreatophyte groups in support of environmental activities along the lower Colorado River. Reclamation will produce a smaller, less detailed, LCRAS report beginning in 2004.

Chapter 2 — LCRAS in Calendar Year 2002

This chapter describes the major activities required to calculate consumptive use with LCRAS and assesses their success in calendar year 2002, including identifying and mapping crop groups, phreatophyte groups, and open water, and calculating the water balance. This chapter also provides an example calculation of agricultural consumptive use for a single diverter.

Identifying and Mapping Crop Groups, Phreatophyte Groups, and Open Water

The following sections provide a brief overview of the image classification processes and geographic information system (GIS) technologies Reclamation used to identify and map crop and phreatophyte groups, and open water areas in calendar year 2002. Chapter 6 provides an in-depth discussion.

Remote sensing is the process of acquiring information about something using indirect measurements. One example of remote sensing is the interpretation of features on the Earth's surface using imagery acquired by satellites orbiting the Earth. Image classification is the process of using image processing programs to identify features or land cover types in digital satellite imagery. Reclamation uses these techniques along with GIS technologies to determine the location and number of acres of crop groups, phreatophyte groups, and open water from Hoover Dam to Mexico. This procedure is also referred to as 'mapping' in this report. The spatial extent (location and area of coverage) of the crop groups, phreatophyte groups, and open water are stored in digital spatial databases referred to as a GIS database. Reclamation uses the data generated from these processes to accurately calculate agricultural and phreatophyte water use and evaporation. When remote sensing processes are not sufficient to map crop groups, phreatophytes, or open water, data collected on the ground (ground surveys or ground reference surveys) are also used. For example, orchards are mapped from ground survey data due to problems in correctly identifying them using only remote sensing processes.

Once data derived from satellite or ground surveys is entered into a GIS database, GIS programs are used to calculate the number of acres of each crop group and phreatophyte group for each diverter, as well as the acres of open water. Acreage calculations are completed for areas located within the flood plain along the mainstream of the lower Colorado River from Hoover Dam to Mexico and crop areas upon the Palo Verde and Yuma Mesas. Post-classification accuracy assessment shows that, overall, the crop groups were mapped with an average accuracy of greater than 90 percent for each image classification date shown on table 2.1.

Once Reclamation maps crop groups, phreatophyte groups, and open water areas (discussed in the following sections), Reclamation calculates agricultural and phreatophyte evapotranspiration (ET) for each diverter and evaporation from the lower Colorado River, its reservoirs, and major canals that divert and convey water from the river. Currently, this analysis does not include areas within domestic diverter boundaries.

Analyzing Remotely Sensed Data

For its analysis, Reclamation selects satellite images acquired by Thematic Mapper (TM) sensors mounted onboard the Landsat 5 and Landsat 7 satellites as well as sensors mounted onboard the Indian Remote Sensing (IRS) 1-C or 1-D satellites that adequately cover the study area, are cloud free, and that capture the variation in crop planting practices during the year. TM satellite data contain digital values recorded by the satellite sensor in different portions of the electromagnetic spectrum (ERDAS, 1999), that represent the spectral reflectance values of crop and phreatophyte groups (spectral characteristics). Table 2.1 shows the dates for which Reclamation acquired TM image data for analysis during calendar year 2002. Path and row designations refer to image locations based on the World Reference System[12]. In chapter 6, figure 6.2 shows the image locations as defined by path and row upon a backdrop of the lower Colorado River from Lake Mead to Mexico.

[12] 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.

Table 2.1 — TM Image path-row designations and acquisition dates used in calendar year 2002

Path-Row Designation	Acquisition Date
Path 38, rows 36 and 37	February 11, 2002
Path 38, row 37	March 15, 2002
Path 38, rows 36 and 37	April 2, 2002
Path 38, rows 36 and 37	July 21, 2002
Path 38, rows 36 and 37	November 10, 2002
Path 39, row 36	July 28, 2002

Collecting ground reference data

Correctly identifying and mapping crop and phreatophyte groups using remotely sensed data requires a thorough understanding of the spectral characteristics of vegetation types for representative (ground reference) sites throughout the study area. Reclamation analyzes the spectral characteristics within ground reference sites to generate spectral statistics, or signatures (ERDAS, 1999), for specific crop and phreatophyte groups.

Reclamation collects ground reference data for approximately 1,900 of the 13,800 irrigated fields in the study area, or about 15 percent of the total irrigated area. Reclamation uses 60 to 65 percent of the ground reference data for image classification (to identify crop groups) and the remaining 35 to 40 percent to assess the accuracy of the image classifications. Reclamation randomly selects irrigated fields as ground reference sites from a GIS database. Where necessary, Reclamation adds additional fields to ensure representation of all major crop groups, and to provide a statistically valid data set for image classification. The variability in planting and harvesting times for each crop group is a critical factor in selecting optimum image dates.

Reclamation purchases satellite images four times a year and collects ground reference data to coincide with the acquisition of these images. Table 2.2 shows the crop groups sampled and identified in calendar year 2002. Groups such as small vegetables, small grains, and crucifers are general group names that consist of a variety of specific crops. (Table 6.4 provides a complete listing of the crop groups and the individual crops within each group.) Table 2.3 shows how Reclamation groups phreatophyte types.

Table 2.2 — Crop groups sampled in calendar year 2002

Alfalfa	Melons - Spring	Tomatoes	Small Vegetables
Cotton	Melons - Fall	Sudan	Root Vegetables
Small Grain	Bermuda Grass	Legume and Solanum Vegetables	Perennial Vegetables
Field Grain	Bermuda Grass with Rye Grass	Crucifers	Sugar Beets
Lettuce - Early	Citrus - Young	Dates	Grapes
Lettuce - Late	Citrus - Mature	Safflower	Fallow
Herbs	Citrus - Declining	Orchards	Moist Soil Unit[13]
			Seasonal Wetland[14]

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

[13] An area flooded in winter and irrigated in summer to maintain vegetation.

[14] An area flooded in winter but not irrigated in summer to maintain a wetland.

Identifying and Mapping Cropped Areas

Reclamation has developed a spatial relational database (GIS database, ESRI, 1995) that delineates the field borders in all irrigated areas along the mainstream of the lower Colorado River from Hoover Dam to Mexico (field border database), to which Reclamation links all the ground reference data collected for image classification. Reclamation originally created the field border database by digitizing[15] field boundaries using 10-meter Systemme Pour l'Observation de la Terre (SPOT) satellite image data acquired in June and August of 1992 as a reference. Since 1995, Reclamation has updated changes in field borders based upon ground reference data collected throughout the year. Reclamation also uses 5-meter Indian Remote Sensing (IRS) satellite images (1-C or 1-D sensors) acquired in the fall of each year to update field borders in areas where ground reference data show significant changes in field border locations.

Delineated cropped areas include all areas along the mainstream of the lower Colorado River from Hoover Dam to Mexico known by Reclamation to divert or pump water as shown on exhibits 1 through 8. Exhibit 9 is an example of digitized field borders; exhibit 10 shows an overview of the diverter boundaries; and exhibit 11 shows the Bill Williams River area.

Identifying and Mapping Phreatophyte Areas

Reclamation initially classified phreatophyte areas in 1994 using TM satellite images and aerial photography. Reclamation updates phreatophyte areas by comparing the current year Landsat TM satellite images to the previous year's images (change detection methods). Reclamation field checks areas of spectral change to confirm that the change is actually due to change in land cover. Reclamation then remaps areas of land cover change and uses these maps to update the phreatophyte database. Reclamation compared images from July 28, 2001, to images from July 21, 2002, to update phreatophyte areas for calendar year 2002.

Identifying and Mapping Open Water Areas

Open water of the mainstream

Reclamation developed an open-water GIS database for calendar year 2000 which contains the spatial boundaries of open water surfaces such as reservoirs, rivers, and canals. For calendar year 2002, Reclamation compared TM satellite images acquired on July 21 and November 10, 2002, to the calendar

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15 Digitizing is the process of creating a graphical representation of a feature such as a road or agricultural field within a digital (computer) environment. Points representing the corners or center line of a feature are stored according to some real-world coordinate system and then can be displayed or analyzed within the computer environment

year 2001 open water GIS database to identify significant (greater than 90 m^2) changes in open water acreage that may have occurred over the calendar year.

<u>Open water in major delivery canals</u>

Reclamation includes evaporation from major canals that serve an irrigation district or Indian reservation in calculations of agricultural ET for the LCRAS program. For calendar year 2000, Reclamation identified bank-to-bank canal area (in acres) by digitizing canal banks using 5 meter IRS panchromatic satellite imagery as a reference. This information was added to the open water GIS database. From this, Reclamation calculated the acreage of open water within each canal. For calendar year 2002, Reclamation compared July 21, 2002, 30-meter TM imagery to the image used for calendar year 2000. This comparison identified seepage ponds alongside canals and newly identified large ponds (greater than 90 square meters in area).

Calculating the Water Balance for the Lower Colorado River

Reclamation calculates a water balance for 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.[16] The following equation shows how Reclamation calculated the water balance in calendar year 2002.

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

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

Sources of Data and Calculations Using Data

[16] 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.

Reclamation gathers data from its own records and reports, as well as from records and reports that others provide to Reclamation. The following sections discuss data sources and water-balance calculations Reclamation makes using the data.

Flow Data Used to Calculate the Water Balance

Flow data include the following measurements, flows at upstream and downstream reach boundaries, water diverted and exported from the mainstream, tributary inflows, and changes in reservoir storage. The U.S. Geological Survey (USGS), Reclamation, the International Boundary and Water Commission (IBWC), Metropolitan Water District of Southern California (MWD), and the Central Arizona Project (CAP) provided these data.

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

Data obtained from the USGS[17] provides most of the mainstream flow data that Reclamation uses to calculate the water balance. Individual diverters and IBWC also report some mainstream flows. Table 2.4 shows the gauges (station numbers) along the mainstream where flow was recorded, measured flow at those gauges, final values after distributing the residual from the water balance, percent change between the measured and final values, and the reporting agency.

[17] The U.S. 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 2002*.

Table 2.4 — Mainstream flow values used to calculate water balance
Lower Colorado River, Below Hoover Dam to Mexico

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	10,447,200	10,772,734	3.1%	GS
Colorado River below Davis Dam	09423000	10,819,800	10,618,913	-1.9%	GS
Colorado River below Parker Dam	09427520	7,565,400	7,407,132	-2.1%	GS
Colorado River at Imperial Dam	09429490	6,181,777	6,192,078	0.2%	GS
Diversion to Mittry Lake	09522400	9,774	Not Calculated	--	GS
All-American Canal (Station 60)	09523000	4,862,000	Not Calculated	--	GS
Gila Gravity Main Canal (Station 30)	09522500	868,673	Not Calculated	--	Reclamation
Colorado River below Imperial Dam	09429500	441,330	Not Calculated	--	GS
Colorado River at NIB	09522000	1,485,250	1,499,407	1.0%	IBWC
Eleven Mile wasteway	09525000	11,532	11,534	0.0%	IBWC
Cooper wasteway	09531850	1,020	1,020	0.0%	IBWC
Twenty-one Mile wasteway	09533000	7,888	7,890	0.0%	IBWC
Main drain + 242 wells	09534000	111,612	111,866	0.2%	IBWC
West Main Canal wasteway	09534300	1,465	1,465	0.0%	IBWC
East Main Canal wasteway	09534500	4,214	4,214	0.0%	IBWC

A Portion of the Underflow to Mexico Must be Accounted for as a Consumptive Use

The portion of the underflow to Mexico (groundwater flow that crosses the international boundaries into Mexico), which originated as a diversion from the Colorado River, must be accounted for as a consumptive use because it is diverted water which does not return to the Colorado River and become available for use in the United States or satisfaction of the Mexican water treaty (underflow is not counted as a treaty delivery). The international boundaries are defined by the southerly international boundary with Mexico (SIB) and the limitrophe section of the Colorado River between the northerly international boundaries with Mexico (NIB) and SIB. The downstream flow (Q_{ds}) of the Colorado River in the Imperial Dam-to-Mexico reach includes an estimate of the underflow to Mexico.

The portion of the underflow that crosses the SIB into Mexico, which Reclamation adds to the agricultural and domestic consumptive use of diverters in the Yuma, Arizona area in this report, is based on a study documented in Chapter 7, "Distribution of Underflow to Mexico To Water Users Below The Northerly International Boundary With Mexico." The portions of underflow which flow across the limitrophe section into Mexico, which Reclamation adds to the agricultural and domestic consumptive use of diverters in the Yuma, Arizona area in this report, is based on the number of acres irrigated by diverters along and near the limitrophe section. Table 4.2 in chapter 4 shows the diverters in the Yuma, Arizona area and their estimated contributions to the underflow across SIB and the limitrophe section.

Reclamation uses an initial estimate of the annual underflow to Mexico of 20,000 acre-feet across the limitrophe section and 62,443 acre-feet across SIB in the Imperial Dam to Mexico water balance. After distributing the residual in the Imperial Dam to Mexico reach and making the final adjustment of the flow to Mexico (table 2.10), the final annual value of underflow to Mexico across the limitrophe section increased to 22,197 acre-feet and 69,149 acre-feet across SIB, or a change of about 11 percent. Of this total, Reclamation considers all of the 22,197 acre-feet to cross the limitrophe section and about 83 percent of the 68,372 acre-feet to cross SIB (or 57,393 acre-feet) to be from water diverted from the mainstream.

Export Flow Data (Q_{ex})

The export flows used in LCRAS are, MWD, CAP, Wellton-Mohawk Irrigation and Drainage District (WMIDD), Imperial Irrigation District (IID), and Coachella Valley Water District (CVWD). MWD reports their diversions from the Colorado River at Lake Havasu into the Colorado River Aqueduct 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 reports their diversions from Lake Havasu at the Havasu Pumping plant from their own measurements. Reclamation calculates WMIDD's net export by adding the evaporation losses from the Gila Gravity Main Canal proportionate to the diversion made for the

WMIDD to the measured diversion at the Wellton-Mohawk Canal. Reclamation measures the diversion at the Wellton-Mohawk Canal using an open-channel acoustic velocity meter (AVMs). Reclamation calculates net export to IID and CVWD by adding the evaporation losses from the All American Canal (AAC) between Imperial Dam and Pilot Knob to the measured flow in the AAC below Pilot Knob. IID measures flows in the AAC below Pilot Knob and the USGS reports the data measured by IID.

In calendar year 2002, Reclamation measured 57,766 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 in Mexico, 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. Because water discharged to the MOD/MODE does not return to the Colorado River, Reclamation adds this discharge to the exports from the Colorado River system to calculate water balance.

Table 2.5 shows measured values, final values after distributing the residuals from the water balance in each reach, and percentage change between measured and final values for exports by MWD, CAP, WMIDD, and CVWD. Reclamation presumes the standard error of estimate for export flows is 1 to 2 percent.

Table 2.5 — Export flow values used to calculate reach water balances

Units: Annual acre-feet

Export location	Station Number	Measured Flow	Final Value after Distribution of Residual	% Change (Final - Measured÷ Measured)	Reporting Agency
Colorado River Aqueduct	9424150	1,237,994	1,238,700	0.1%	GS
Central Arizona Project Canal	9426650	1,581,595	1,582,496	0.1%	GS
Wellton-Mohawk Canal	9522700	425,887	426,147	0.1%	Reclamation
All American Canal below Pilot Knob	9527500	3,481,920	3,484,044	0.1%	GS

The sum of the final values of export flows (excluding the discharge into the MOD/MODE from the DPOC's) accounts for about 83 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 Bill Williams River in west-central Arizona and the Gila River in southwestern Arizona. USGS measures and reports inflows from the Bill Williams River below Alamo Dam and from the Gila River near Dome.

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[18] 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 and Owen-Joyce, 1994) upstream from Lake Havasu into the Bill Williams River[19].

Table 2.6 shows the measured tributary inflow values used to calculate the water balance.

Table 2.6 — Measured tributary Inflows, Lower Colorado River

Units: Annual acre-feet

Measured tributary	Station Number	Measured Flow	Final Value After Distribution of Residual	% Change (Final - Measured÷ Measured)	Reporting Agency
Bill Williams River below Alamo Dam	09426000	5,702	5,700	0.0%	GS
Gila River near Dome	09520500	13,173	13,172	0.0%	GS

18 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.

19 The extent of the accounting surface upstream into the Bill Williams River represents the maximum influence of Lake Havasu upon the Bill Williams River in a normal operating year, based upon the areal extent of the contiguous alluvium at the normal high annual operating elevation of Lake Havasu.

Unmeasured tributary inflow data (T_{rum})

To calculate the water balance, Reclamation uses the unmeasured tributary inflow values published by USGS in Owen-Joyce (1987), except for unmeasured groundwater inflow from Sacramento Valley, which is from an Arizona Department of Water Resources investigation, ADWR (1997). The flow values in Owen-Joyce (1987) are primarily compilations of existing studies, based on mean annual precipitation, available at the time of publication.

Table 2.7 shows the estimated unmeasured tributary inflow data for each reach used to calculate the water balance. Reclamation does not include the unmeasured tributary inflows to the Bill Williams River in the Colorado River water balances, using them 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 — Estimated Unmeasured Tributary Inflows, Lower Colorado River
Hoover Dam to Mexico
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

Reach	Description		Flow
Parker Dam to Imperial Dam			
	Unmeasured Runoff		
		Whipple Mountains	1,150
		Big Marie-Riverside Mountains	2,300
		Palo Verde-Mule Mountains	1,200
		Dome Rock-Trigo-Chocolate Mountains	16,200
	Unmeasured Runoff in Tributary Streams		
		Vidal Wash	1,300
		Bouse Wash	4,800
		Tyson Wash	2,600
		McCoy Wash	800
		Milpitas Wash	1,200
	Groundwater Discharge		
		Bouse Wash	1,200
		Tyson Wash	350
		Vidal Wash	250
		Chuckwalla Valley	400
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			79,008
Difference in acre-feet (sum of final values - sum of values used in water balances)			-512
Difference in percent (difference in acre-feet ÷ sum of values used in water balances)			-0.6%

Evapotranspiration Data

To calculate agricultural consumptive use and phreatophyte water use, Reclamation must first calculate evapotranspiration (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 items:

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

The following sections describe how Reclamation calculates the four items mentioned above.

Calculating Reference ET

The first step in calculating ET is securing or calculating a reference ET value for the area of interest. Reference ET represents a fundamental measure of water use by vegetation to which the water use of all types of vegetation (as well as evaporation from a water body) can be related. Reclamation uses reference ET values calculated with the standardized equation derived from the American Society of Civil Engineers (ASCE) Penman Monteith equation[20] (standardized equation) and climatological data provided by the California Irrigation Management Information System (CIMIS) and Arizona Meteorological Network (AZMET) stations located in irrigated areas along the Colorado River from Hoover Dam to Mexico. The standardized equation is currently recognized by the ET community of scientists as the most accurate representation of a fundamental measure of water use by vegetation available. A more detailed explanation of the standardized equation can be found in Chapter 5.

The AZMET and CIMIS networks report reference-ET values directly, however Reclamation noticed a disparity in the reference-ET values reported by each network. Upon investigation, Reclamation discovered that the AZMET and CIMIS networks do not use exactly the same reference-ET equation. Calculating reference ET using the standardized equation and the climatological data provided by the AZMET and CIMIS networks eliminates the portion of the disparity in reference-ET values reported by the CIMIS and AZMET networks which results from the use of slightly different reference-ET equations. Chapter 5 presents a detailed account of the disparity between the reference evapotranspiration values reported by the CIMIS and AZMET networks and Reclamation's cooperative efforts with the networks to resolve the disparity, which led 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.

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[20] 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.

Figure 2.1 shows the reference-ET and precipitation values used to develop the ET estimates used by this report to calculate crop and phreatophyte ET, and evaporation for the water balance.

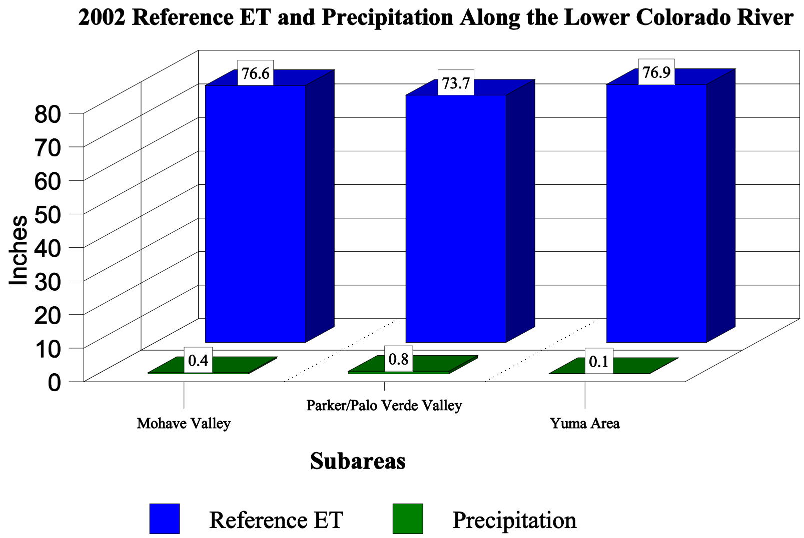


Figure 2.1 — Reference ET and precipitation values by subarea along the lower Colorado River.

Refining ET Coefficients for Crop and Phreatophyte Groups

ET coefficients are the values that relate reference ET to the ET of specific crop and phreatophyte groups (as well as evaporation from a water body). 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) lists the crop groups and subgroups, and table 2.3 lists the phreatophyte groups.

Calculating the Number of Acres of Each Crop and Phreatophyte Group

The number of acres of each crop and phreatophyte group are required to calculate ET for the water balance. Reclamation calculates the number of acres of each crop and phreatophyte group by applying the analysis previously described in "Identifying and Mapping crop groups, phreatophyte groups, and open-water."

Calculating Effective Precipitation

Effective precipitation is a correction to the ET rate of crop groups required to remove the impact of precipitation so the ET calculated is the ET of Colorado River water. Reclamation calculates effective precipitation as the product of recorded precipitation and an effective precipitation coefficient. Precipitation gauges at CIMIS and AZMET stations, and precipitation gages operated by the National Weather Service (NWS), sited along the lower Colorado River 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 (1993) contains the documentation for the effective precipitation coefficients used for this report.

Reclamation uses the following equation to calculate effective precipitation for this report:

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

The amount precipitation that the lower Colorado River Valley received in calendar year 2002 ranged from 1.66 inches, measured by the Blythe NE CIMIS station, to zero measured by the Riply CIMIS, Ehrenberg 2E MWS, Yuma Citrus NWS, and Yuma Quartermaster MWS stations. The correction to the ET rate for precipitation is very small, as can be discerned from an examination of figure 2.1which shows annual reference ET and annual precipitation.

Calculating Agricultural ET (ET_{ag})

The summation of agricultural ET for all diverters within a reach is the outflow, ET_{ag}, in the water balance. Agricultural ET includes the ET of the crops in the study area plus an estimate of the evaporation from major delivery canals serving each district or Indian reservation and evaporation from ponds each district or Indian reservation maintains. Agricultural ET currently does not include any ET from phreatophytes that may consume diverted Colorado River water. Therefore, agricultural ET, as used in this report, should be considered a minimum agricultural ET. Agricultural ET is calculated on a monthly basis and summed to produce annual values for the water balance.

To calculate the ET of the crops in the study area, Reclamation must calculate an ET rate for each crop group. To calculate an ET rate (inches) for each crop group, Reclamation multiplies the average daily reference ET values (inches) by each group's unique daily ET coefficients (dimensionless). Reclamation considers the effect 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). Reclamation sums the daily ET rates for each crop group to produce a monthly ET rate (inches).

In parallel with the calculations of ET rate, Reclamation must determine the number of acres covered by each crop group within each diverter boundary. Reclamation calculates the number of acres covered by each crop group within each diverter boundary by using GIS technologies, remote sensing, and field survey data, as previously described in "Identifying and Mapping crop, phreatophyte, and open water."

With the ET rates for each crop group and number of acres covered by each crop group described previously, Reclamation calculates the ET of the crop groups (in acre-feet) within each diverter boundary by multiplying the ET rate for each crop group (inches) by the area covered by each crop group (acres) within each diverter boundary, and dividing by 12 (inches/foot). These calculations are performed monthly and the results summed to produce annual agricultural ET values within each diverter boundary. The annual agricultural ET values within each diverter boundary are then summed to produce the annual agricultural ET value used in the water balance. Table 2.2 lists the crop groups used for this report.

The following example illustrates an ET calculation for cotton:

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

Where:

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

Σ_n = Summation for n time (monthly or annual)

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, “Calculating evaporation from major delivery canals serving irrigation districts and Indian reservations ” under the section entitled, “Calculating Evaporation (E) ” discusses canal evaporation calculations.

The sum of the agricultural ET compiled for calendar year 2002 from Hoover Dam to Mexico was 1,272,786 acre-feet. After distributing the residuals from the water balance in each reach, the final value increased to 1,280,868 acre-feet, a change of less than 1 percent. Agricultural consumptive use is the final value of the agricultural ET, which accounts for about 16 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 IID, CVWD, and 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 section “Export Flow Data (Q_{ex})” for more details.

Calculating Phreatophyte ET (ET_{pht})

Reclamation calculates phreatophyte ET for this report the same way it calculates agricultural ET, except that Reclamation makes no correction to the ET rates of phreatophytes for effective precipitation and does not add evaporation from canals or other areas of open water to phreatophyte ET. The sum of the ET of all phreatophyte groups within a diverter boundary yields the phreatophyte ET for a diverter. The sum of phreatophyte ET within all diverter boundaries within a reach yields the phreatophyte ET_{pht} outflow used in the water balance.

Reclamation analyzed remotely sensed data, as well as 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 lists the phreatophyte groups used in this report. Beginning with calendar year 1996 and continuing through calendar year 2002, Reclamation has updated phreatophyte acreage values by comparing the current year satellite images to the previous year's images (change detection methods) and field verifying major changes, which are usually due to fire or development.

The sum of the ET_{pht} calculated for calendar year 2002 from Hoover Dam to Mexico was 619,706 acre-feet. After distributing the residuals from the water balance in each reach, the final value of phreatophyte water use increased to 621,222 acre-feet, a change of less than 1 percent. Phreatophyte water use accounted 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.

Calculating Evaporation (E)

Calculating evaporation from the mainstream

To calculate a water balance, 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. 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 regarding accounting for consumptive use.

Reclamation calculates open water evaporation 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 determined the open water area for this report by analyzing satellite images acquired on July 21, 2002, and November 10, 2002. Chapter 6 contains the details of this analysis. Reclamation calculated evaporation from Hoover Dam to Mexico for calendar year 2002 was 346,275 acre-feet. After distributing the residuals from the water balance in each reach, the final value of evaporation decreased to 346,502 acre-feet, a change of less than 1/10 of 1 percent. Evaporation accounted 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.

Calculating 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 to derive agricultural ET for the water balance. Evaporation from delivery canals is a loss associated with the delivery and use of water for growing crops. Reclamation calculates evaporation from major delivery canals using the same technique it uses to calculate evaporation from the mainstream, except that the open water area is that of the major delivery canals. Reclamation initially digitized the open water area of major delivery canals using IRS 5-meter panchromatic satellite imagery acquired on October 20, 1999.

Reclamation categorized major delivery canals into two groups: those that provide water to a single irrigation district or Indian reservation (single user canals) and those that provide water to two or more irrigation districts and/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.

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

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) 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 that receive water from the canal. The proportionate use of the canal can be expressed as fractions or percentages.

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 (appendix I), as the proportion of open water area of the shared canal assigned to each district or Indian reservation multiplied by 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 included in agricultural ET, domestic use, and exports totaled about 12,000 acre-feet in 2002, less than two tenths of one percent of the combined consumptive use from agriculture, domestic users, and exports along the lower Colorado River from Hoover Dam to Mexico.

Calculating Domestic Consumptive Use (CU_d)

Domestic use, as used in LCRAS, 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 as follows:

1. Subtract a measured return flow from a measured diversion, or
2. If a measured return flow is unavailable, apply 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, apply 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.

To the above, Reclamation adds a proportional amount of evaporation from single user or shared major delivery canals to domestic users who take delivery from such canals. Reclamation estimates domestic water use from Hoover Dam to Mexico was 84,412 acre-feet in calendar year 2002. After distributing the residuals from the water balance in each reach, the final value of domestic water use (domestic consumptive use) increased by 1 acre-foot to 84,413 acre-feet. Domestic consumptive use accounts for about 1 percent of the consumptive use (agrucultural, domestic, and export) along the lower Colorado River from Hoover Dam to Mexico.

Calculating Change in Reservoir Storage ()S_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 Region 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 reservoir storage values used in this report.

Table 2.8 — Change in reservoir storage
Lower Colorado River Hoover Dam to Mexico
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	24,300	24,275	-0.1%	Reclamation
Change in storage, Lake Havasu	09427500	-5,200	-5,199	0.0%	Reclamation
Change in storage, Senator Wash	--	343	343	0.0%	Reclamation

Calculating Change in Aquifer Storage (ΔS_a)

Reclamation uses an initial value of zero for change in aquifer storage in the water balances for all reaches of the river. Currently, no network of monitored 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 an opportunity for some portion 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 (486 acre-feet).

Calculating the Residual (Q_{res})

The residual is primarily a summation of the error in all the measurements and estimates used in the water balance. It 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 summarized the water balance, including the residuals for each reach, as well as inflows, outflows, and water uses.

Table 2.9 — Water balance summary (not adjusted for residual)
Lower Colorado River
Hoover Dam to Mexico

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})	10,447,200	10,819,800	7,565,400	6,181,777	10,447,200
Flow at the downstream boundary (Q_{ds})	10,819,800	7,565,400	6,181,777	1,705,424	1,705,424
Residual	-526,949	44,413	178,564	16,132	-287,840
Residual as a percentage of the flow at the upstream boundary (Q_{us})	-5.04%	0.41%	2.36%	0.26%	-2.76%
Difference between flow at the upstream and downstream boundaries (Q_{dif})	-372,600	3,254,400	1,383,623	4,476,353	8,741,776
Measured Tributary inflow (Trm)	0	5,702	0	13,173	18,875
Unmeasured Tributary inflow (Trum)	6,480	36,290	33,750	3,000	79,520
Exported flow (Q_{ex})	0	2,819,589	0	3,965,573	6,785,162
Evaporation (E)	135,404	128,784	72,472	9,842	346,502
Domestic consumptive use (CU_d)	383	44,364	6,442	33,223	84,412
Agricultural ET (ET_{ag})	0	76,715	806,132	389,939	1,272,786
Phreatophyte ET (ET_{pht})	742	187,727	353,420	77,817	619,706
Change in reservoir storage ()S_r)	24,300	-5,200	343	0	19,443
Change in aquifer storage ()S_a)	0	0	0	0	0

The residuals in calendar year 2002 varied from less than 1 percent to slightly more than 5 percent of the flow at the upstream reach boundaries. The overall residual from Hoover Dam to Mexico was less than 3 percent. 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 on the variance (the square of the standard error of estimate) of each inflow, outflow, and water use as described in Lane (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 the resultant proportion of the residual (in acre-feet) from the inflows and adds the resultant proportion of the residual (in acre-feet) 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 on values recommended in Lane (1998) in this report, adjusting some recommended values based on 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 2002.

Calculating The Final Value of the Underflow to Mexico and Resolving Uncertainties in the Final Value of the Flow at Reach Boundaries

To calculate the final agricultural consumptive use for some of the irrigation districts near Yuma, Arizona, Reclamation must first determine the final value of the underflow to Mexico and add a portion of it to the agricultural consumptive use.. (See previous section entitled, "A Portion of the Underflow to Mexico Must be Accounted for as a Consumptive Use" and table 4.2 in chapter 4). Reclamation calculates the final value of underflow to Mexico from the final value of the flow to Mexico from the Imperial Dam to Mexico water balance. However, the final value of flow to Mexico is uncertain because the final value of the flow to Mexico depends on the final value of the flow at Imperial Dam, which has two values.

The final value of the flow at Imperial Dam has two values because the flow at Imperial Dam is used in the water balances of two reaches that are balanced independently. The flow at Imperial Dam is the outflow of the Parker Dam to Imperial Dam reach, and it is also the inflow in the Imperial Dam to Mexico reach. When each reach is balanced independently and the residual is distributed, two different final values for the flow at Imperial Dam result. The final value of the flow to Mexico is uncertain because the final value of the flow at Imperial Dam is uncertain. The same is true for the flow below Davis and Parker dams. Reclamation adjusts the final values of the flows at the reach boundaries, which compensate for the uncertainties that result from balancing each reach independently, to calculate a single final value of flow at each of the reach boundaries. From the adjusted final value of the flow to Mexico, Reclamation can calculate a final value of the underflow to Mexico.

The method Reclamation uses to resolve the uncertainty in the final value of flow at the reach boundaries 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, as described in Lane, 1998, in “Interaction between Reaches.”

Reclamation resolves the uncertainty in the final value of flow at the reach boundaries 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}[21] from each reach.
3. Subtract the average of the difference between the gaged flows and the temporary adjusted flows, 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 2002 values and the adjusted flow below Hoover, Davis, and Parker Dams; at Imperial Dam; and to Mexico.

[21] 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 [22]	Average
Gaged flow	10,447,200	10,819,800	7,565,400	6,181,777	1,705,424	
Amount of residual from the water balance of each reach below each dam apportioned to Q_{dif} .	-526,421	42,620	168,568	13,017	N/A	
Temporary adjustments to flows (start with zero at most upstream dam and add cumulatively to most downstream flow)	0	-526,421	-483,801	-315,233	-302,216	-325,534
Temporary adjusted flows (gaged flow + temporary adjustment)	10,447,200	10,293,379	7,081,599	5,866,544	1,403,208	
Final flows (temporary adjusted flow - average of temporary adjustments)	10,772,734	10,618,913	7,407,132	6,192,078	1,728,743	
Final adjustments (final adjusted flow - gaged flow)	325,534	-200,887	-158,268	10,301	23,319	
Final adjustments to gaged flows in percent	3.12%	-1.86%	-2.09%	0.17%	1.37%	

By resolving the uncertainty in the final value of flow at the reach boundaries, Reclamation can create a table of adjusted values for the water balance in all reaches that yields a residual of zero for each reach of the lower Colorado River below Hoover Dam, and calculate a single final value of the underflow to Mexico. Table 2.11 shows the final values of the water balance.

[22] 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 Lower Colorado River Hoover Dam to Mexico

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})	10,772,734	10,618,913	7,407,132	6,192,078	10,772,734
Flow at the downstream boundary (Q_{ds})	10,618,913	7,407,132	6,192,078	1,728,743	1,728,743
Residual (Q_{res})	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	153,821	3,211,781	1,215,054	4,463,335	9,043,991
Measured tributary inflow (Trm)	0	5,700	0	13,172	18,872
Unmeasured tributary inflow (Trum)	6,505	36,230	33,274	2,999	79,008
Exported flow (Q_{ex})	0	2,821,196	0	3,967,992	6,789,188
Evaporation (E)	135,095	128,805	72,533	9,842	346,275
Domestic consumptive use (CU_d)	383	44,364	6,442	33,224	84,413
Agricultural consumptive use(CU_{ag})	0	76,722	813,676	390,470	1,280,868
Phreatophyte water use (CU_{pht})	742	187,772	354,870	77,838	621,222
Change in reservoir storage () S_r)	24,275	-5,199	343	0	19,419
Change in aquifer storage () S_a)	-169	51	464	140	486

Sample Calculation of Agricultural Consumptive Use for a Diverter

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

Calculating agricultural consumptive use requires 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 magnitude and variance (the square of the presumed standard error of estimate) .
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 sections describe agricultural ET and consumptive use at CRIR and within the Parker Dam to Imperial Dam reach and present detailed explanations of each of these four steps. 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. Because 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.[23]

Calculating 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 multiplied by 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).

[23] 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.

The following paragraphs provide a sample ET calculation for a single crop (alfalfa) and the evaporation from open water areas and major delivery canals within a single diverter boundary (CRIR).

ET calculations begin with a daily reference ET, calculated as noted previously in "Calculating Evapotranspiration." 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 sample ET calculation begins with the area-specific reference ET for the Parker/Palo Verde Valleys for March 18, 2002. The area-specific reference ET for the Parker/Palo Verde Valleys is used to calculate ET for CRIR. Reclamation chose March 18th 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 March 18, 2002
Parker/Palo Verde Valleys
(Standardized equation)

AZMET/CIMIS Station	Reference ET in Millimeters	Reference ET in Inches
Parker AZMET station site	3.7	0.15
Blythe NE CIMIS station site	2.9	0.11
Ripley CIMIS station site	2.8	0.11
Palo Verde CIMIS station site	3.1	0.12
Area-specific reference ET	3.1	0.12

The following is the area-specific reference ET calculation for March 18, 2002:

Area-specific reference ET = (3.7 + 2.9 + 2.8 + 3.1)÷4÷25.4 millimeters/inch
= 0.12 inches (rounded)

This sample calculation continues using alfalfa - perennial as the sample crop group (alfalfa). Note the following values for March 18, 2002:

Area-Specific reference ET	=	0.12 (listed on Sheet D, inches)
ET coefficient for alfalfa	=	0.368 (listed on page 2 of 2, Sheet E, dimensionless)
Precipitation	=	0.03 (listed on Sheet B, inches)

The daily ET rate for alfalfa is calculated by multiplying the area-specific daily reference ET by 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 multiplied by a dimensionless coefficient that varies by the month of the year (0.2 for March, from Sheet C).

The following shows the daily ET rate[24] calculation for alfalfa on March 18, 2002:

Daily ET Rate$_{alfalfa}$ = Reference ET (0.12 inches from Sheet D) * ET coefficient for alfalfa (0.368 from Sheet E, page 2 of 2), - effective precipitation (0.03 inches, * 0.4 = 0.012inches) rounded to 0.01 inches on Sheet C)

= 0.043 inches (round to 0.04 as shown on Sheet E, page 1 of 2)

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. 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.

This sample calculation continues with the calculation of ET (in acre-feet) for alfalfa for the month of March. The ET rate for alfalfa for the month of March is the summation of the daily ET rates for alfalfa

[24] 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.

calculated for all the days of March (4.47 inches, from the Parker/Palo Verde ET-rate Table, Sheet E, page 1 of 2) and the acreage of alfalfa on CRIR listed for March 2002 (54,100 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 is the calculation of ET for alfalfa for the month of March:

$ET_{alfalfa}$ for January = 4.47 (inches) * 54,101 (acres) ÷ 12 (inches/foot)

= 20,152 acre-feet (rounded to nearest acre-foot, Sheet O, Page 1 of 5).

Calculating Evaporation from Open Water for the Reach

Reclamation calculates evaporation from open water (including the open water of major delivery canals) much like ET for crops, except that Reclamation uses monthly instead of daily calculations and assumes that all precipitation effectively reduces evaporation; thus, 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 March 2002 (all values are shown on Sheet H).

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

Canal evaporation for March = [(5.45 inches *0.83) - 0.03 inches] * 279.29 acres ÷ 12 inches/foot = 105 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.

Calculating the Residual for the Reach

The next step in the sample calculation 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 calculates the water balance between Parker and Imperial Dams using annual values. The water balance consists of many parts and each part and the value used for calendar year 2002 is described in the following paragraphs.

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

The mainstream inflow to the Parker Dam to Imperial Dam reach (Q_{us})—the flow below Parker Dam—is 7,565,400 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. USGS (page 46 of Owen-Joyce and Raymond [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—the flow at Imperial Dam—is 6,181,777 acre-feet, as shown on Sheet A. This flow is the sum of the four flows shown on Sheet H of the Parker Dam to Imperial Dam Water-Balance Table:

1) Station 60 on the All-American Canal, 4,862,000 acre-feet.
2) Station 30 on the Gila Gravity Main Canal, 868,673 acre-feet.
3) Inflow to Mittry Lake, 9,774 acre-feet.
4) the Colorado River Sluiceway, 441,330 acre-feet.

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

Calculating Evaporation

The evaporation calculation represents the evaporation from the open water of the mainstream, including reservoirs. This calculation does not include evaporation from the open water of major delivery canals or ponds within an irrigation district or Indian reservation, which are included in agricultural ET.

Reclamation calculates evaporation by multiplying the area of open water by a monthly evaporation rate, less 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 March for river section 1.

Evaporation = [[March sum of daily reference ET (5.45 inches) * March evaporation coefficient (0.83)] - precipitation (0.03 inches)] * area of open water (4,008 acres) ÷ 12 (inches/foot)

= 1,501 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 March in river section 1 of 1,501 acre-feet.

Calculating Domestic Consumptive Use

Reclamation sums the domestic water use of 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 "Calculating Domestic Use (CU_d)" to develop these values. For example, Reclamation estimates Poston, a municipal area without a measured diversion or a measured return and 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 a monthly per-capita use rate (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 Poston's domestic water use in the month of March as 4.5 acre-feet (389 people * 0.14 ÷ 12).

Calculating Changes in Reservoir Storage

Senator Wash is the only reservoir between Parker and Imperial Dams. Therefore, Reclamation calculates the change in reservoir storage at Senator Wash, as shown on Sheet D of the Parker Dam to Imperial Dam Water-Balance Table. Change in reservoir storage is calculated monthly and the monthly change in storage values summed to produce an annual change in storage value. Annual change in storage values can also be calculated as the difference between the January beginning-of-month storage and the December end-of-month storage. In calendar year 2002, the beginning-of-year storage, measured midnight December 31, 2001, was 1,625 acre-feet; end-of-year storage, measured midnight December 31, 2002, was 1,968 acre-feet, resulting in an annual change in storage value of 343 acre-feet.

Calculating the Residual

The residual for calendar year 2002, as shown on Sheet A, page 1 of 2, of the Parker Dam to Imperial Dam Water-Balance Table, is 178,564 acre-feet, or about 2.4 percent of the flow below Parker Dam. The following shows the residual calculation.

$$\text{Residual} = Q_{dif}\ (1{,}383{,}623) + Q_{Trum}\ (33{,}750) - \Delta S_r\ (343) - CU_d\ (6{,}442) - ET_{ag}\ (806{,}132) - ET_{pht}\ (353{,}420) - E\ (72{,}472)$$

$$= 178{,}564 \text{ acre-feet}$$

Where:

Q_{dif}	=	the difference between Q_{us} and Q_{ds} (Q_{us}-Q_{ds})
T_{rum}	=	the unmeasured tributary inflow to the reach
ΔS_r	=	the change in reservoir storage in the reach
CU_d	=	the domestic, municipal, and industrial use
ET_{ag}	=	the total agricultural ET in the reach
ET_{pht}	=	the total phreatophyte ET in the reach
E	=	the open water evaporation in the reach

Calculating 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 multiplied by 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 standard error of estimate (SEE) of the agricultural ET in the Parker Dam to Imperial Dam reach, 806,132 acre-feet, to be 5 percent, yielding a variance of 1,624,654,249 acre-feet squared. The TVAR of the reach is 38,452,740,929 acre-feet squared, and the residual is 178,564 acre-feet. Sheet A of the Parker Dam to Imperial Dam Water-Balance Table shows the values.

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:

$$\text{Agricultural } CU_{Reach} = 806{,}132 + [(1{,}624{,}654{,}249 \div 38{,}452{,}740{,}929) \times (178{,}564)]$$

$$\text{Agricultural } CU_{Reach} = 813{,}676 \text{ acre-feet}$$

Calculating Agricultural Consumptive Use for Each Diverter

Reclamation calculates the agricultural consumptive use for each diverter by proportioning 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:

Agricultural CU_{CRIR} = Agricultural consumptive use for CRIR,
Agricultural ET_{CRIR} = Agricultural ET for CRIR,
Agricultural ET_{Reach} = Agricultural ET between Parker and Imperial Dams,
Agricultural CU_{Reach} = Agricultural consumptive use between Parker and Imperial Dams.

Sheet O, page 1 of 5 or 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:

Agricultural CU_{CRIR} = 361,333 acre-feet ÷ 806,132 acre-feet * 813,676 acre-feet
Agricultural CU_{CRIR} = 364,714 acre-feet [25]

Summary of Results for LCRAS for Calendar Year 2002

Table 2.13 summarize the water use values calculated using LCRAS and the consumptive use values reported in the decree accounting report for calendar year 2002. As noted previously, LCRAS reports phreatophyte water use separately from agricultural, domestic, and export consumptive use. Figure 2.2 shows results for the States of California and Arizona.

Some of the differences between consumptive use values reported by the decree accounting report and those calculated by LCRAS can be attributed to the following:

[25] 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. LCRAS reports the consumptive use for some diverters that the decree accounting report does not,
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, and
3. LCRAS currently reports consumptive use for agricultural 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 — Agricultural, Domestic, and Export Consumptive Use, Phreatophyte Water Use Developed by LCRAS and Consumptive Use Compiled by 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 2002 decree accounting report)		307,238	307,238	Uses above Hoover Dam
Uses below Hoover Dam	18,298	17,799	19,480	Uses below Hoover Dam
			1,491	Unmeasured return flow credit
Nevada Total	18,298	325,037	325,227	Nevada Total
California				
			5,365,608	Sum of individual diverters
			90,002	Unmeasured return flow credit
California Total	177,250	5,215,255	5,275,606	California Total
Arizona				
Subtotal (Below Hoover Dam, less Wellton-Mohawk IDD)	425,671	2,517,054	2,743,682	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (from the 2002 decree accounting report)		148	148	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (from 2002 decree accounting report)		285,755	285,755	Wellton-Mohawk IDD
			60,354	Pumped from South Gila wells (DPOCs): returns
			163,244	Unmeasured return flow credit
Arizona Total	425,671	2,802,957	2,805,987	Arizona Total
Lower Colorado River Basin Total				
Total Use	621,219	8,343,249	8,406,820	Total Use

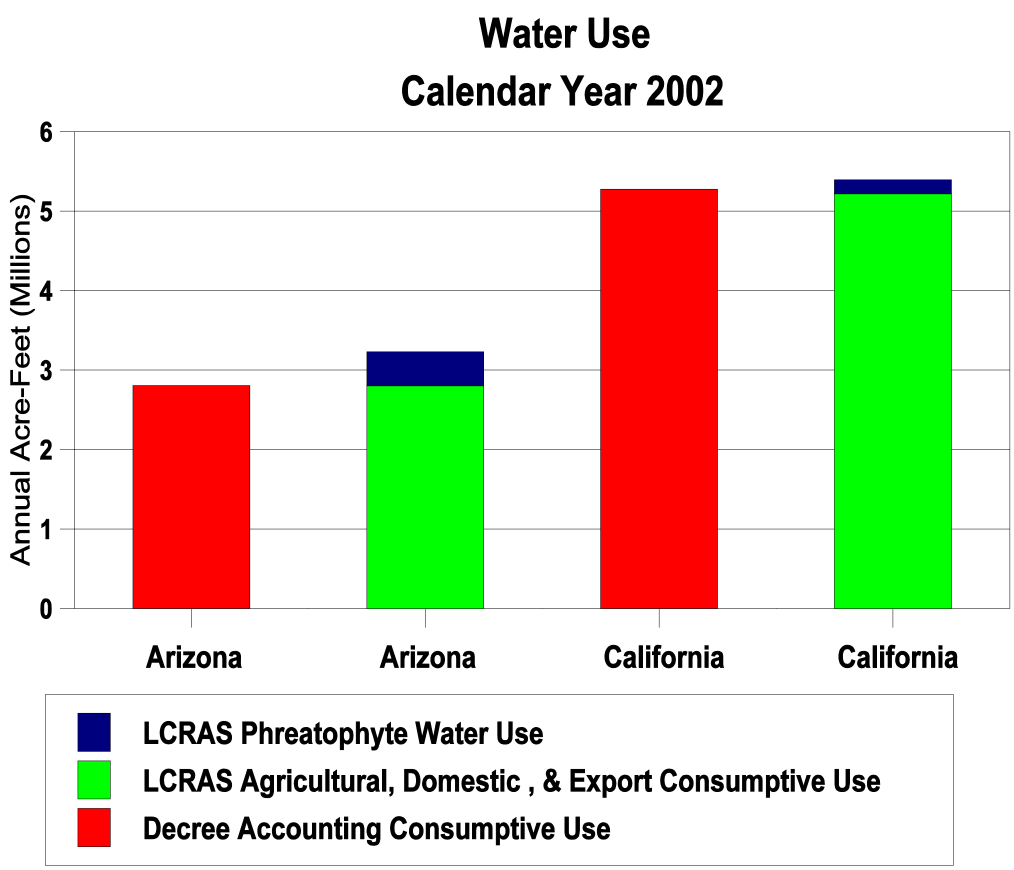


Figure 2.2 — State water use totals for Arizona and California (calendar year 2002).

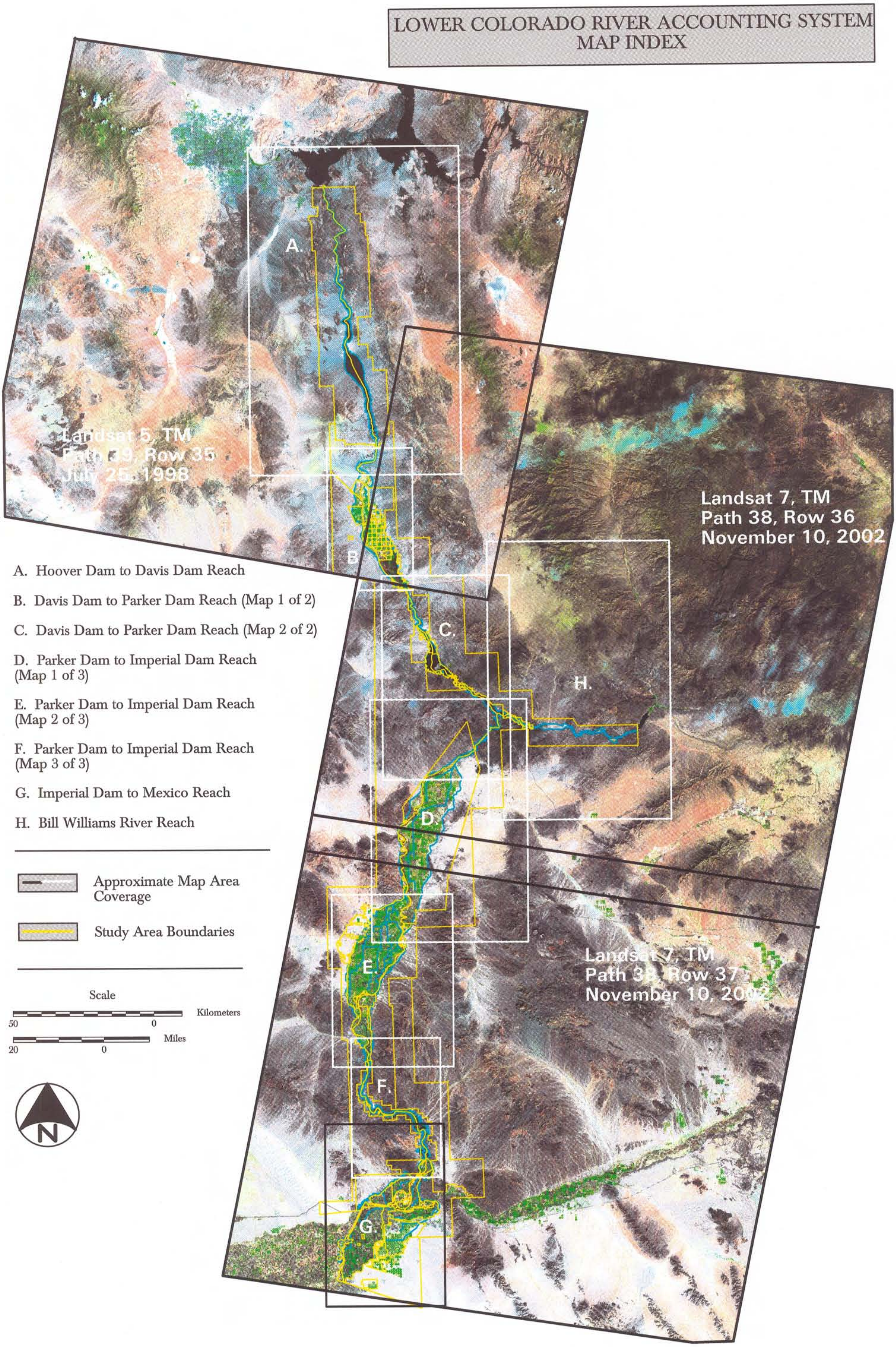

LOWER COLORADO RIVER ACCOUNTING SYSTEM
MAP INDEX
A.
B.
C.
D.
E.
F.
G.
H.
Landsat 5, TM
Path 39, Row 35
July 25, 1998
Landsat 7, TM
Path 38, Row 36
November 10, 2002
Landsat 7, TM
Path 38, Row 37
November 10, 2002
A. Hoover Dam to Davis Dam Reach
B. Davis Dam to Parker Dam Reach (Map 1 of 2)
C. Davis Dam to Parker Dam Reach (Map 2 of 2)
D. Parker Dam to Imperial Dam Reach (Map 1 of 3)
E. Parker Dam to Imperial Dam Reach (Map 2 of 3)
F. Parker Dam to Imperial Dam Reach (Map 3 of 3)
G. Imperial Dam to Mexico Reach
H. Bill Williams River Reach
Approximate Map Area Coverage
Study Area Boundaries
Scale
Kilometers
50
0
Miles
20
0
N

Exhibit 1

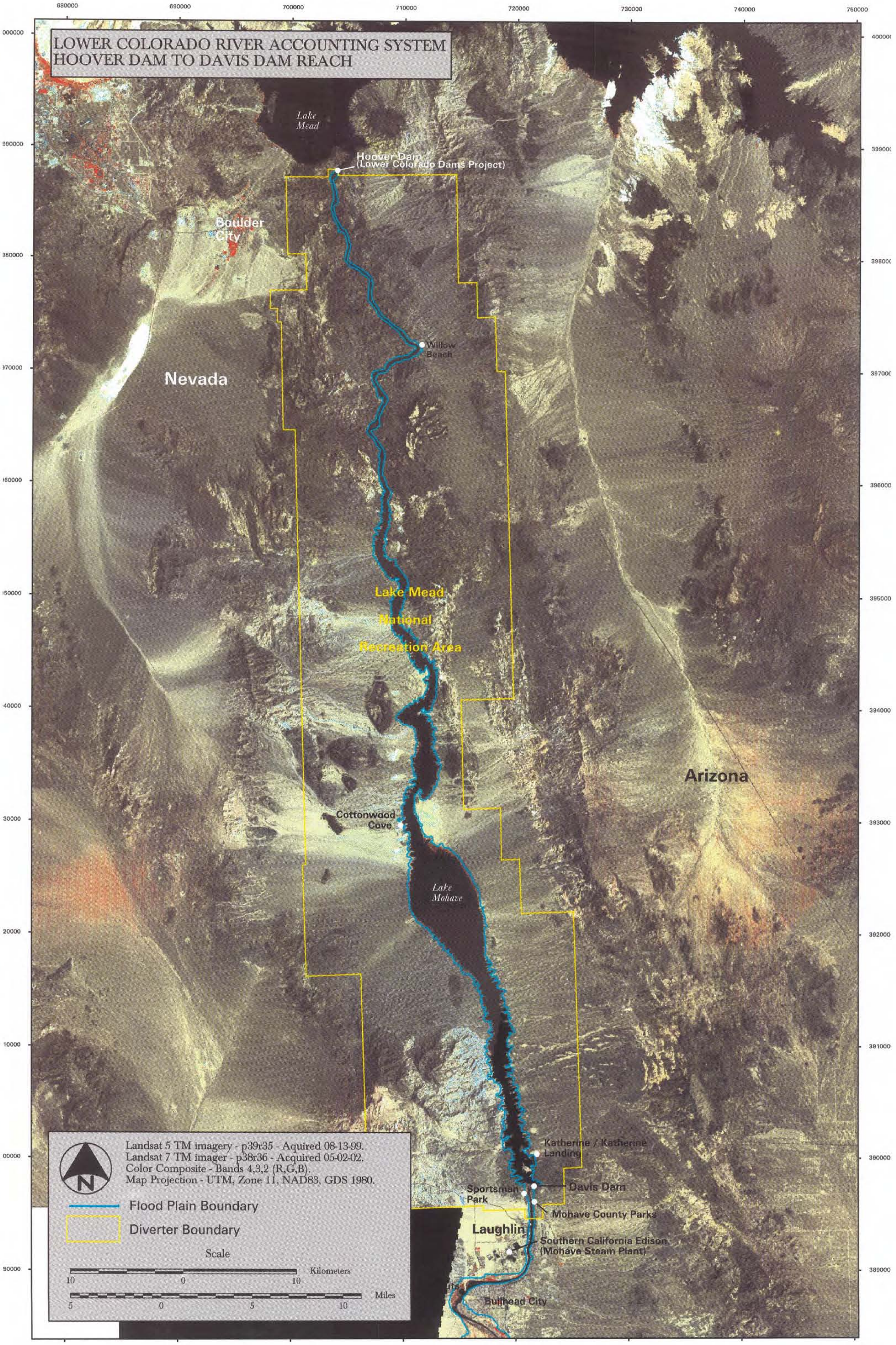

LOWER COLORADO RIVER ACCOUNTING SYSTEM
HOOVER DAM TO DAVIS DAM REACH
Lake Mead
Hoover Dam
(Lower Colorado Dams Project)
Boulder City
Willow Beach
Nevada
Lake Mead National Recreation Area
Arizona
Cottonwood Cove
Lake Mohave
Katherine / Katherine Landing
Davis Dam
Sportsman Park
Mohave County Parks
Laughlin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

Exhibit 2

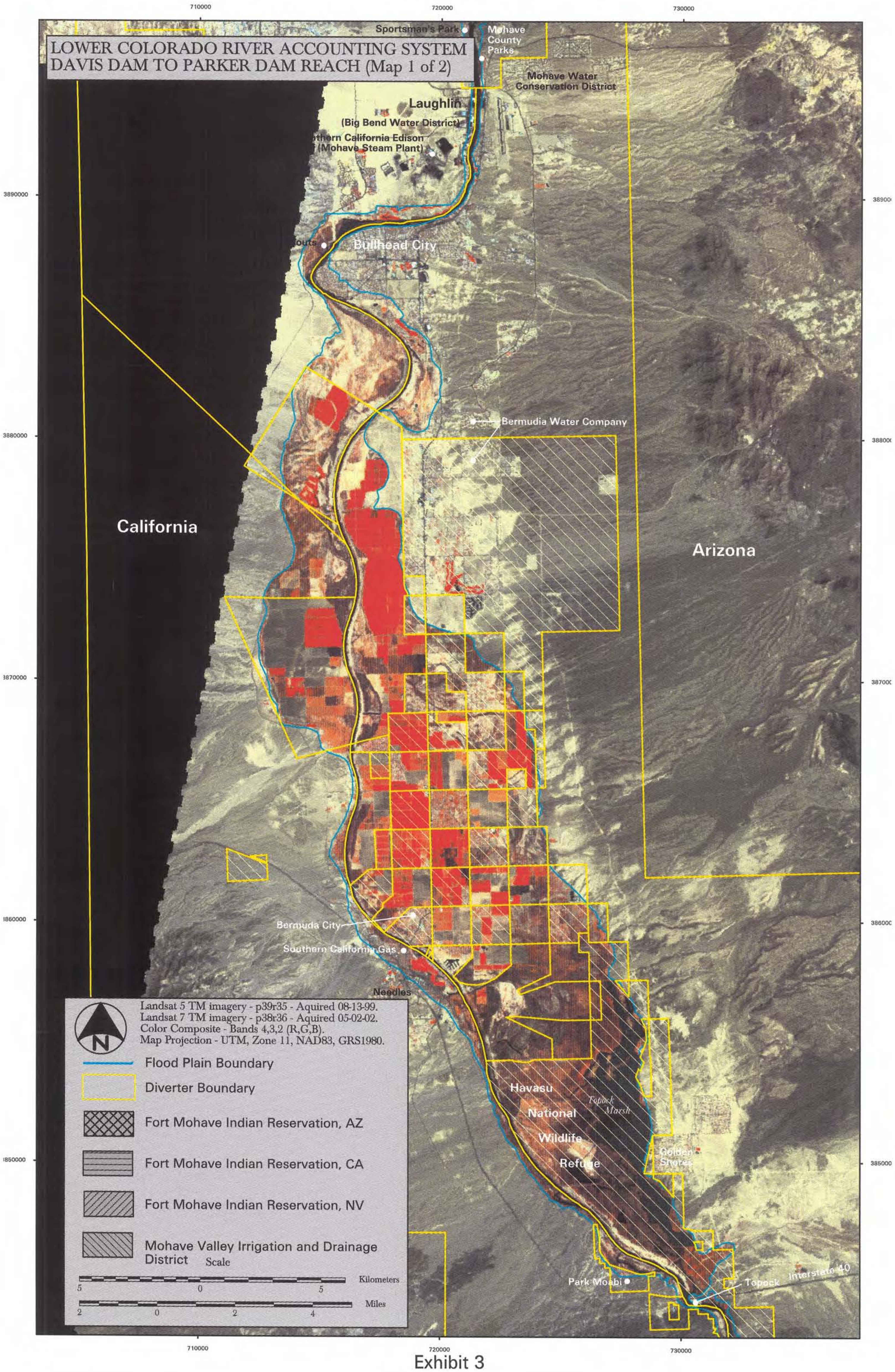

LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 1 of 2)
710000
720000
730000
3890000
3880000
3870000
3860000
3850000
Sportsman's Park
Mohave County Parks
Mohave Water Conservation District
Laughlin
(Big Bend Water District)
(Mohave Steam Plant)
Bullhead City
Bermudia Water Company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

Exhibit 3

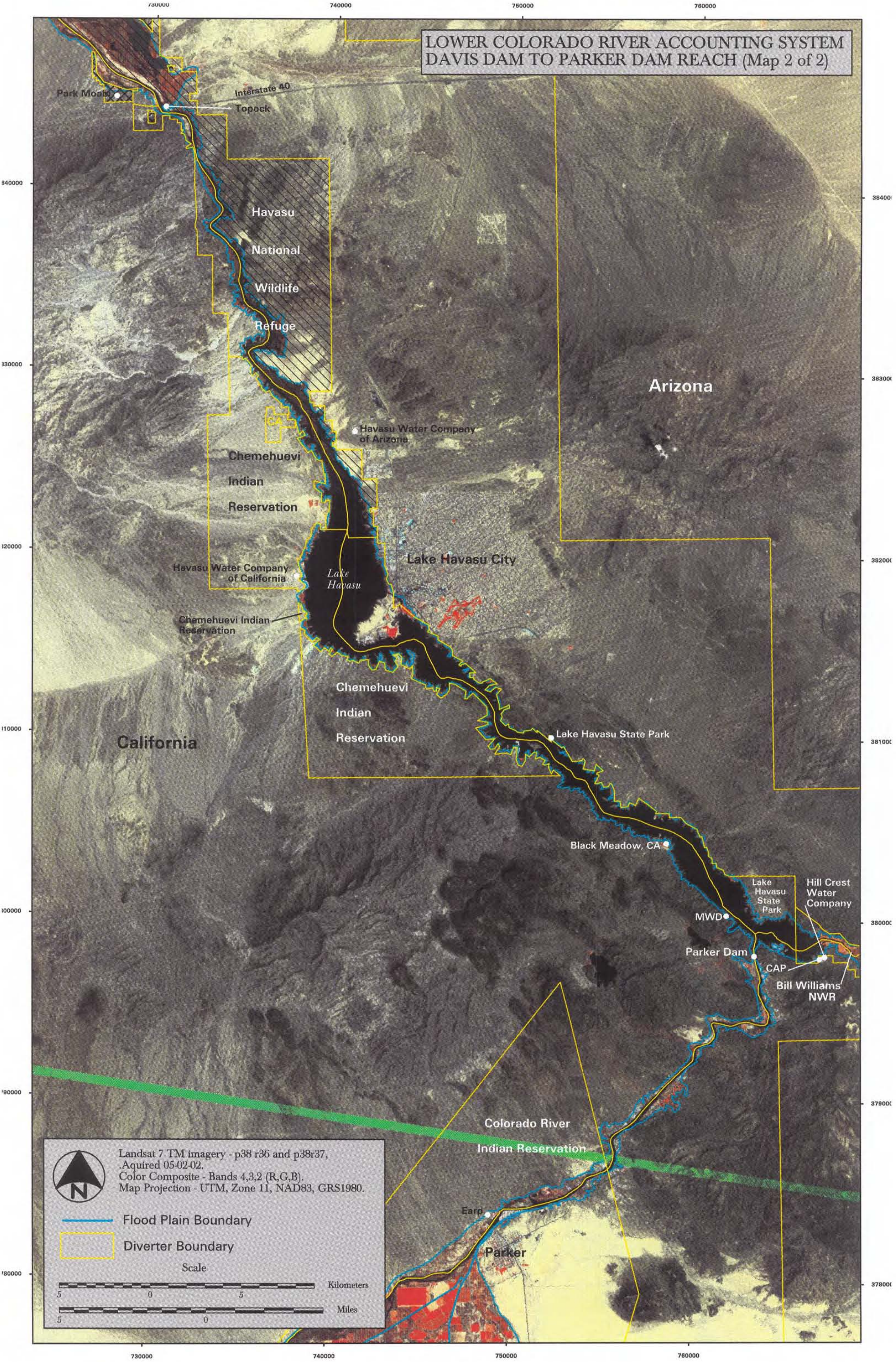

LOWER COLORADO RIVER ACCOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 2 of 2)
730000
740000
750000
760000
Park Moabi
Interstate 40
Topock
Havasu
National
Wildlife
Refuge
Havasu Water Company of Arizona
Chemehuevi
Indian
Reservation
Arizona
Lake Havasu City
Havasu Water Company of California
Lake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

Exhibit 4

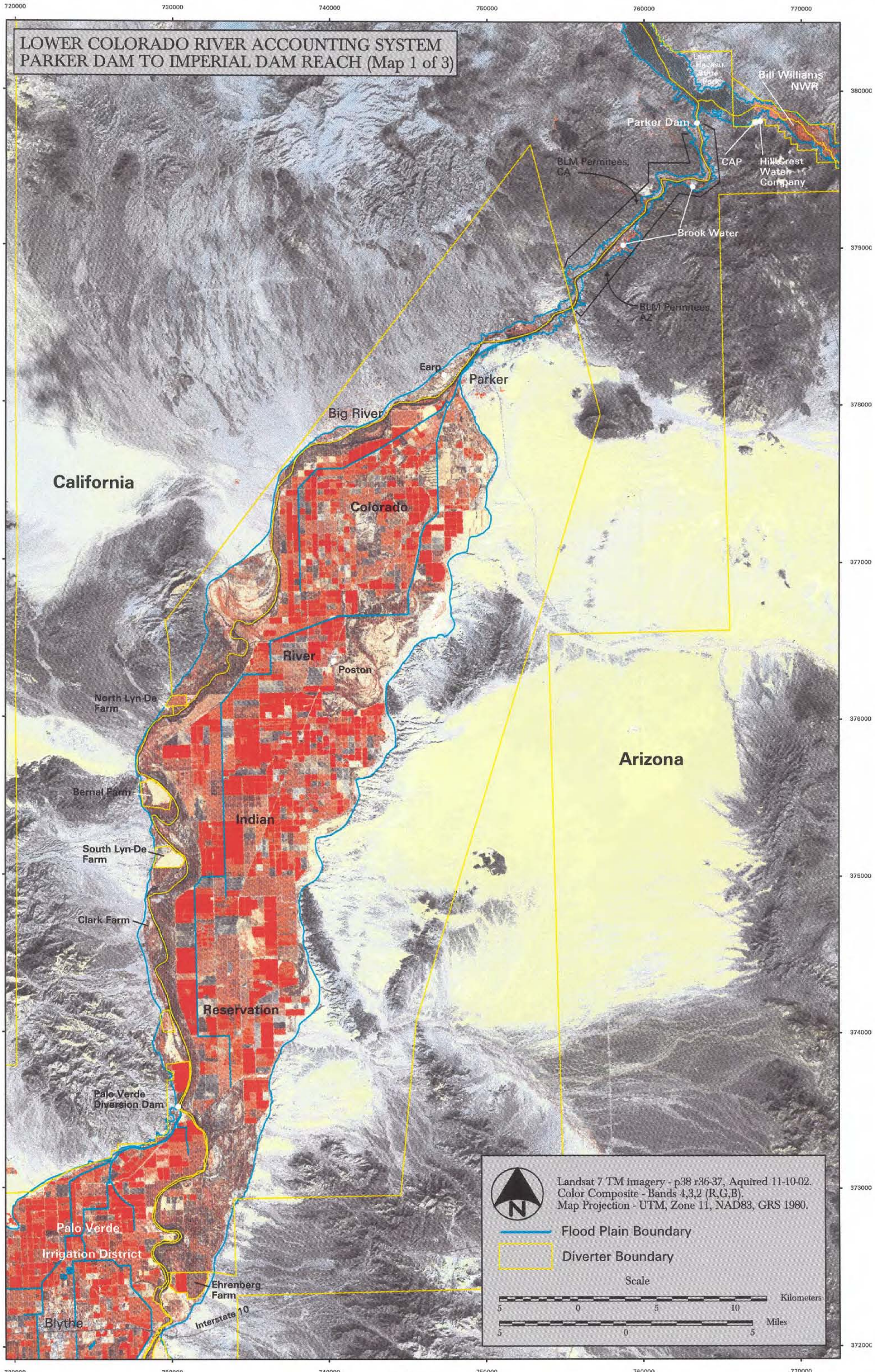

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 1 of 3)
720000
730000
740000
750000
760000
770000
Bill Williams NWR
Parker Dam
CAP
Hill Crest Water Company
BLM Permitees, CA
Brook Water
BLM Permitees, AZ
Earp
Parker
Big River
California
Colorado
River
Poston
North Lyn-De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

Exhibit 5

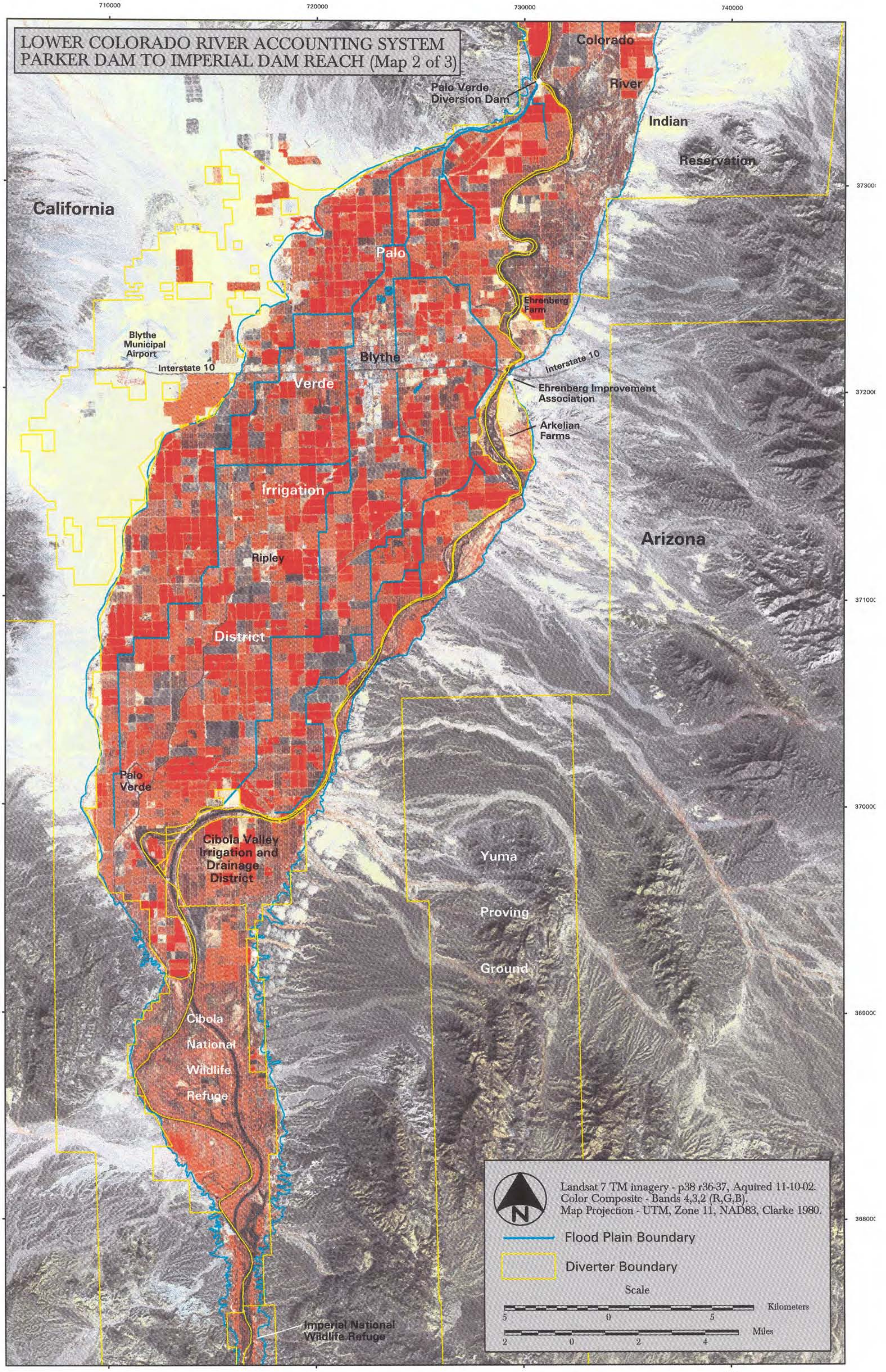
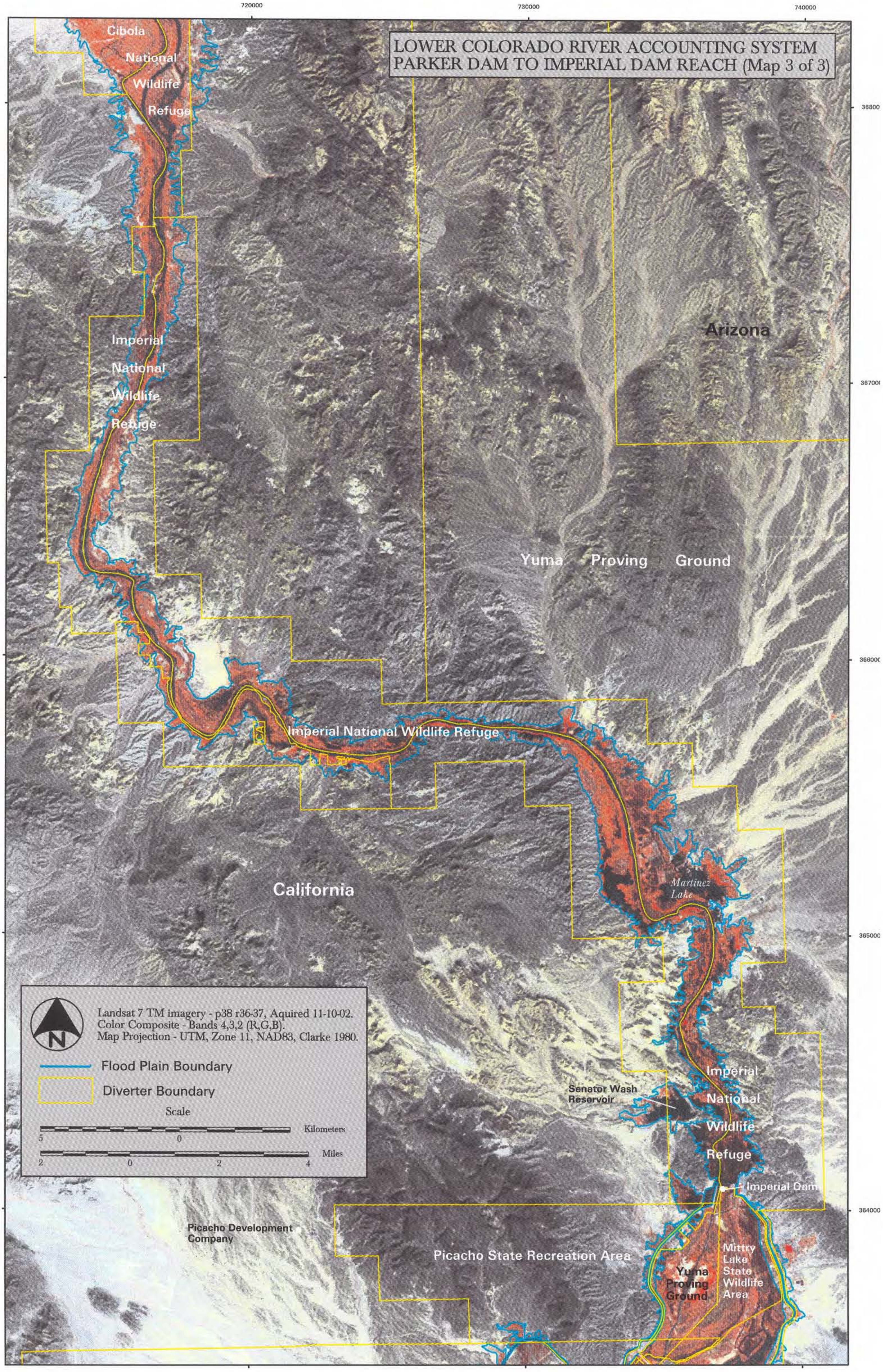

LOWER COLORADO RIVER ACCOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 2 of 3)
710000
720000
730000
740000
3730000
3720000
3710000
3700000
3690000
3680000
Colorado
River
Indian
Reservation
Palo Verde
Diversion Dam
California
Palo
Verde
Irrigation
District
Blythe
Ripley
Ehrenberg
Farm
Blythe
Municipal
Airport
Interstate 10
Interstate 10
Ehrenberg Improvement
Association
Arkelian
Farms
Arizona
Palo
Verde
Cibola Valley
Irrigation and
Drainage
District
Yuma
Proving
Ground
Cibola
National
Wildlife
Refuge
Imperial National
Wildlife Refuge
N
Landsat 7 TM imagery - p38 r36-37, Aquired 11-10-02.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD83, Clarke 1980.
Flood Plain Boundary
Diverter Boundary
Scale
Kilometers
5
0
5
Miles
2
0
2
4

Exhibit 6



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

Exhibit 7

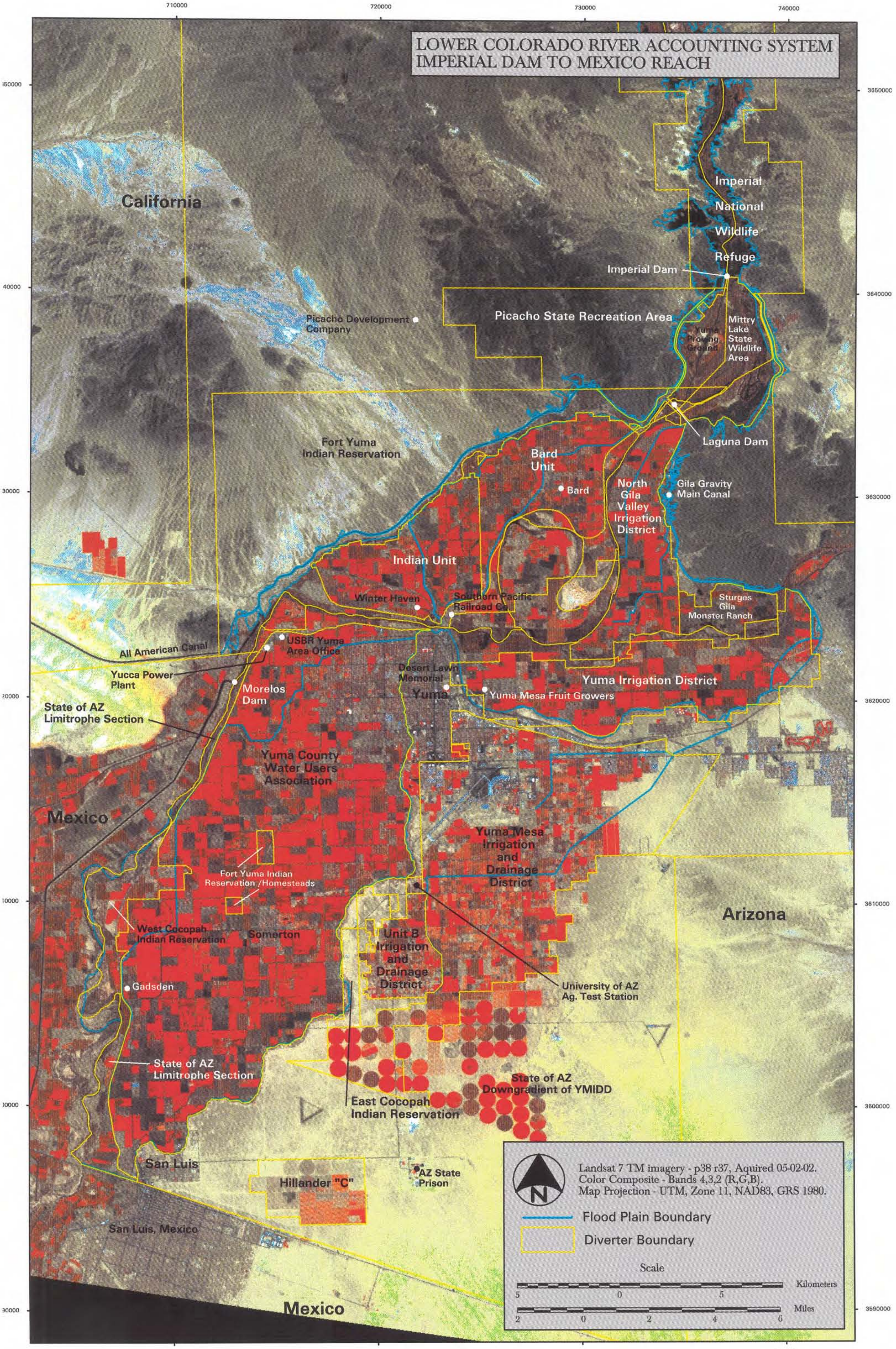
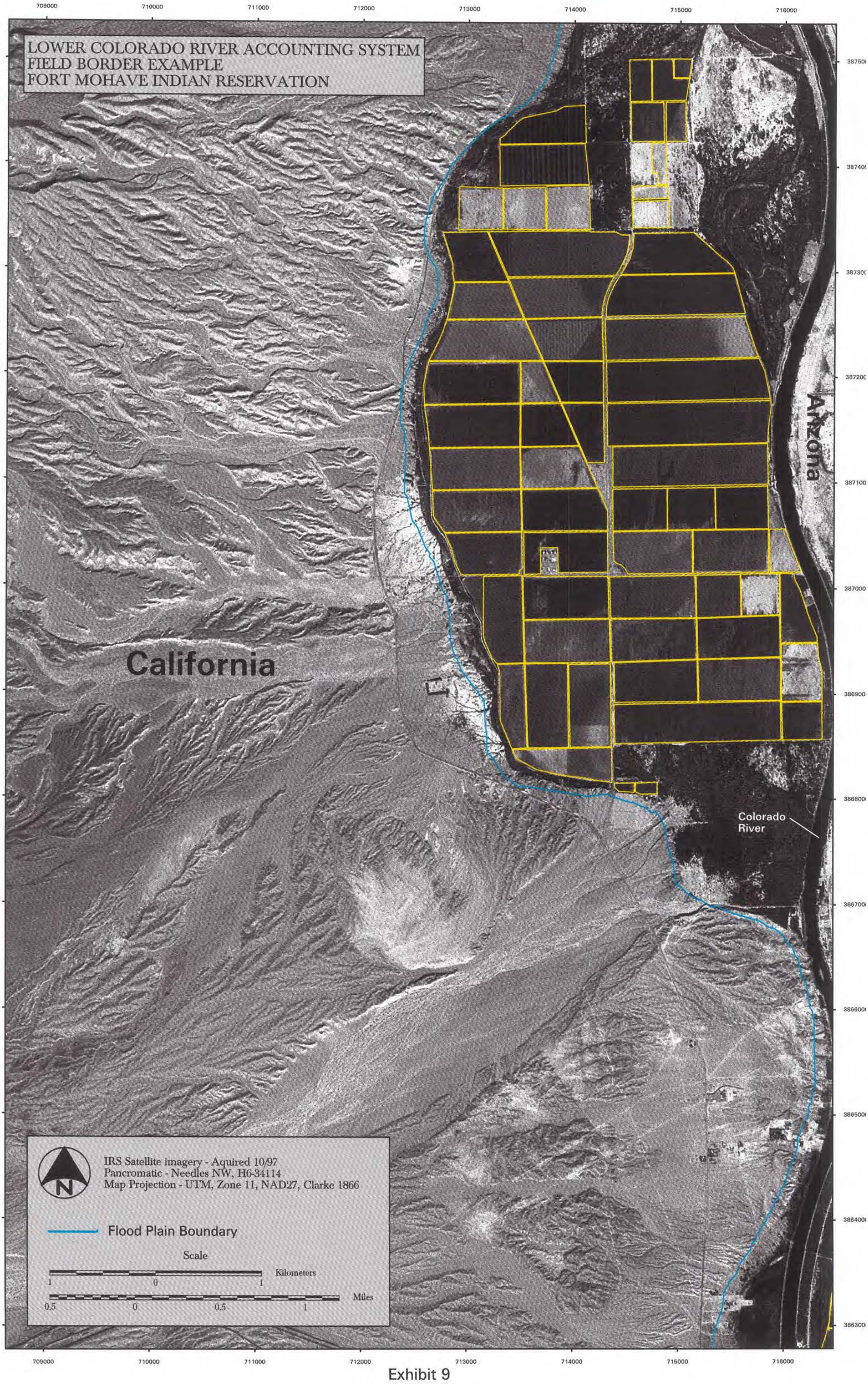

LOWER COLORADO RIVER ACCOUNTING SYSTEM
IMPERIAL DAM TO MEXICO REACH
California
Imperial
National
Wildlife
Refuge
Imperial Dam
Picacho Development Company
Picacho State Recreation Area
Yuma Proving Ground
Mittry Lake State Wildlife Area
Laguna Dam
Fort Yuma Indian Reservation
Bard Unit
Bard
North Gila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

Exhibit 8



LOWER COLORADO RIVER ACCOUNTING SYSTEM
FIELD BORDER EXAMPLE
FORT MOHAVE INDIAN RESERVATION
California
Arizona
Colorado River
IRS Satellite imagery - Aquired 10/97
Pancromatic - Needles NW, H6-34114
Map Projection - UTM, Zone 11, NAD27, Clarke 1866
N
Flood Plain Boundary
Scale
Kilometers
1 0 1
Miles
0.5 0 0.5 1
709000
710000
711000
712000
713000
714000
715000
716000
3875000
3874000
3873000
3872000
3871000
3870000
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3863000

Exhibit 9

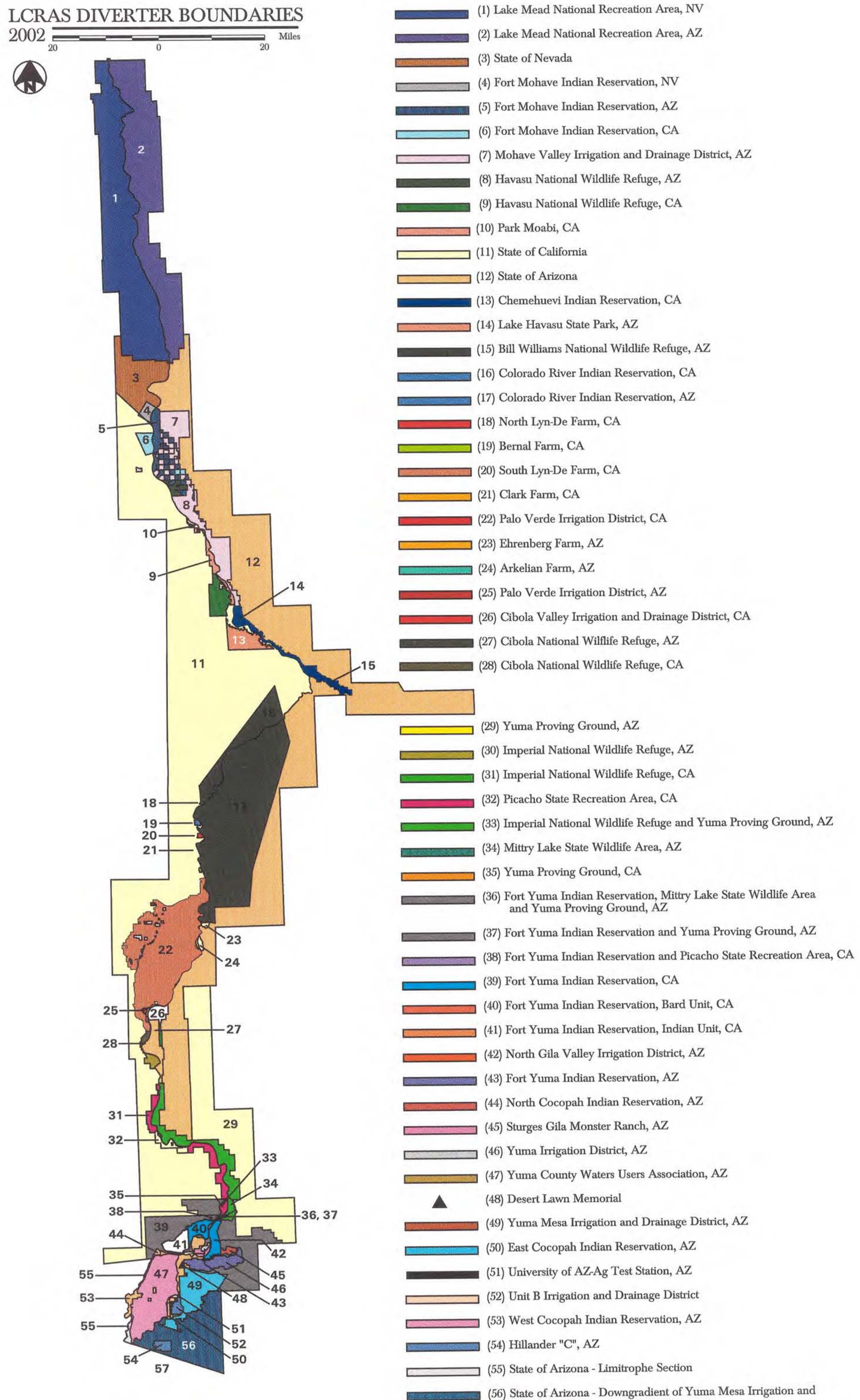
LCRAS DIVERTER BOUNDARIES
2002
Miles
20 0 20
(1) Lake Mead National Recreation Area, NV
(2) Lake Mead National Recreation Area, AZ
(3) State of Nevada
(4) Fort Mohave Indian Reservation, NV
(5) Fort Mohave Indian Reservation, AZ
(6) Fort Mohave Indian Reservation, CA
(7) Mohave Valley Irrigation and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

Exhibit 10

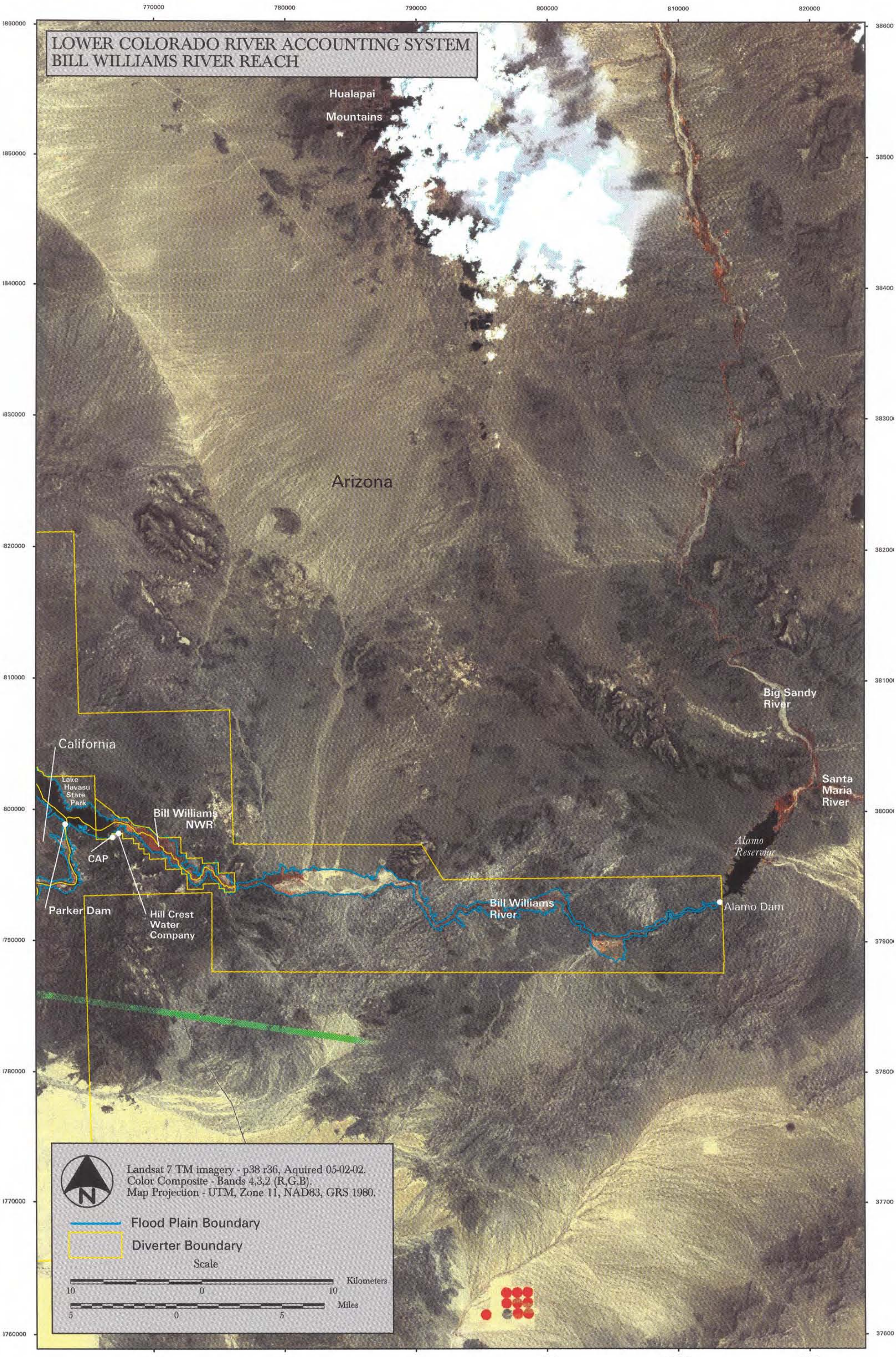
LOWER COLORADO RIVER ACCOUNTING SYSTEM
BILL WILLIAMS RIVER REACH
Hualapai
Mountains
Arizona
California
Lake Havasu State Park
Bill Williams NWR
CAP
Parker Dam
Hill Crest Water Company
Big Sandy River
Santa Maria River
Alamo Reservoir
Alamo Dam
Bill Williams River
Landsat 7 TM imagery - p38 r36, Aquired 05-02-02.
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM, Zone 11, NAD83, GRS 1980.
N
Flood Plain Boundary
Diverter Boundary
Scale
Kilometers
10 0 10
Miles
5 0 5
770000
780000
790000
800000
810000
820000

Exhibit 11

Chapter 3 — LCRAS Improvements For Calendar Year 2002

This chapter describes improvements made since the issuance of the 2001 LCRAS Demonstration of Technology report. This chapter does not repeat improvements completed in previous years or potential improvements identified in previous reports to which Reclamation has assigned a low priority.

Improving Phreatophyte Evapotranspiration Estimates

Reclamation continues a cooperative study initiated in fiscal year 2001 with the Nevada District of the USGS 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.

The study plan includes producing phreatophyte evapotranspiration values as described previously, 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.

Adjusting Diverter Boundaries

Reclamation made minor adjustments to the diverter boundaries for 2002. 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.

Adjusting Open Water and Phreatophyte Acreage

Reclamation reviewed satellite imagery acquired on July 21, 2002 to assess the need for changes to the geographic data used to identify the area of open water of the Colorado River which results from the operation of major delivery canals, and areas covered by phreatophytes used in the previous LCRAS Demonstration of Technology Report. This review resulted in the addition of three ponds on the mesa northwest of Blythe, California to the open water area identified within the Palo Verde Irrigation District, and the addition of several seepage ponds along the Gila Gravity Main Canal and the All American Canal upstream from Pilot Knob to the open water area resulting from the operation of these canals.

This review also resulted in modifications to the boundaries of subreaches used to identify areas of open water and areas covered by phreatophytes to be more consistent with evaporation and phreatophyte ET calculations. Reclamation modified the boundary of the Bill Williams subreach by moving the western boundary east to the maximum extent of Lake Havasu at normal operating levels, as delineated by the accounting surface boundary defined in the Geological Survey Water Resources Investigations Report 94-4005. Reclamation also modified the Senator Wash subreach to include West Lake. These modifications effected changes to the open water areas and phreatophyte areas within the Davis Dam to Parker Dam and Imperial Dam to Mexico reaches used for the water balance.

Including Fort Mojave Indian Reservation Domestic Use

Reclamation included domestic use for the Fort Mojave Indian Reservation in the State of Arizona in this 2002 report. The Tribe included the domestic use value in its report on water use for Reclamation's annual decree accounting report.

Identifying Patterns In Changes in Residuals

The value of the water balance residual for each reach changes from year to year. The sign (positive or negative) of the residual can also change from year to year. Understanding the pattern of change of these values over time could help Reclamation understand the potential for bias in the measured flows and calculated terms. For example, a bias might be inferred if the residual for a reach is consistently positive or negative over time.

Table 3.1 displays the water balance residuals for each reach for calendar years 1995 through 2002.

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%
2002	-526,949	-5.04%	44,413	0.41%	178,564	2.36%	16,132	0.26%	-287,840	-2.76%
Average	-199,450	-1.84%	-166,831	-1.68%	99,571	1.18%	74,162	1.16%	-192,548	-1.91%

Identifying 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 help Reclamation understand 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 2002.

[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%
2002	325,534	3.12%	-200,887	-1.86%	-158,268	-2.09%	10,301	0.17%	23,319	1.37%
Average	212,405	2.00%	-33,286	-0.29%	-165,427	-2.07%	-32,339	-0.50%	18,639	0.88%

Determining Portions of Phreatophyte Water Use to be Added to Agricultural or Domestic Consumptive Use

Reclamation has met with other Interior agencies, State water agencies, and Indian Reservations along the lower Colorado River to openly discuss what portion, if any, of the phreatophyte water use within the boundary of a diverter should be added to the diverter's agricultural or domestic consumptive use. 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.

Corrected Domestic Use Calculation for the City of Yuma, AZ

The City of Yuma receives it's water from two sources, the All American Canal (AAC) via the Yuma Main Canal, and the Gila Gravity Main Canal (GGMC). Returns are generated from two sources, filter backwash water from the potable water treatment plant, and treated effluent from the waste water treatment plant. Deliveries to the City of Yuma are reported monthly by the City for both the AAC deliveries and GGMC deliveries. In previous LCRAS reports, the City of Yuma domestic use was calculated as the measured diversion from the AAC, plus canal loss, times a 60% domestic use factor. This discrepancy was noted during a detailed comparison with the Methodology used to tabulate the Decree Accounting report.

New in this report, domestic use for the City of Yuma is calculated as measured diversions less measured returns, using the following calculations,

1. Total diversions of Colorado River water for the City of Yuma are calculated as the sum of the deliveries to the City from the AAC and GGMC, which includes the cogeneration plant, Smucker park and the golf course, plus prorated canal loss from the AAC and GGMC, and
2. Total returns from the City of Yuma are calculated as the wastewater treatment plant effluent plus filter backwash effluent.

The calculation of the City of Yuma's domestic use, and monthly data used in the calculation, can be found in Appendix I, Part 2, Imperial to Mexico section, sheet E (CUd Outflow Component), with footnotes explaining the sources of data. The canal loss (evaporation) calculation and monthly data can be found in Appendix I, Part 2, Imperial to Mexico section, Sheet H (E and Qds Outflow Components), also with footnotes explaining the procedure and the data used.

Chapter 4 — LCRAS Results in Tabular and Graphical Form

Chapter 4 uses tables and graphs to show calendar year 2002 agricultural, domestic, and export consumptive use, and phreatophyte water use developed by LCRAS, and calendar year 2002 consumptive use reported in the decree accounting report. This chapter also shows how LCRAS distributes underflow to Mexico among U.S. water users below the Northerly International Boundary with Mexico.

Table 4.1 shows the consumptive use results of LCRAS from agricultural, domestic, and export uses, and the consumptive use results of the decree accounting report. Consumptive use results are shown for each known diverter, grouped to provide a definition of each diverter as consistent with the decree accounting report as possible. The consumptive use results for each diverter from the decree accounting report do not include unmeasured return flows, which are subtracted from the State consumptive use totals as a correction for the basin total. No equivalent correction is required for the consumptive use results from LCRAS.

Table 4.1 shows the phreatophyte water use results of LCRAS separately for each diverter, and separately as state and basin totals, because the amount of phreatophyte water use that should be included in the consumptive use total for each diverter is an unresolved question at this time. Some portion of what LCRAS calls phreatophyte water use is most likely included in the consumptive use values from the decree accounting because the decree accounting report cannot separately identify water consumption from agricultural, domestic, and export consumptive use and phreatophyte water use separately.

The subsequent section entitled, "Distributing Underflow to Mexico Among US Water Users Below The Northerly International Boundary " shows the distribution of underflow to Mexico that must be included in the consumptive use values of LCRAS for diverters below the Northerly International Boundary with Mexico. These underflow-to-Mexico values are estimates of diverted Colorado River water that entered Mexico through the underground flow system and did not become available to downstream users in the United States or available for delivery to Mexico in accordance with treaty. Underflow to Mexico is included in the consumptive use values from the decree accounting because the decree accounting report cannot separately identify water use from underflow to Mexico.

The bar charts in the section entitled, "Selected Results in Graphical Form" show the water use results from LCRAS and the decree accounting report for selected water users, each with an explanation of the results depicted and questions that are made apparent by the bar chart.

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.	296	0	310	Lake Mead National Recreation Area, diversion from Lake Mohave (Cottonwood). Reported as a diversion.
Cottonwood Cove (domestic consumptive use).		186		
Southern California Edison (domestic consumptive use).		12,297	12,297	Southern Nevada Water Authority (Southern California Edison), pumped from Sec 24 T32S R66E. Diversion = consumptive use.
Big Bend Water District (domestic consumptive use).		2,355	2,355	Big Bend Water District Diversion Sec 12 T32S R66E. Reported as a consumptive use.
Sportsman's Park (domestic consumptive use).		2	0	Sportsman's Park.
Boy Scouts (domestic consumptive use).		0	0	Boy Scouts of America. Reported as a diversion.
Total Fort Mojave Indian Reservation, NV	7,162	2,959	4,518	Fort Mohave Indian Reservation (Avi), Hotel and Golf Course, 2 wells, sections 27 & 5. Reported as a diversion.
Fort Mojave Indian Reservation, NV.	7,162	2,170		
Fort Mojave Indian Reservation, NV (Avi) (domestic consumptive use).		789		
State of Nevada[1].	10,840	0		Not reported.
Subtotal: Uses below Hoover Dam.	18,298	17,799	19,480	Subtotal: Uses below Hoover Dam.
Uses above Hoover Dam [2].		307,238	307,238	Uses above Hoover Dam.
			1,491	Unmeasured return flow credit to Nevada.
Nevada Totals.	18,298	325,037	325,227	Nevada Total[3].

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

[2] From the 2002 decree accounting report.

[3] 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.	4,924	11,053	16,494	Fort Mohave Indian Reservation, delivered by City of Needles, and pumped from river and wells. Reported as a diversion.
Fort Mohave Indian Reservation Agriculture	4,924	11,011		
Fort Mohave Indian Reservation domestic use		42		
Needles (domestic consumptive use).		1,425	1,425	City of Needles, Pumped from river and wells. Reported as a consumptive use.
Havasu Water Company.		36	60	Havasu Water Company. 1 well, T5N/R25E Sec. 31.
Metropolitan Water District of Southern California (Colorado River Aqueduct export).		1,238,700	1,237,994	Metropolitan Water District, diversion from Lake Havasu. Reported as a consumptive use.
Parker Dam and Government Camp (domestic consumptive use).		147	147	Parker Dam and Government Camp, diversion at Parker Dam. Reported as a consumptive use.
Total Colorado River Indian Reservation, CA[4].	37,274	1,482	3,059	Colorado River Indian Reservation, pumped from 4 river pumps, 4 pumps Big River. Reported as a consumptive use[5].
Colorado River Indian Reservation, CA.	35,893	0		
North Lyn-De Farm, CA[6].	1	850		
South Lyn-De Farm, CA.	3	0		
Bernal Farm, CA.	1,243	0		
Clark Farm, CA.	134	632		
Total Chemehuevi Indian Reservation, CA.	38	253	89	Chemehuevi Indian Reservation, pumped from river and wells (Reported as a diversion).
Chemehuevi Indian Reservation, CA.	38	205		
Chemehuevi Indian Reservation, CA. (domestic use).		48		
Park Moabi, CA.	201	0		Not Reported.
Havasu National Wildlife Refuge, CA.	5,823	0		Not reported.

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

[5] 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.

[6] 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**	
Total BLM Permittees (Lake Havasu and Yuma Field offices)	0	310	521	BLM Permittees (Multiple diversion points).
BLM-Black Meadow (Domestic Consumptive Use)		91		(Reported as a diversion)
BLM Permittees (Lake Havasu Field Office and Yuma Field Office), CA.		219		
Blythe Energy Project, CA		0		Not Reported
Total Palo Verde Irrigation District, CA.	8,994	422,824	540,786	Palo Verde Irrigation District, diversion from Palo Verde Dam. Reported as a consumptive use.
Palo Verde Irrigation District, CA.	8,409	420,261		
Palo Verde Irrigation District, AZ.	585	775		
Blythe (city, domestic consumptive use).		1,702		
Ripley (domestic consumptive use).		53		
Palo Verde (domestic consumptive use).		33		
Cibola National Wildlife Refuge, CA.	19,509	0		Not reported.
Imperial National Wildlife Refuge, CA.	20,018	0		Not reported.
Fort Yuma Indian Reservation and Picacho State Recreation Area, CA.	4	0		Not reported.
Total Picacho State Recreation Area, CA.	5,167	0		Not reported.
Picacho State Recreation Area (Parker to Imperial)	5,038	0		
Picacho State Recreation Area (Imperial to Mexico)	129	0		
Lakeside Enterprises, (Chemgold, Inc) CA (domestic consumptive use).		2	3	Lake Enterprises of California (was Pichaco Dev't). 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[7].		3,484,044	3,484,091		Sum of IID and CVWD
				3,152,984	Imperial Irrigation District, diversion at Imperial Dam.
				331,107	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).		38	51		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.	53	0			Not reported.
Yuma Proving Ground, CA.	8,883	17			Not reported.
Fort Yuma Indian Reservation and Yuma Proving Ground, CA.	892	0			Not reported.

[7] 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.	14,663	45,629	66,675		Total Fort Yuma Indian Reservation, CA
Fort Yuma Indian Reservation, Indian Unit, CA.	1,430	17,060	61,395		Sum Yuma Projects, Reservation Division (consumptive use).
				46,387	Yuma Projects, Res. Div., Indian Unit, div. at Imp. Dam (consumptive use).
Fort Yuma Indian Reservation, Bard Unit, CA.	862	23,964		46,811	Yuma Projects, Res. Div., Bard Unit, div. at Imp. Dam (consumptive use).
Bard (domestic consumptive use).		214		31,803	Yuma Project, Reservation Div. returns.
Winterhaven (domestic consumptive use).		77	128		Total Winterhaven (diversion).
				128	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.	12,371	4,314	1,000		Valdez, Mike Ft. Yuma Tribe/CA, USGS#s CDP-01, CDP-02, & CEW-01 (diversion).
			550		Living Earth Farm Ft. Yuma Tribe/CA, USGS#s CEW-02& CDP-03 (diversion).
			39		MivCo Ft. Yuma Tribe/CA, USGS# CEW-14 (diversion).
			0		Valdez, Mike (Ranch 5)Ft. Yuma Tribe/CA, USGS # CEW-15 (diversion).
			3,188		Power/Valdez Ft. Yuma Tribe/CA, USGS #s CEW-03, CDP-04, & CDW-01 (diversion).
			375		Huerta Packing Ft. Mohave Tribe/CA, USGS# CDP-06 & CDP-07 (diversion).

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[8].	50,807	8,980	14,213	Total of Other State of California
Other uses, Davis Dam to Parker Dam	21,046	1,450	0	Subtotal: Davis Dam to Parker Dam
			0	De Soto Ranch Private/CA, USGS# CEW-17
			0	De Soto Ranch Private/CA, USGS# CEW-18
Other uses, Parker Dam to Imperial Dam	27,187	1,005	260	Subtotal: Parker Dam to Imperial Dam
			260	Citrus Ranch (C. Lye) Private/CA, USGS# CEW-16
Other uses Imperial Dam to Mexico	2,574	6,525	13,953	Subtotal: Imperial Dam to Mexico
			5	Wetmore, Kenneth C
			1	Williams, Jerry
			0	Lindeman, William H. & Hazel D. (less than ½ acre-foot)
			1	Carney, Jerome D.
			0	Wetmore, Mark M.
			1,188	Ranch “5" Lands, Yuma Island, CA (530 ac)
			509	Horizon Farms (Island) Private/CA USGA# CEP-01.
			391	Horizon Farms (Island) Private/CA USGS# CEP-02.
			0	Horizon Farms (Island) Private/CA USGS# CEW-08..
			59	Horizon Farms (Island) Private/CA USGS# CEP-03.
			225	Horizon Farms (Island) Private/CA USGS# CDP-05.

[8] 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**	
			225	Horizon Farms (Island) Private/CA USGS# CDW-07.
			225	Horizon Farms (Island) Private/CA USGS# CDW-06.
			225	Horizon Farms (Island) Private/CA USGS# CDW-05.
			167	Horizon Farms (Island) Private/CA USGS# CDEW-01.
			1,063	Horizon Farms (Island) Private/CA USGS# CEW-07.
			401	Horizon Farms (Island) Private/CA USGS# CEW-10.
			565	Horizon Farms (Island) Private/CA USGS# CEW-05.
			1,689	Horizon Farms (Island) Private/CA USGS# CEW-04.
			225	Horizon Farms (Island) Private/CA USGS# CDW-03.
			2,148	Horizon Farms (Island) Private/CA USGS# CEW-06.
			225	Horizon Farms (Island) Private/CA USGS# CDW-04.
			1,953	L. O Power (Island) Private/CA USGS# CEW-13.
			180	R. Harp (Island) Private/CA USGS# CDW-02.
			2,204	Alex Dees (Island) Private/CA USGS# CEW-09.
			79	Wilson Farms (Island) Private/CA USGS# CEW-11.
			0	K. H. Land (Island) Private/CA USGS# CEW-12.

Diverter Name	Phreatophyte Water Use	Agricultural, Domestic, and Export Consumptive Use	Consumptive Use	Diverter Name
LCRAS				**Decree Accounting Report**
			90,002	Unmeasured return flow credit to California.
California Totals.	177,250	5,215,255	5,275,606	California Total[9].

[9] 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.	895	193	322	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).	547	0		
Lake Mead National Recreation Area, AZ (Davis Dam to Parker Dam).	348	0		
Katherine Landing and Willow Beach (domestic consumptive use).		193		
Lower Colorado Region Dams Project (domestic consumptive use).		0	0	Lower Colorado River Dams Project (Davis Dam), Diversion at Davis Dam. Reported as a consumptive use.
Bullhead City (domestic consumptive use).		5,084	8,472	Bullhead City, Pumped from wells. Reported as a diversion.
Mohave County Parks (domestic consumptive use).		61	103	Diversion at Davis Dam, Mohave Co. Parks. Reported as a diversion.
South Point Power Plant, AZ		3,996		Not Reported
Mc Alister Housing Subdivision (domestic consumptive use)		3	6	Mc Alister, M. River Intake
Arizona State Parks (Windsor Beach)		21	36	Arizona State Parks (Windsor Beach).
Total Mohave Valley Irrigation and Drainage District	33,486	25,570	35,770	Mohave Valley I.D.D.Pumped from wells.
MVIDD (domestic consumptive use)[10].		2,980		
Mohave Valley Irrigation and Drainage District, AZ (includes no domestic use).	33,486	22,590		
Total Fort Mojave Indian Reservation, AZ.	33,987	43,402	61,982	Fort Mohave Indian Reservation, 14 pumps and wells in flood plain. Reported as diversions.
Fort Mojave Indian Reservation, AZ.	33,987	39,296		
Fort Mojave Indian Reservation, AZ. (domestic consumptive use)		4,106		
Golden Shores (domestic consumptive use).		324	538	Golden Shores Water Conservation District, pumped from wells. Reported as a diversion.
Topock (domestic consumptive use).		126		Not reported.

[10] 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**
Crystal Beach Water Conservation District		54	90	Crystal Beach Water Conservation District, T4N/R20W Sec 7 Reported as a diversion
Arizona-American (formerly Havasu) Water Company, AZ (domestic consumptive use).		442	736	Arizona-American Water Co (Havasu Water Co). Reported as a diversion.
Mohave Water Conservation District (domestic consumptive use).		418	701	Mohave Water Conservation District; pumped from wells. Reported as a diversion.
Brook Water (domestic consumptive use).		243	404	Brook Water, pumped from river. Reported as a consumptive use.
Havasu National Wildlife Refuge, AZ[11].	51,800	0	32,326	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).		9,493	15,821	Lake Havasu I.D.D. (City), pumped from wells. Reported as diversions.
Bill Williams National Wildlife Refuge (Lake Havasu).	11,191	0		Not reported.
Central Arizona Project Canal (export).		1,582,496	1,581,595	Central Arizona Project; pumped from Lake Havasu. Reported as a diversion.
Town of Parker (domestic consumptive use).		624	624	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[12].	3,005	0		Not reported.
Poston (domestic consumptive use).		54		Not reported.
Total, Colorado River Indian Reservation	140,344	366,915	384,860	Colorado River Indian Reservation; diversion at Headgate Rock Dam, 3 pumps & Town of Parker. Reported as a consumptive use.
Colorado River Indian Reservation, AZ.	140,344	364,714		
CRIR Domestic Use (Delivered by town of Parker)		2,201		
Ehrenburg Improvement Association (domestic consumptive use).		287	479	Ehrenburg Improvement Association, 1 pump SW Sec 3 T3N R22W G&SRM. Reported as a diversion.

[11] 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.

[12] 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**
Cibola (domestic consumptive use).		24		Not reported.
Ehrenberg Farm, AZ.	1	2,743	3,188	Total Jack Rayner at Ehrenberg Farm
				2,787 Jack Rayner Jr. Private/AZ Map #12 33°38'14.9"N 114°31'15.8"W, USGS# AEP-09.
				401 Jack Rayner Jr. Private/AZ Map #12 33°38'19.3"N 114°31'08.6"W, USGS# AEW-35.
				Reported as diversions.
Arkelian Farms, AZ.	2,577	0	0	Total George Arkelian at Arkelian Farms
				0 George Arkelian? Private/AZ Map #13, 33°36'01.4"N 114°31'54.0"W, USGS# ADGP-01.
				0 Unknown Industrial (formerly) George Arkelian Map #13, 33°35'58.1"N 114°31'48.6"W, USGS# AEW-34.
				Reported as diversions.
Total Bureau of Land Management permittees.	0	653	1,179	Bureau of Land Management permittees (LHFO & YFO). Reported as a diversion.
Bureau of Land Management permittees (Davis Dam to Parker Dam, domestic consumptive use).		136		
Bureau of Land Management permittees (Parker Dam to Imperial Dam, domestic consumptive use).		517		
Hillcrest Water Company (domestic consumptive use).		19	32	Hillcrest Water Co. Reported as a diversion.
Total Yuma Proving Ground.	403	400	666	Yuma Proving Ground, diversion at Imperial Dam, wells W,X,Y,Z. Reported as a consumptive use.
Yuma Proving Ground.	403	0		
Yuma Proving Ground (domestic consumptive use).		400		
Fort Yuma Indian Reservation, Mittry Lake State Wildlife Area and Yuma Proving Ground, AZ.	775	0	298	Pratt, L. 32d49'31.2"N 114d29'10.3"W, USGS# ADW-01.
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.[13]	6,955	14,413	27,069	Cibola Valley Irrigation District, 3 pumps Sections 20, 21, and 26T1N R23W. Reported as a diversion.
Cibola National Wildlife Refuge, AZ.	46,929	8,282	13,339	Cibola National Wildlife Refuge, 3 pumps, Section 2 and 31 T1S R23W (33d22'19.7"N 114d42'11.4"W, USGS# AEP-07, 33d18'09.4"N 114d40'41.6"W, USGS# AEP-06 & 33d18'09.8"N 114d40'36.3"W, USGS# AEP-05.) Reported as a diversion.
Total Imperial National Wildlife Refuge, AZ.	25,681	89	3,000	Imperial National Wildlife Refuge, 2 wells, Sec 13 T5S R22W G&SRM. (32d59'28.0"N 114d28'59.8"W, USGS# AEW-01 & 32d59'53.6"N 114d29'23.1"W, USGS# AEW-02). Reported as a diversion.
Imperial Wildlife Refuge (Parker to Imperial Reach)	20,048	0		
Imperial Wildlife Refuge (Imperial to Mexico Reach)	5,633	89		
Mittry Lake State Wildlife Area, AZ.	10,791	132		Not reported
Sturges Gila Monster Ranch, AZ.	864	6,975	11,433	Gila Monster Ranch, diversions at Imperial Dam (Warren Act). Reported as a consumptive use.
City of Yuma (domestic consumptive use).		18,188	18,036	City of Yuma, diversion at Imperial Dam (All-American Canal), diversion at Imperial Dam (Gila). Reported as a consumptive use.
Marine Corps Air Station [14] (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.

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

[14] 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	255	755	University of Arizona, diversion at Imperial Dam (Warren Act). Reported as a diversion.
University of Arizona Agricultural Station Agricultural CU & Phreatophyte water use.	0	255		
Underflow to Mexico from the application of water by the U. of A.[15]		0		
Yuma Union High School (domestic consumptive use).		86	146	Yuma Union High School, diversion at Imperial Dam. Reported as a diversion.
Desert Lawn Memorial.	0	393	336	Desert Lawn Memorial, diversion at Imperial Dam. Reported as a diversion.
North Gila Valley Irrigation District, AZ.	2,481	20,947	18,417	North Gila Valley Irrigation District, diversion at Imperial Dam. Reported as a consumptive use.

[15] 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**		
Yuma Irrigation District, AZ.	1,273	34,731	56,331		Total for Yuma Irrigation and Drainage District
				52,631	Yuma Irrigation District, diversion at Imperial Dam and pumped from private wells. Reported as a consumptive use.
				8	Ott, Judd T. 32d42'48.1"N 114d33'33.7"W, USGS# AEW-06.
				501	Ott, Judd T. 32d42'49.4"N 114d33'34.9"W, USGS# AEW-07.
				411	Cameron Bros. 32d42'34.0" N 114d34'13.1" W, USGS # AEW-08.
				281	Ogram, George 32d42'54.2" N 114d34'12.5" W, USGS # AEW-09.
				1,044	Cameron Bros. 32d43'0.00" N 114d34'28.1" W, USGS # AEW-10.
				419	Cameron Bros. 32d42'59.7" N 114d34'43.4" W, USGS # AEW-11.
				268	Peach 32d42'47.3" N 114d35'35.0" W, USGS # AEW-12.
				0	Peach 32d42'49.0" N 114d36'05.3" W, USGS # AEW-13.
				768	Peach 32d42'21.9" N 114d34'50.5" W, USGS # AEW-41.
					Decree accounting reports individual wells as diversions.

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	145,649	159,168	Yuma Mesa Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use[16].
Yuma Mesa Irrigation and Drainage District, AZ.	0	74,428		
Underflow to Mexico[17].		32,500		
State of AZ-Down Gradient from YMIDD (Consumptive use by down gradient users[18]).	0	32,228		
Hillander "C" Irrigation District, AZ .	0	6,481		
State Prison (domestic consumptive use).		12		

[16] 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.

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

[18] 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.	7,779	185,521	247,643	Total Yuma County Water Users Association
Yuma County Water Users Association, AZ.	12	133,968	241,227	Yuma County Water Users Association, diversion at Imperial Dam and pumped from wells[19].
Underflow to Mexico[20].		44,350	2	Glen Curtis Cit. 32d38'11.4"N 114d45'47.0"W, USGS# AEW-17
City of Somerton (domestic use).		1,017	37	Glen Curtis Cit. 32d38'08.1"N 114d45'46.7"W, USGS# AEW-18
City of Gadsden (domestic use).		133	27	Glen Curtis Cit. 32d38'05.4"N 114d45'46.0"W, USGS# AEW-19
City of San Luis (domestic use).		2,145	1,285	Waymon Farms 32d36'39.0"N 114d46'09.8"W, USGS# AEW-28
Fort Yuma Indian Reservation and Homesteads, AZ.	3,211	1,346	1,383	Waymon Farms 32d36'38.4"N 114d45'54.6"W, USGS# AEW-29
State of Arizona - limitrophe section.	4,556	2,562		State of Arizona limitrophe section (BLM):
			588	Jim Cuming 32d33'48.0"N 114d47'21.5"W, USGS# AEW-32.
			312	Earl Hughs 32d29'55.8"N 114d48'25.6"W, USGS# AEW-33.
			219	Burell 32d41'48.0"N 114d43'46.4"W, USGS# ADW-05.
			1,219	Jim Cuming 32d32'13.5"N 114d47'51.2"W, USGS# ADW-09.
			531	J. Barkley 32d30'56.6"N 114d47'56.7"W, USGS# ADW-10.
			813	Roger S. Brown 32d30'25.9"N 114d48'02.4"W, USGS# ADW-11.

[19] 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.

[20] 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	9,407	14,415	Total Unit "B" Irrigation and Drainage District
Unit B Irrigation and Drainage District, AZ.	0	7,333	14,314	Unit "B" Irrigation and Drainage District, diversion at Imperial Dam. Reported as a consumptive use[21].
Underflow to Mexico[22].		2,074	101	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).		850	850	Yuma Area Office, USBR diversion from Well No.8. Reported as a consumptive use.
Yucca Power Plant [23](domestic consumptive use).		555	926	Yucca Pwr Plant 32d43'12.6"N 114d42'47.2"W. Reported as a diversion.
Yuma County (domestic consumptive use).		7,779		Not reported.

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

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

[23] 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	7,404		8,039		16,006	Cocopah Indian Reservation
Subtotal, West Cocopah Indian Reservation, AZ.	6,626		6,983			
West Cocopah Indian Reservation, AZ.		6,626		6,317		
Underflow to Mexico[24].				666		
Subtotal, North Cocopah Indian Reservation, AZ.	778		912			
North Cocopah Indian Reservation, AZ.		778		708		
Cocopah Bend RV (domestic consumptive use)[25].				204		
East Cocopah Indian Reservation, AZ. (domestic consumptive use + bingo)			144			

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

[25] 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[26].	37,050	9,697	23,217	Total Other State of Arizona (reported as diversions)
Other Users, State of Arizona (Davis to Parker)	3,817	0	875	Subtotal: DavisDam to Parker Dam
			625	Vanderslice 34d50'17.8" N 114d34'11.0" W, USGS# ADP-07.
			250	Pelican Bend Farm 34d50'08.3" N 114d34'29.4" W, USGS# ADP-08.
Other Users, State of Arizona (Parker to Imperial)	20,048	0	521	Subtotal: Parker Dam to Imperial Dam
			500	Cibola Sportsman 33d18'09.8" N 114d40'36.3" W, USGS# ADP-06.
			21	North Baja Pipeline, LLC, (PG&E).
Other Users, State of Arizona (Imperial to Mexico)	13,185	9,697	21,821	Subtotal: Imperial Dam to Mexico
			500	Hall, Ansil, 32d43'26.6"N 114d42'54.8"W, USGS# ADP-05.
			1,344	Power, R.E. & P. 32d44'10.2"N 114d40'45.4"W, USGS# ADP-03 & Power, R.E. & P. 32d44'11.6"N 114d41'09.9"W, USGS# ADP-04
			281	Curry Family LTD 32d44'00.3"N 114d40'03.9"W, USGS# AEP-04 & Curry Family LTD 32d43'59.5"N 114d39'52.5"W, USGS# ADP-02
			344	Amigo Farms 32d43'53.5"N 114d39'21.9"W, USGS# AEW-14 & Amigo Farms 32d44'00.2"N 114d39'28.2"W, USGS# ADP-01
			1,710	Ranch “5" lands, Yuma island, AZ (760ac)

[26] 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**	
			264	Dulin, A. 32d44'50.9"N 114d31'56.3W (Yuma Island), USGS# AEW-03.
			1,679	Dulin, A. 32d44'26.5"N 114d31'52.4W (Yuma Island), USGS# AEP-01.
			4,129	Glen Curtis Cit. 32d43'17.8"N 114d33'50.2W (Yuma Island), USGS# AEP-02/03.
			0	Glen Curtis Cit. 32d43'59.7"N 114d33'41.4W (Yuma Island), USGS# AEW-04.
			1,503	Glen Curtis Cit. 32d44'32.9"N 114d33'36.7W (Yuma Island), USGS# AEW-05.
			600	Glen Curtis Cit. 32d43'47.1"N 114d32'49.1W (Yuma Island), USGS# ADW-03.
			1,031	Yowelman, R. 32d43'59.9"N 114d32'44.4W (Yuma Island), USGS# ADW-02.
			0	Harp, R. 32d44'25.1"N 114d33'50.4W (Yuma Island), USGS# ADW-04.
			8,436	State of Arizona (Arizona State Land Department)

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).	425,671	2,517,054	2,743,682		Arizona Subtotal (Below Hoover Dam, less Wellton-Mohawk Irrigation and Drainage District).
			60,354		Pumped from South Gila Wells (drainage pump outlet channels): Returns.
Arizona uses above Hoover Dam[27].		148	148		Arizona uses above Hoover Dam.
				121	Lake Mead Nat'l Recreation, AZ. Diversions from Lake Mead (Temple Bar).
				27	Marble Canyon Company.
Wellton-Mohawk Irrigation and Drainage District [27].		285,755	285,755		Wellton-Mohawk Irrigation and Drainage District.
			163,244		Unmeasured return flow credit to Arizona.
Arizona Totals.	425,671	2,802,957	2,805,987		Arizona Total[28].
Lower Basin Totals.	621,219	8,343,249	8,406,820		Total Lower Basin Use[28].

[27] From the 2002 decree accounting report.

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

Distributing 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.

Reclamation performs the calculations shown in table 4.2 to derive the following values:

1. The final value of underflow across the Southerly International Boundary (SIB) and the limitrophe section based on the following items:

   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,

   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	91,346	
Final value of Underflow Across SIB (acre-feet/year)	69,149	75.7%
Final value of Underflow Across the limitrophe section (acre-feet/year)	22,197	24.3%
Check Total	91,346	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	3%	2,074
YMIDD & Yuma Mesa Canals	47%	32,500
YCWUA & Yuma Valley Canals	33%	22,819
YID	0%	0
River (Mor. - SIB)	10%	6,915
Other Sources	7%	4,840
Total Underflow Across SIB	100%	69,148

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	69,909	97.0%	21,531
West Cocopah Indian Reservation	2,151	3.0%	666
Check Totals	72,060	100%	
Total Underflow - limitrophe section			22,197

Selected Results in Graphical Form

This section shows bar charts for the following uses of water:

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 bar charts show the consumptive use reported for calendar year 2002 by the decree accounting report, and the agricultural, domestic, and export consumptive uses, and phreatophyte water uses developed by LCRAS for State totals and selected irrigation districts and wildlife refuges. The 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[29].

The consumptive use totals for each State reported by 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 for individual diverters reported by 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.

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

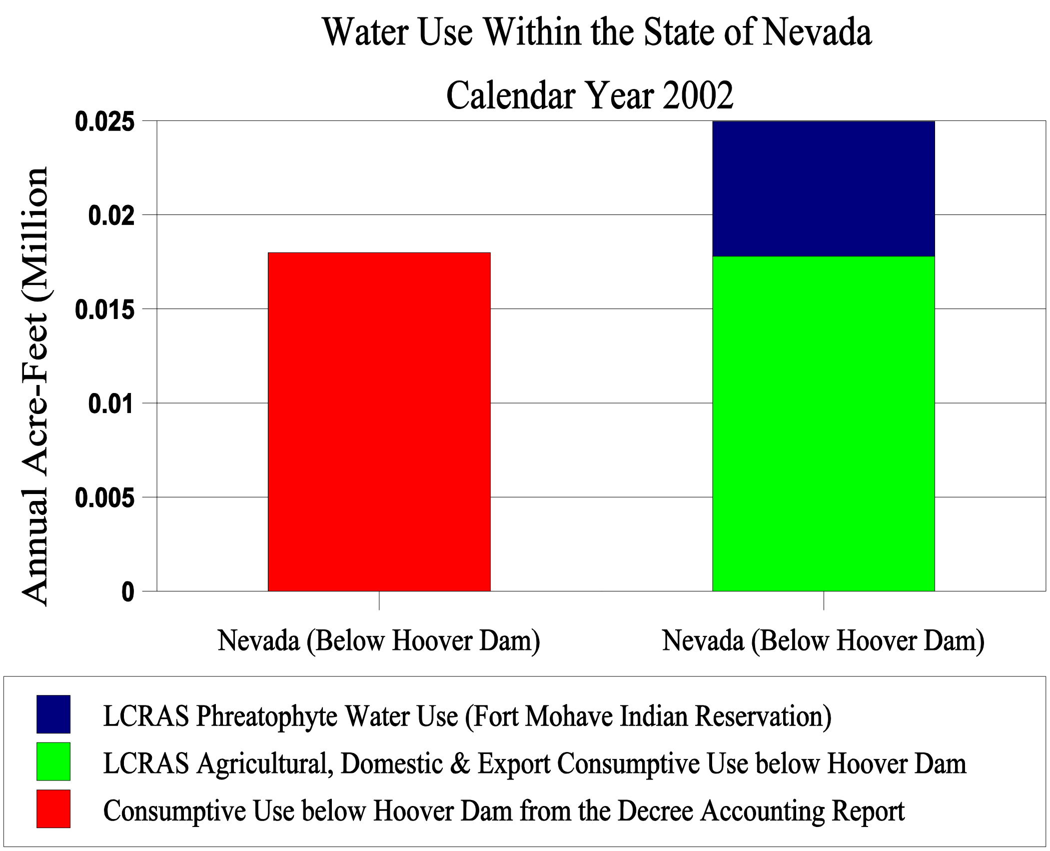

Figure 4.1 — Water use within the State of Nevada below Hoover Dam

Figure 4.1 compares the agricultural, domestic, and export consumptive uses and the phreatophyte water use developed by LCRAS to the consumptive uses reported in 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.

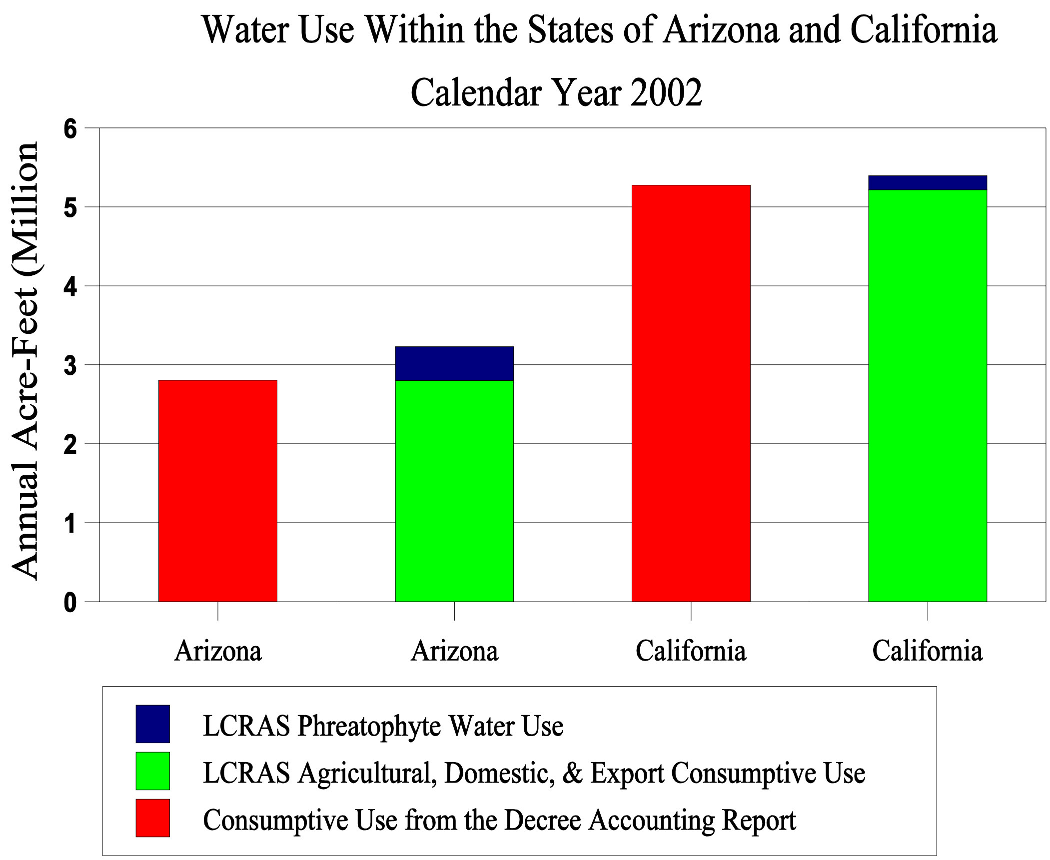

Figure 4.2 — Water use within the states of Arizona and California

Figure 4.2 compares the agricultural, domestic, and export consumptive uses and the phreatophyte water use reported by LCRAS to the consumptive uses reported in 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 relatively 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.

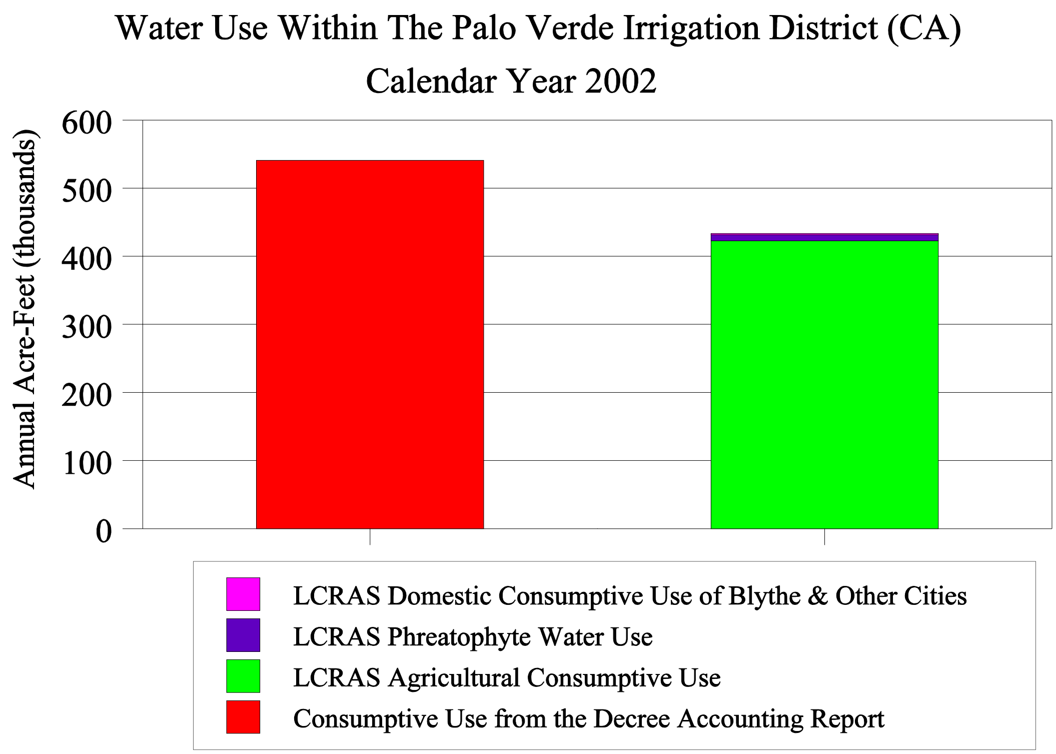

Figure 4.3 — Water use within the Palo Verde Irrigation District

Figure 4.3 compares the sum of agricultural and domestic consumptive use and phreatophyte water use within the Palo Verde Irrigation District developed by LCRAS to the consumptive use reported in the decree accounting report. The consumptive use reported 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.

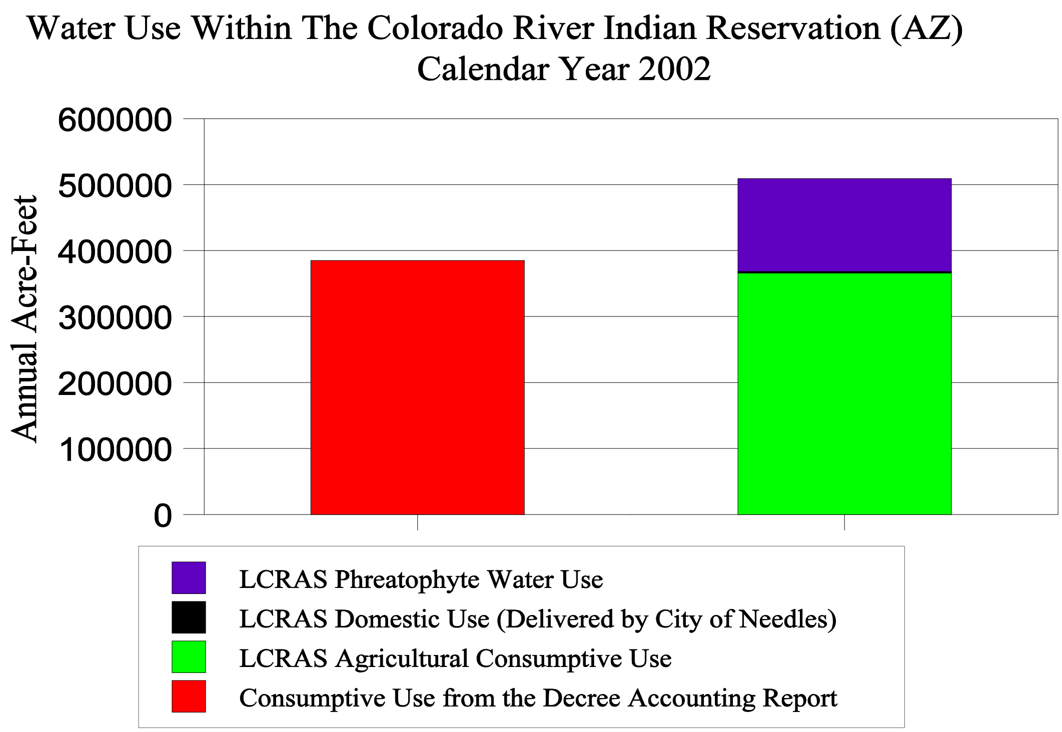

Figure 4.4 — Water use within the Colorado River Indian Reservation (AZ)

Figure 4.4 compares the agricultural and domestic consumptive use (delivered by City of Needles), and phreatophyte water use within the Colorado River Indian Reservation developed by LCRAS to the consumptive use reported in the decree accounting report. The consumptive use reported in the decree accounting report does not include the estimate of unmeasured return flow from the Colorado River Indian Reservation that is applied to the Lower Basin as a whole.

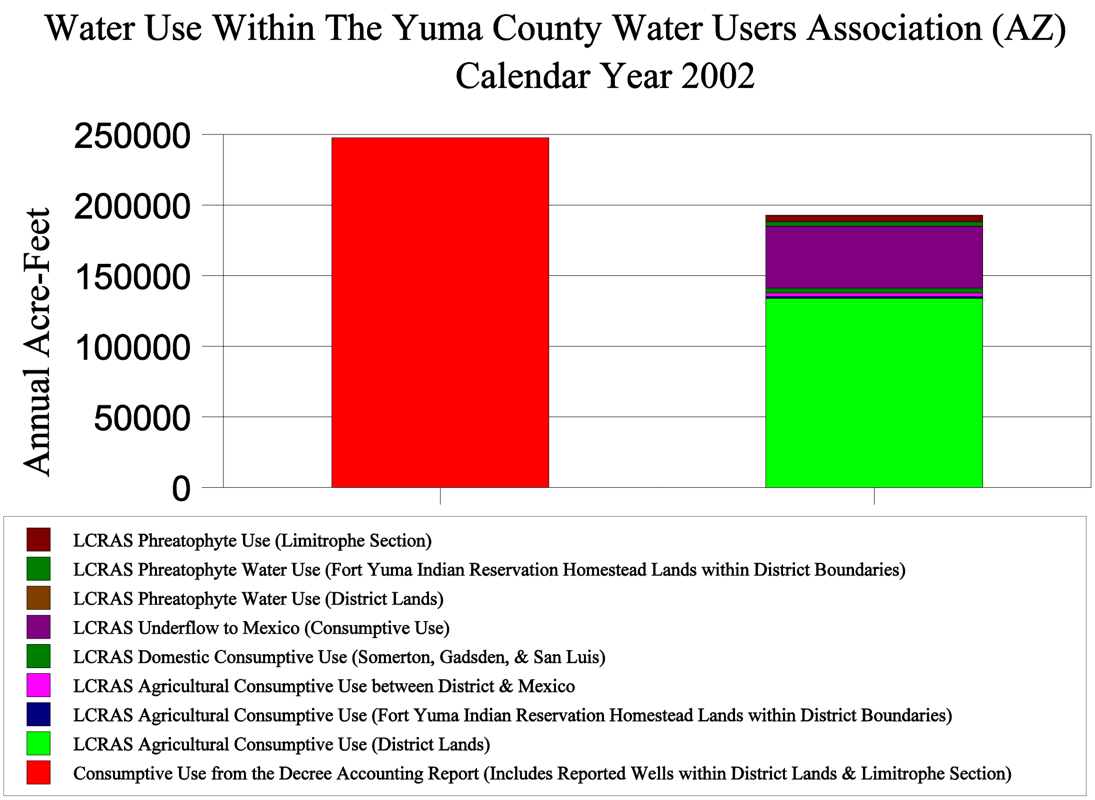

Figure 4.5 — Water use within the Yuma County Water Users Association (AZ)

Figure 4.5 compares Yuma County Water Users Association (YCWUA) agricultural and domestic consumptive uses, phreatophyte water use, and the final value of the underflow to Mexico that results from the application of water, plus agricultural consumptive use and phreatophyte water use between the district boundary and the Mexican border, developed by LCRAS to the consumptive use reported in the decree accounting report. The consumptive use reported 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 compares the agricultural consumptive use and phreatophyte water use within the Cibola

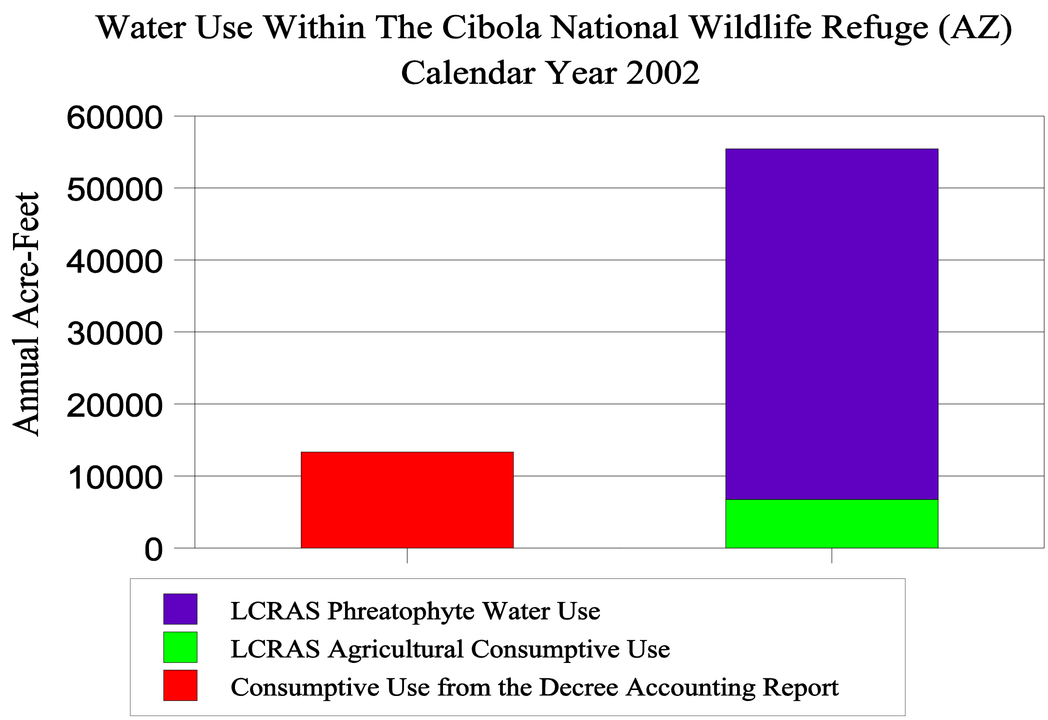

Figure 4.6 — Water use within the Cibola National Wildlife Refuge (AZ)

National Wildlife Refuge developed by LCRAS to 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 in which determining 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.

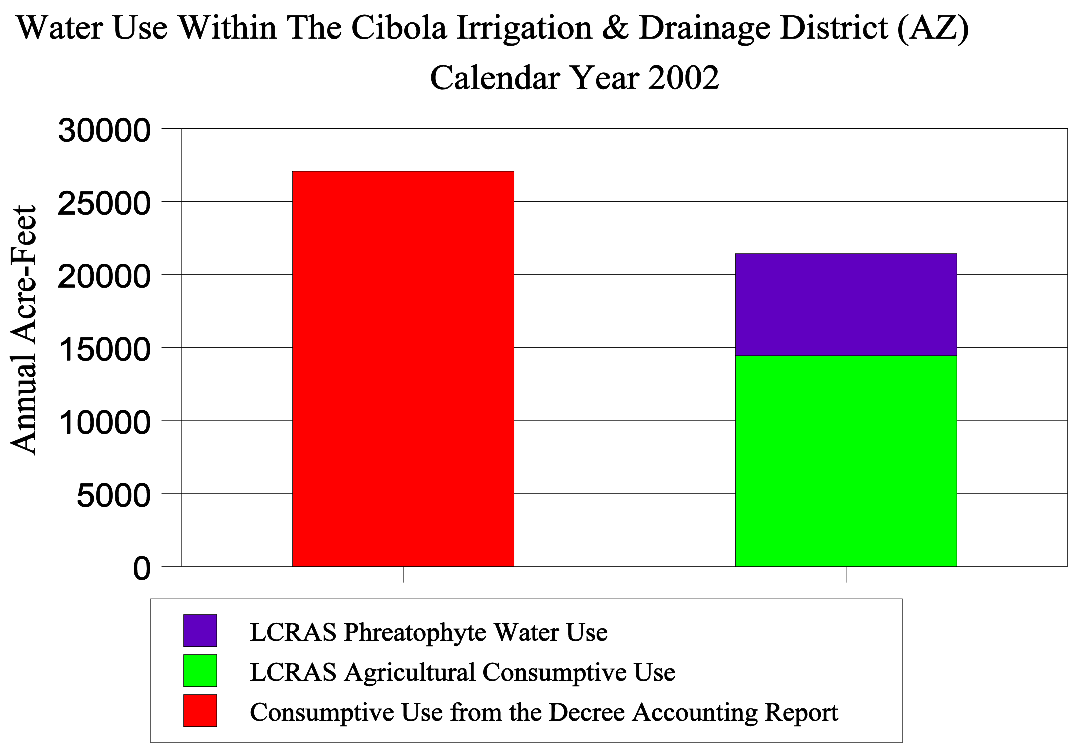

Figure 4.7 — Water use within the Cibola Irrigation and Drainage District (AZ)

Figure 4.7 compares the agricultural consumptive use and phreatophyte water use within the Cibola Irrigation and Drainage District developed by LCRAS to 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 in which determining 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 Reclamation uses to calculate agricultural and phreatophyte ET for each crop and phreatophyte group, and to calculate evaporation, and describes 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.

Developing Reference ET for use in LCRAS

The Arizona Meteorological Network calculates reference ET values for Reclamation's use in 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 develops area-specific reference ET values for the following areas in the following ways:

1. Mohave Valley: from data collected by the single AZMET station sited in the Mohave Valley using the standardized equation.
2. Palo Verde/Parker area: by averaging the reference ET values calculated from data collected by the three CIMIS stations sited in the Palo Verde Valley (Blythe North East, Palo Verde II, and Ripley) and the Parker AZMET station sited in the Parker Valley using the standardized equation .
3. Yuma area: by averaging the reference ET values calculated from data collected by the three AZMET stations sited in Yuma area (North Gila, Yuma Valley, and Yuma Mesa) using the standardized equation.

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

Table 5.1 lists annual summations of the averaged daily reference ET values used in this report.

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
2002	76.57	73.67	76.92	75.72

Resolving 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

While compiling 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 those reported by the CIMIS stations from 1995 through 1997. The average annual reference ET values reported by the AZMET stations were 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 1995 through 2002. (The Palo Verde CIMIS station was taken out of service in December of 2000. It has been replaced by Palo Verde II, used in the 2002 report.)

Table 5.2 — Annual Summation of Daily Reference ET Values
Reported by AZMET and CIMIS Stations: 1995-2002

Units: inches

Year	Mohave AZMET Station	Parker AZMET Station	Blythe NE CIMIS Station	Palo Verde(II) 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	69.16	67.51	75.00	79.31	81.29
2002	83.75	81.98	72.41	71.13	69.33	83.37	85.32	84.62

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. Reclamation calculates crop and riparian ET along the river using a single set of ET coefficients. As a result, Reclamation needs a consistent set of reference ET values on both the California and Nevada, and Arizona sides of the Colorado River. Reclamation discussed the requirement for a consistent set of reference ET values with representatives from the CIMIS and AZMET networks and Reclamation's consultant. In 1998, this discussion resulted in a recommendation to develop an interim solution until a permanent solution could be developed.

In 1999, Reclamation adopted the interim solution to calculate agricultural and phreatophyte ET using an average of the reference ET values reported by all the CIMIS and AZMET stations sited along the lower Colorado River. The averaged reference ET solution was used to calculate crop and riparian ET for the 1997 and 1998 LCRAS Demonstration of Technology Reports. The LCRAS public meeting in Henderson, Nevada, in October 1998 provided the forum for a thorough discussion of the use of averaged reference ET values. In 1998 and 1999, Reclamation participated in an analysis of the reference ET values reported by the AZMET and CIMIS networks to identify the sources of the difference in reference ET values reported by the two networks, and to recommend a permanent solution to address the disparity (1998-1999 analysis).

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

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
4. micro-climatic differences between station sites

The representatives of the AZMET and CIMIS networks and Reclamation's consultant further reached the following conclusions:

1. Net radiation is the most significant component of the methods used by the AZMET and CIMIS networks to calculate reference ET, and each network uses a slightly different equation to calculate it[2].
2. The effects of siting conditions on reference ET values, including variations in crop conditions, at AZMET or CIMIS station sites, are not fully known.
3. AZMET and CIMIS stations use very similar equipment and maintenance and calibration procedures.
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.

The following sections discuss these conclusions.

Analyzing the Effect of Net Radiation on Reference ET

Dr. Paul Brown of the University of Arizona evaluated the reference ET calculations used by AZMET and CIMIS to identify and quantify the effect the different ET net radiation calculations used by AZMET and CIMIS have on reference ET values. In a 1999 unpublished report to Reclamation, Dr. Brown concluded that the difference in equations used to calculate net radiation is the major source of the disparity between the CIMIS and AZMET reported reference ET values. Specifically, Dr, Brown concluded that the 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. As a result, AZMET stations generally report higher reference ET values than CIMIS stations.

Dr. Brown further concluded, that upon comparing the reference ET values reported by AZMET and CIMIS networks to reference ET values calculated using the standardized Penman-Monteith equation and measured net radiation, that 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 percent. Also, that 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 percent.

[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.

Analyzing the Effect of Station Siting Conditions on Reference ET

The 1998-1999 analysis concluded that siting conditions, including variations in crop conditions, at individual AZMET or CIMIS station sites most likely affect the accuracy of the calculated reference ET, however the magnitude of this effect is unknown. Reclamation is cooperating with the University of Arizona (operators of the AZMET network) in an additional study to identify the effect of siting conditions at individual stations on reported reference ET values. Preliminary results indicate that a micro-meteorological station not located in an actively irrigated reference field reports a reference ET higher than a micro-meteorological station located in an actively irrigated reference field.

Analyzing Effect of Equipment Used at AZMET and CIMIS Stations on Reference ET

Following discussions with representatives from the AZMET and CIMIS networks, Reclamation concluded that both networks use equipment that is standard for the industry and that is calibrated to the manufacturer's specifications during installation and site visits for periodic maintenance. Both networks perform regularly scheduled (usually monthly) maintenance to the best of their abilities and perform additional maintenance when equipment fails. Both networks review data to identify anomalies and problems with sensors. Thus, Reclamation and the 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.

Analyzing Effect of Micro-Climatic Differences Between Station Sites on Reference ET

The 1998-1999 analysis concluded that micro-climatic differences between AZMET and CIMIS station sites contribute no more than 5 percent of the variation in reported reference ET between individual the stations. The data also do not indicate a trend as a function of latitude in the value of reference ET from the most northerly to the most southerly parts of the LCRAS study area as might be expected. The reference ET values reported by the AZMET and CIMIS stations differ by more than 5 percent. 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

In 1999, 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), using 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 calculated reference ET using the standardized equation, for each AZMET and CIMIS station site —using the data collected by each station—and Reclamation has calculated area-specific reference ET values, as described at the beginning of this chapter, using the reference ET values calculated by Dr. Paul Brown using the standardized equation.

The Standardized Equation

Reclamation's investigations were precipitated by our recognition of a disparity between the two meteorological networks and our need for a consistent set of reference ET values. At the same time, ASCE recognized a need for a single reference ET equation and that they finished their work in time for LCRAS to use the resultant equation. The efforts by ASCE and LCRAS were entirely separate efforts, however they did use some of the same experts in the field. As a result, we became aware of the ASCE-ET and their efforts, and we were able to take advantage of the work that they did and their recommendation

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]

[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.

In early 1999, 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 evaluating 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).

The following is the standardized equation used to calculate the reference ET values used in this report.

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

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 ($^{\circ}C$),
*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 $^{\circ}C^{-1}$),

(= the psychrometric constant (kPa $^{\circ}C^{-1}$),
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 AZMET and CIMIS Sites along the lower Colorado River
using the Standardized Equation

Units: inches

Year	Mohave	Parker	Blythe NE	Palo VerdeII	Ripley	North Gila	Yuma Mesa	Yuma Valley	Average
2002	76.57	78.99	75.35	72.20	67.82	77.32	74.89	78.50	75.21

Impact of using the standardized equation on ET coefficients

The standardized equation produced an annual summation of the daily reference ET that averages 7.8 percent lower than the annual summation of the daily reference ET produced by the AZMET network and 2.4 percent higher than the annual summation of the daily reference ET produced by the CIMIS network in calendar year 2002.

Chapter 6 — Remote Sensing and GIS Procedures

Chapter 6 provides a detailed discussion of Reclamation's integration of remote sensing and GIS technologies. Reclamation uses these technologies to determine the location and number of acres of crop groups, phreatophyte groups, and open water from Hoover Dam to Mexico. This procedure is also referred to as 'mapping' in this report. The location and number of acres of crop groups, phreatophyte groups, and open water from Hoover Dam to Mexico are used to calculate agricultural evapotranspiration (agricultural ET), phreatophyte evapotranspiration (phreatophyte ET), and evaporation from the mainstream and reservoirs of the Colorado River from Hoover Dam to Mexico and from major delivery canals. These quantities become components of the water balance (discussed previously in chapter 2) from which agricultural consumptive use and phreatophyte water use are calculated.

Reclamation performs accuracy assessment for crop and phreatophyte groups. The spatial extent (location and area of coverage) of the crop groups, phreatophyte groups, and open water are stored in digital spatial databases referred to as a GIS database. Reclamation uses the GIS databases to generate annual acreage summaries for each land cover group (i.e. crop group, phreatophyte group, open water) by diverter boundary, river reach, and State. The next section discusses the annual acreage summaries for crop groups. The annual acreage summary for crop groups is the report of the location and number of acres of crop groups which is the result of the technical processes discussed later in this appendix.

Annual Acreage Summaries For Crop Groups

Reclamation generates an annual number of acres of each crop group and summarizes the number of acres of each crop group by diverter boundaries, river reach boundaries, and State boundaries. This summary is based on all crop group image classification periods. Reclamation creates an Arc/Info "regions" coverage (ESRI,Inc., 1994.) that is a GIS database containing crop groups assigned to each agricultural field for all image classification periods. This GIS database also contains the 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 has developed 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 (more than 800 unique combinations used for calendar year 2002) and assigns acreage of crop group(s) for each field. Figure 6.1 is a graphic example of how this program functions. In Figure 6.1, 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.

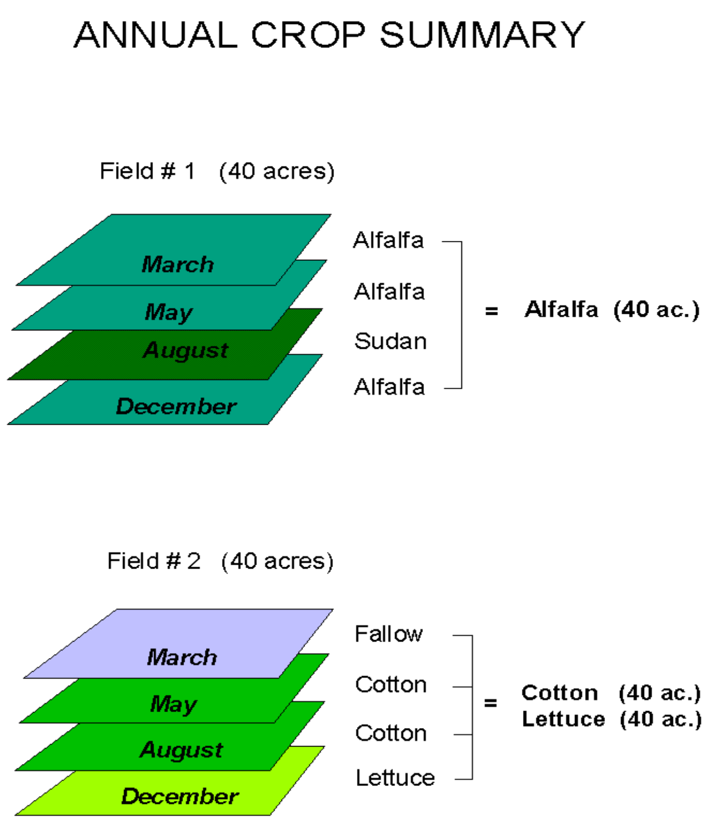

Figure 6.1 — Example of classification correction from logic accounting for error indicated in accuracy assessment and ground reference data, and knowledge of the crop calendar.

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. The following sections provide more detailed information on the processes used for generating data for the acreage summaries described in this section.

Developing a GIS Field Border Database

As the first step in identifying cropped areas, Reclamation developed a GIS database 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 to this field border database for image classification procedures. Image classification is the process of using digital image processing procedures to identify features or land cover types in digital satellite imagery. Reclamation originally derived these field borders from 10-meter Systemme Pour l'Observation de la Terre (SPOT) satellite images acquired in June and August of 1992. Reclamation digitized all field borders using the SPOT image data as a reference. Reclamation currently uses 5-meter IRS satellite images to routinely update field borders when field staff observe changes during ground reference data collection. Reclamation last completed a comprehensive field border update in 1998 using fall 1997 IRS orthorectified 5-meter panchromatic satellite images.

Table 6.1 provides "data about the data" (metadata) for the field border database. Five field border databases cover the lower Colorado River from below Hoover Dam to Mexico (figure 6.2). The extent of these field border databases define individual processing areas for crop image classification procedures. Each agricultural field represented in the database has a unique identification number (FIELD-ID) as well as various other attributes. "CROP-LABEL" contains the crop group Reclamation assigns based on the image classification process. Reclamation populates "CROP-TYPE" with the name of a specific crop if the field is a ground reference field and populates other attributes, such as "AVG-HT" (average crop height), and "GROWTH-STAGE," for ground reference fields. The attribute, "AA," is coded to differentiate those agricultural fields reserved for accuracy assessment from those used for the image classification process.

Table 6.2 compares acreage calculated for fields based on the field border database captured from SPOT image data and acreage calculated using Global Positioning System (GPS) control points. This comparison ensures that acreage values derived from field borders captured from the SPOT satellite images 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, well within an acceptable degree of error.

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

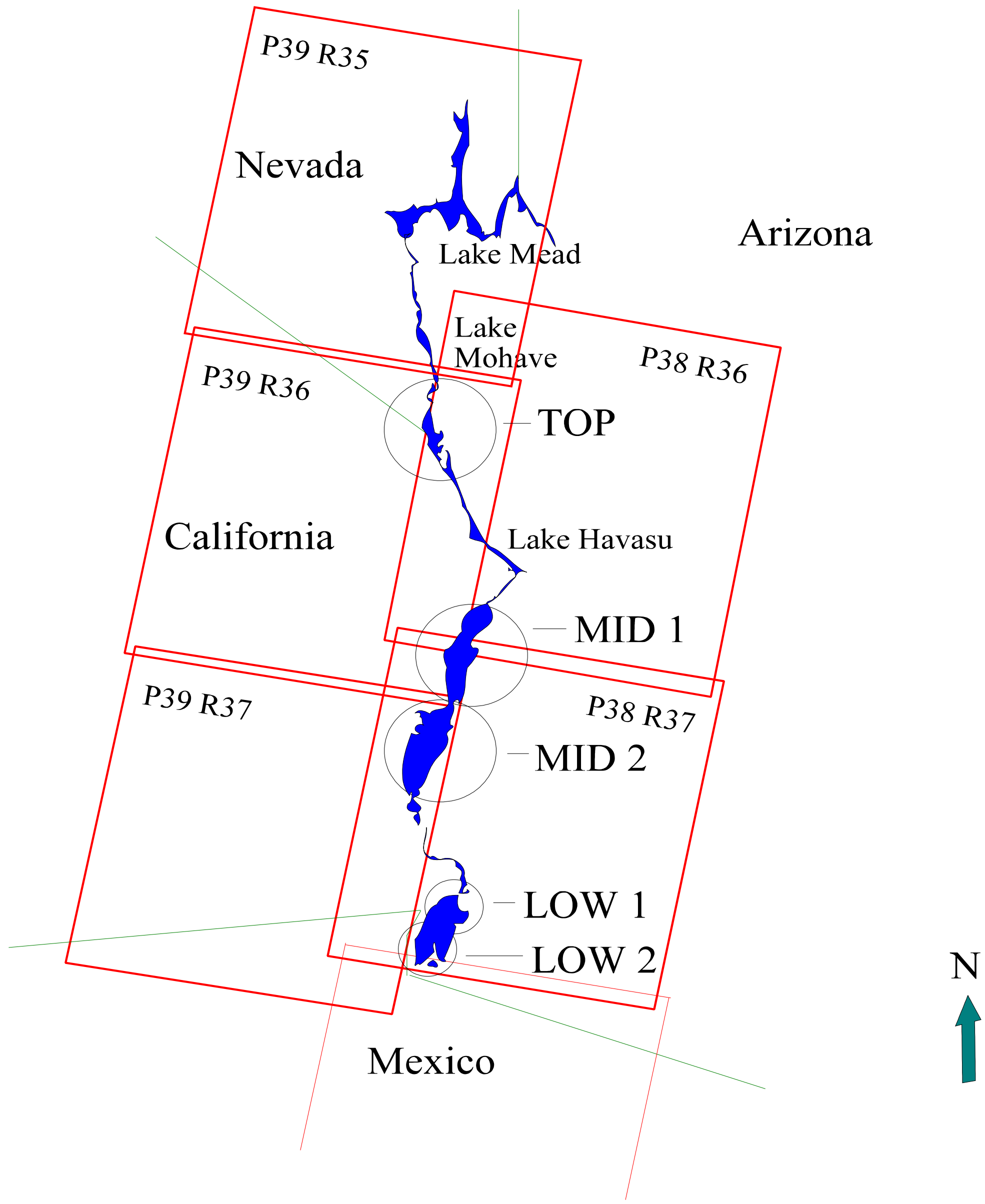

Figure 6.2 — Image Processing Areas and Landsat Scene Boundaries.

Table 6.2 — Field Acreage Comparison (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 databases used in this process include Diverter, Floodplain, and River Reach boundaries. Reclamation continuously improves the diverter GIS database based on consultation with diverters in the project area. If needed, Reclamation will provide additional metadata on digital GIS databases used in this process.

Image Classification for determining the location and number of acres of crop groups

Introduction

Figures 6.4, 6.5, and 6.6, at the end of this chapter, are flow diagrams that summarize the crop classification procedures discussed in this section. Crop groups identified by Reclamation consist of individual crops that are grouped according to their similarity in water requirements.

Reclamation completes image classification in all processing areas four times a year with the exception of the 'TOP' processing area (figure 6.2), which Reclamation classifies twice a year. Crop calendar information for the area provides the basis for the number of classifications necessary and the classification dates. Reclamation does not map orchards from satellite images, but updates orchard fields in the GIS database based on field verification because Reclamation determined that the desired levels of accuracy for identifying the location of orchards could not be achieved with image classification processes used for mapping other crop groups. The principal source of data for image classification are Landsat Thematic Mapper satellite images. Alternate sources of satellite images (in the case of sensor failure or cloud cover for Landsat TM data) include 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 over a 10-day period for each image classification, chosen on the basis of the Landsat satellite flyover date and crop planting practices. Reclamation selected the processing areas for image classification (figure 6.2) based on the extent of cropped areas delineated in the field border database, and the variability of crops grown in each area..

Reclamation, in conjunction with Pacific Meridian Resources (a private contractor), developed image classification methods for use by the LCRAS program. Reclamation and Pacific Meridian Resources tested a variety of these methods and improved them during their joint effort. Reclamation continues to improve the image classification methods and presents a discussion of significant improvements made during the year of this report in chapter 3.

Collecting Ground Reference Data

Reclamation collects ground reference data each time it classifies cropped areas. Each data collection period takes approximately 8 days over a 10-day period using three ground reference crews. Each ground reference data collection field crew (field crew) consists of a driver and coder (a person who records the data).

Reclamation designed the ground reference data collection program to capture as much of the variability in crops and crop conditions as possible to account for as much of the spectral variability in the satellite images as possible. Reclamation samples approximately 15 percent of the fields in the project area, which were originally chosen as ground reference fields using a random number generator, and then reviewed to ensure adequate geographic distribution. Reclamation routinely visits these fields during ground reference data collection and often samples additional fields to capture rare crops or other anomalous conditions important for the image classification process.

Each field crew uses 7.5 minute quadrangle plots with 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 for navigation. The quadrangle plots show fields to be sampled (ground reference fields) in unique colors to help the field crew to easily identify them. The colors indicate the crop observed at the previous ground reference data collection visit, which often helps the field crew identify crop residue or any significant changes in planting practices. Table 6.3 lists ground reference attributes collected for the GIS field border database. Table 6.4 is a complete crop group and name list used for this report.

The driver 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 other staff perform an additional check of the field data at the office and then use the data to attribute data fields (Arc/Info data fields) in the GIS field border database.

Table 6.3 — Ground Reference Attributes for GIS Field Border Database

Attribute	Comments
Date	MM/DD/YR
Quad Name	7.5' Geological Survey Quad Name
Field-ID	Unique ID from GIS field border database (ARC/INFO)
Crop Name	See Table 6.4 for a crop group and name 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 > 10%

Attribute	Comments
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.

Table 6.4 — Crop Group and Name List used for Calendar Year 2002

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
			Turnip & Rutabaga
	Klein Grass	Herbs	Thyme, dill, basil, rosemary, tarragon, oregano
	Timothy Grass		
Citrus	Young, 1-2 Meter	Perennial Vegetables	Artichokes
	Mature, 2 + Meter		Asparagus
	Declining	Sugar Beets	Sugar Beets (summer)
Tomatoes	Tomatoes	Sugar Beets	Sugar Beets (winter)
Sudan	Sudan	Grapes	Grapes

Crop Group	Crop Name	Crop Group	Crop Name
Legume/Solanum Vegetables	Beans (green)	Crucifers	Broccoli
	Beans (dry)		Cauliflower
	Beans (Garbanzo)		Cabbage
	Peas		Bok-Choy
	Peanuts		Mustard
	Peppers		Kale
Moist Soil Unit	Moist Soil Unit	Seasonal Wetland	Seasonal Wetland

***Selection of Ground Reference Fields for use in the Image Classification Process and for assessing the accuracy of the Image Classification*.**

Reclamation reserves about one-third of the ground reference fields as accuracy assessment fields after populating the field border database with ground reference data, using a random stratified approach to ensure a statistically valid sample. Reclamation uses the remaining ground reference fields for spectral signature development.

Automated Spectral Signature generation

Spectral signatures are files containing numeric values from the satellite imagery for ground reference fields and are used in the image classification process. Initially, Reclamation created a single spectral training site within each ground reference field (except those fields reserved for accuracy assessment) using the SEED function in ERDAS Imagine image processing software (ERDAS, 1999). A spectral training site consists of image pixels sampled within the ground reference field. The ERDAS SEED function “grows” a training site from a starting pixel using user-defined parameters (ERDAS, 1999). 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 spectral signature sets to achieve the desired classification accuracy, Reclamation needed a process requiring less time to implement.

To meet this need, Reclamation created a process to automatically extract spectral signatures for image classification, using 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 now reselects ground reference fields from the GIS field border database and uses these fields to mask a Landsat TM 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 statistically similar regions based on the spectral values from the image. 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 6.3 shows ground reference fields masked and partitioned into spectral regions.

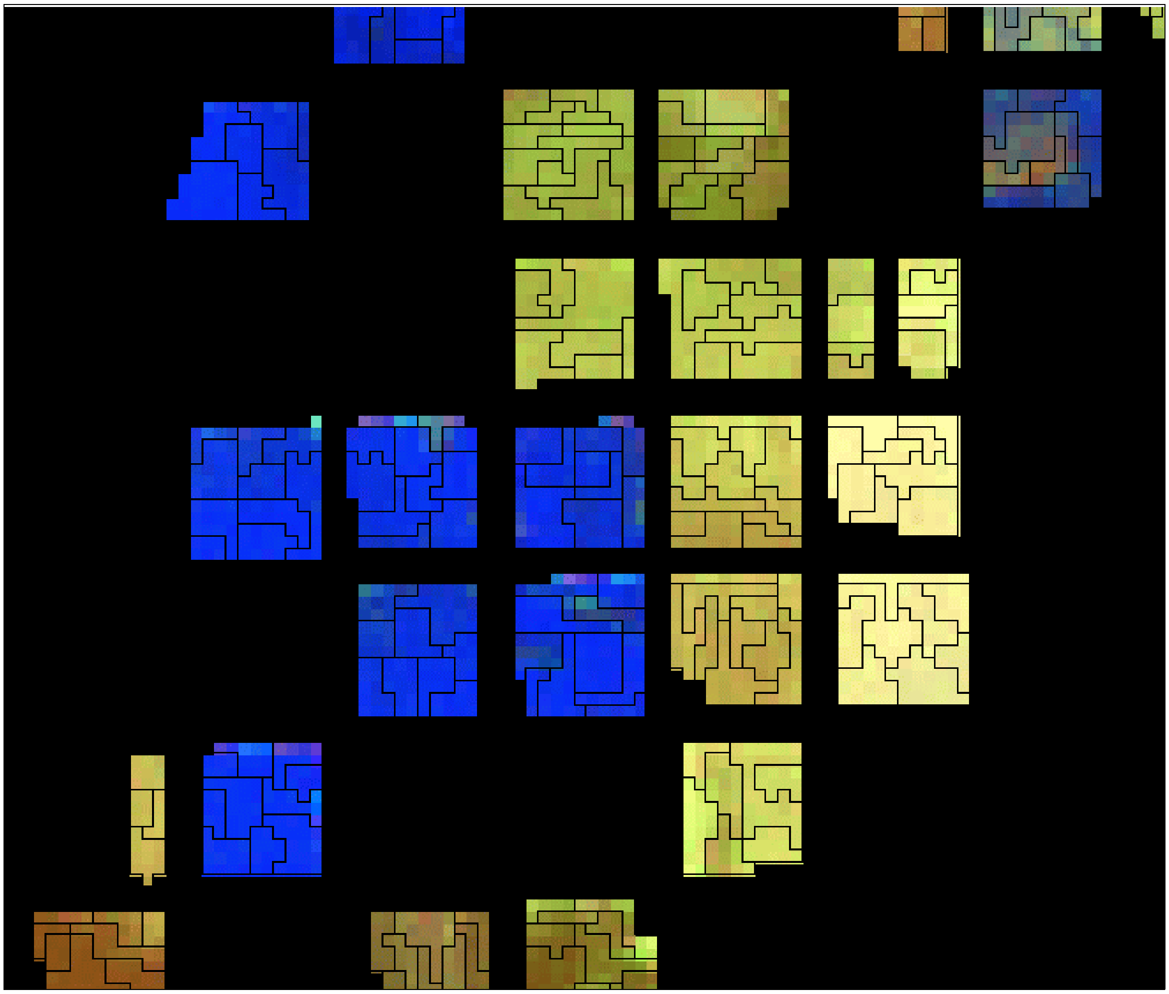

Figure 6.3 — Ground Reference Fields - masked and partitioned into spectral regions for signature generation. Black lines denote spectral regions plotted on Landsat bands 4,3,2.

After generating statistically similar regions in the ground reference training fields, Reclamation performs the following steps:

1. Converts the spectral region coverage of ground reference fields to Arc/Info vector format.

2. 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.
3. 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.

This process typically produces more than 4,000 training signatures (more than one spectral region per ground reference field), which Reclamation refines based on the following criteria,

1. a valid signature must consist of 10 or more pixels,
2. the standard deviation value of the 10 or more pixels must be less than or equal to three, in all six bands.

Reclamation chose standard deviation cutoffs based on classification results; however, this cutoff can vary depending on spectral properties of individual crop groups. Reclamation also visually inspects the group of spectral signatures over the satellite images to check for any signatures representing anomalous field conditions that would be better left out of the image classification process.

The Image Classification Process

Once Reclamation defines the signature set, Reclamation does the following:

1. Performs a supervised maximum likelihood classification (ERDAS 1999) in ERDAS Imagine to classify all fields,
2. "Overlays" the resulting pixel classification with the GIS field border database and gives each field a single crop group label based on the distribution of classified pixels within that field using a simple plurality rule (the field label is given to the group that has the most classified pixels within that field),
3. Evaluates this initial classification by creating a frequency table that compares labels derived from ground observations to labels derived from the image classification, including only those fields used for spectral training sites in the frequency table, which 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),

4. Applies an iterative classification procedure to improve the classification,
5. Identifies spectral training signatures that may be responsible for field mislabeling by generating a summary table of the pixel classification for mislabeled training fields which shows the signatures responsible for classifying each pixel within a field, and
6. If necessary, performs cluster analysis to evaluate spectrally similar signatures that may represent different crop groups.

Once Reclamation identifies problem spectral signatures and refines the group of spectral signatures used for the image classification, 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.

Generating Accuracy Assessment Error Matrices

Reclamation generates accuracy assessment error matrices for all final crop classifications (Story and Congalton, 1986). These matrices report errors of omission and commission based on crop group acreage and number of fields correct. As discussed previously, Reclamation reserves about one third of the ground reference fields as an independent sample for accuracy assessment purposes for each classification time.

The selection of accuracy assessment fields is a random stratified sample that represents the relative proportions of crop groups grown at each classification time, as well as the variety of conditions for each crop group. Under-sampled crop groups generally represent crops grown either in such a small 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 calculations of agricultural ET. Reclamation is currently working with an independent statistician to review and identify ways to improve the ground reference field sampling design used for spectral classification and accuracy assessment, and plans to implement identified improvements as they become available.

Reclamation considers accuracy assessment error matrices based on the number of acres correctly classified and error matrices based on the number of fields correctly classified to be useful. Reclamation includes in this report only accuracy assessment error matrices reported on an acreage basis, the most useful for relating crop classification error to agricultural ET calculations. Reclamation analysts use accuracy figures reported on the number of fields correctly classified to help define the crop groups being confused in the image classification process, 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 for calendar year 2002. These 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, the columns in the matrix represent "truth" derived from ground observation (GROUND REFERENCE FIELDS) and the rows represent the label given by the spectral classification process for the same reference fields (MAP LABEL). An accuracy assessment error matrix represents the accuracies of each crop group in the map and can be interpreted for 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 an incorrect group.

These error matrices also contain additional information specific to this application, such as adjustments to some of the reported accuracy percentages for expected spectral confusion between any crop group and a fallow condition. When at an immature growth stage, the crown closure of most crops is not great enough to spectrally differentiate them from a fallow field. Of important note is that after the annual crop group summary (discussed under “*Annual Acreage Summaries for Crop Groups*” at the beginning of this chapter) takes into account all image classification times, error between fallow and any crop group is negligible. Further studies will present the effects of known error on calculations of agricultural ET.

Table 6.5 — February 2002 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**	**7909.5**		306.5		10.0												93.2			**8319.2**	95%	95%
Cotton	**2**		**0.0**																		**0.0**		
Small Grain	**4**	53.7		**884.4**		70.6												14.8			**1023.5**	86%	86%
Corn	**5**				**0.0**																**0.0**		
Lettuce	**6**	29.6		3.7		**1462.1**							137.0	177.6				1.6			**1811.6**	81%	91%
Melons	**7**						**0.0**														**0.0**		
Bermuda Grass	**8**							**600.0**													**600.0**	100%	100%
Citrus	**9**								**750.0**												**750.0**	100%	100%
Tomatoes	**10**									**0.0**											**0.0**		
Sudan Grass	**11**										**0.0**										**0.0**		
Legume/Solanum Vegetables	**12**											**0.0**									**0.0**		
Crucifers	**13**			38.0		102.1							**663.3**	20.5				32.9			**856.8**	77%	80%
Fallow	**14**	462.7		470.1		125.1	0.0					39.5	13.4	**5463.7**				116.6			**6691.1**	82%	100%
Dates	**15**														**150.0**						**150.0**	100%	100%
Safflower	**16**															**0.0**					**0.0**		
Deciduous Orchards	**17**																**52.7**				**52.7**	100%	100%
Small Vegetables	**18**	24.6																**42.9**			**67.5**	64%	64%
Root Vegetables	**19**																		**0.0**		**0.0**		
Perennial Vegetables	**20**																			**0.0**	**0.0**		
TOTALS		**8480.2**	**0.0**	**1702.7**	**0.0**	**1770.0**	**0.0**	**600.0**	**750.0**	**0.0**	**0.0**	**39.5**	**813.7**	**5661.7**	**150.0**	**0.0**	**52.7**	**302.0**	**0.0**	**0.0**	**20322.4**	Total Samples	
%correct by crop		93%		52%		83%		100%	100%			0%	82%	97%	100%		100%	14%			**17978.41**	Total Correct	
																					88%	**% correct**	
total with fallow correction		8372.20	0.00	1354.43	0.00	1587.20	0.00	600.00	750.00	0.00	0.00	39.53	676.63	5463.65	150.00	0.00	52.69	159.51	0.00	0.00	19205.84		
% correct with fallow correction		99%		80%		90%		100%	100%			100%	83%	97%	100%		100%	53%			**95%**		

Table 6.6 — April 2002 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		**1.0**	**2.0**	**4.0**	**4.0**	**6.0**	**7.0**	**8.0**	**9.0**	**10.0**	**11.0**	**12.0**	**13.0**	**14.0**	**15.0**	**16.0**	**17.0**	**18.0**	**19.0**	**20.0**		(commission)	fallow correction
Alfalfa	**1**	**8761.6**	67.5	105.3	33.4						332.0			33.6							**9333.4**	94%	94%
Cotton	**2**		**0.0**																		**0.0**		
Small Grain	**4**	27.7	119.0	**2746.2**	99.3		85.9				45.8	19.9	8.7			38.1		23.6			**3214.1**	85%	85%
Corn	**5**	50.2		127.8	**123.5**		18.3				79.2										**399.0**	31%	31%
Lettuce	**6**					**0.0**															**0.0**		
Melons	**7**	57.7	8.3	61.8	28.1		**319.3**				9.4					17.7					**502.4**	64%	64%
Bermuda Grass	**8**							**600.0**													**600.0**	100%	100%
Citrus	**9**								**750.0**												**750.0**	100%	100%
Tomatoes	**10**									**0.0**											**0.0**		
Sudan Grass	**11**	16.1			9.5		61.2				**644.6**										**731.4**	88%	88%
Legume/Solanum Vegetables	**12**	62.0																			**62.0**	0%	0%
Crucifers	**13**												**0.0**								**0.0**		
Fallow	**14**	141.7	3281.6	25.9	62.0		160.8				405.5	55.0	24.2	**1111.5**		37.8					**5306.1**	21%	100%
Dates	**15**														**150.0**						**150.0**	100%	100%
Safflower	**16**			18.4												**67.6**					**86.1**	79%	79%
Deciduous Orchards	**17**																**50.0**				**50.0**	100%	100%
Small Vegetables	**18**	19.8																**404.2**			**424.0**	95%	95%
Root Vegetables	**19**																		**0.0**		**0.0**		
Perennial Vegetables	**20**																			**0.0**	**0.0**		
TOTALS		**9136.7**	**3476.5**	**3085.4**	**355.8**	**0.0**	**645.6**	**600.0**	**750.0**	**0.0**	**1516.5**	**74.9**	**32.9**	**1145.1**	**150.0**	**161.2**	**50.0**	**427.8**	**0.0**	**0.0**	**21608.4**	Total Samples	
%correct by crop		96%	0%	89%	35%		49%	100%	100%		43%	0%	0%	97%	100%	42%	100%	94%			**15728.62**	Total Correct	
																					73%	**% correct**	
total with fallow correction		8903.28	3281.64	2772.12	185.55	0.00	480.16	600.00	750.00	0.00	1050.07	55.03	24.17	1111.50	150.00	105.43	50.00	404.25	0.00	0.00	19923.20		
% correct with fallow correction		97%	94%	90%	52%		74%	100%	100%		69%	73%	74%	97%	100%	65%	100%	94%			**92%**		

Table 6.7 — July 2002 Accuracy Assessment Error Matrix - by Acreage

Ground Reference Fields

MAP LABEL		Alfalfa **1.0**	Cotton **2.0**	Small Grain **4.0**	Corn **4.0**	Lettuce **6.0**	Melons **7.0**	Bermuda Grass **8.0**	Citrus **9.0**	Tomatoes **10.0**	Sudan Grass **11.0**	Legume/ Solanum Vegetables **12.0**	Crucifers **13.0**	Fallow **14.0**	Dates **15.0**	Safflower **16.0**	Deciduous Orchards **17.0**	Small Vegetables **18.0**	Root Vegetables **19.0**	Perennial Vegetables **20.0**	**TOTALS**	%correct (commission)	% correct with fallow correction
Alfalfa	**1**	**8666.2**	141.5	18.0							201.4	81.3		32.8							**9141.2**	95%	95%
Cotton	**2**	201.4	**3462.5**								219.0	18.6									**3901.5**	89%	89%
Small Grain	**4**			**29.2**																	**29.2**	100%	100%
Corn	**5**				**91.6**											55.3					**146.9**	62%	62%
Lettuce	**6**					**0.0**															**0.0**		
Melons	**7**						**187.7**														**187.7**	100%	100%
Bermuda Grass	**8**							**650.0**													**650.0**	100%	100%
Citrus	**9**								**750.0**												**750.0**	100%	100%
Tomatoes	**10**									**0.0**											**0.0**		
Sudan Grass	**11**	427.7	55.3	106.4	9.2						**1213.2**			161.0							**1972.7**	61%	70%
Legume/Solanum Vegetables	**12**			17.7							18.2	**36.6**									**72.5**	50%	50%
Crucifers	**13**												**0.0**								**0.0**		
Fallow	**14**	619.1		368.7	85.2		18.3				395.2	2.8		**4798.2**							**6287.4**	76%	100%
Dates	**15**														**160.0**						**160.0**	100%	100%
Safflower	**16**															**37.8**					**37.8**	100%	100%
Deciduous Orchards	**17**																**50.0**				**50.0**	100%	100%
Small Vegetables	**18**																				**0.0**		
Root Vegetables	**19**																				**0.0**		
Perennial Vegetables	**20**																				**0.0**		
TOTALS		**9914.4**	**3659.3**	**539.9**	**186.0**	**0.0**	**206.0**	**650.0**	**750.0**	**0.0**	**2047.0**	**139.3**	**0.0**	**4991.9**	**160.0**	**93.1**	**50.0**	**0.0**	**0.0**	**0.0**	**23387.0**	Total Samples	
%correct by crop		87%	95%	5%	49%		91%	100%	100%		59%	26%		96%	100%	41%	100%				**20132.85**	Total Correct	
																					86%	**% correct**	
total with fallow correction		9285.26	3462.49	397.89	176.79	0.00	206.01	650.00	750.00	0.00	1608.37	39.40	0.00	4798.15	160.00	37.78	50.00	0.00	0.00	0.00	21622.14		
% correct with fallow correction		94%	95%	74%	95%		100%	100%	100%		79%	28%		96%	100%	41%	100%				**92%**		

Table 6.8 — November 2002 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		**1.0**	**2.0**	**4.0**	**4.0**	**6.0**	**7.0**	**8.0**	**9.0**	**10.0**	**11.0**	**12.0**	**13.0**	**14.0**	**15.0**	**16.0**	**17.0**	**18.0**	**19.0**	**20.0**		(commission)	fallow correction
Alfalfa	**1**	**6772.1**	110.9	18.3			74.0						28.5	156.5							**7160.3**	95%	97%
Cotton	**2**	117.4	**579.0**										22.0					39.3			**757.7**	76%	76%
Small Grain	**4**			**0.0**																	**0.0**		
Corn	**5**				**75.1**																**75.1**	100%	100%
Lettuce	**6**	7.8				**1667.0**						4.7	256.8	37.6				20.0			**1993.8**	84%	85%
Melons	**7**						**34.6**														**34.6**	100%	100%
Bermuda Grass	**8**							**600.0**													**600.0**	100%	100%
Citrus	**9**								**750.0**												**750.0**	100%	100%
Tomatoes	**10**									**0.0**											**0.0**		
Sudan Grass	**11**										**0.0**										**0.0**		
Legume/Solanum Vegetables	**12**											**0.0**									**0.0**		
Crucifers	**13**					126.1							**351.9**								**478.0**	74%	74%
Fallow	**14**	994.3	466.4			1010.5					113.3		281.1	**2958.2**				236.2			**6060.0**	49%	100%
Dates	**15**														**170.0**						**170.0**	100%	100%
Safflower	**16**															**0.0**					**0.0**		
Deciduous Orchards	**17**																**52.7**				**52.7**	100%	100%
Small Vegetables	**18**					27.9												**11.5**			**39.4**	29%	29%
Root Vegetables	**19**																		**0.0**		**0.0**		
Perennial Vegetables	**20**																			**0.0**	**0.0**		
TOTALS		**7891.6**	**1156.3**	**18.3**	**75.1**	**2831.5**	**108.7**	**600.0**	**750.0**	**0.0**	**113.3**	**4.7**	**940.2**	**3152.2**	**170.0**	**0.0**	**52.7**	**307.0**	**0.0**	**0.0**	**18171.6**	Total Samples	
%correct by crop		86%	50%	0%	100%	59%	32%	100%	100%		0%	0%	37%	94%	100%		100%	4%			**14022.09**	Total Correct	
																					77%	**% correct**	
total with fallow correction		7766.45	1045.40	0.00	75.10	2677.50	34.65	600.00	750.00	0.00	113.34	0.00	632.95	2958.15	170.00	0.00	52.69	247.68	0.00	0.00	17123.91		
% correct with fallow correction		98%	90%	0%	100%	95%	32%	100%	100%		100%	0%	67%	94%	100%		100%	81%			**94%**		

Results Of The Image Classification Process For Classification Of Crop Groups

Accuracy assessment error matrices indicate that Reclamation can achieve overall image classification accuracies for crop groups of more than 90 percent after accounting for expected confusion due to different growth stages. Multiple image classifications during the calendar year ensure the correct classification of immature crops as they mature. Crop groups (at a particular classification time) that represent the majority of the acreage are generally the most accurately classified. Individual crops that do not represent a significant amount of acreage, or are statistically undersampled for that particular time because of planting practices (that is, little to no acreage planted in the crop during the classification period) are generally less accurately classified.

Classification error has meaning to the LCRAS program, as a whole, only in terms of the impact the classification error has on the calculated values of consumptive use. Classification error resulting from the misidentification of crop groups with similar water demands, or the misidentification of crop groups which represent a very small portion of the irrigated acreage, negligibly impact the calculated values of consumptive use.

Image Classification for determining the location and number of acres of phreatophytes

Reclamation initially classified phreatophyte areas in 1994 using Landsat Thematic Mapper satellite images as the principle source data, and routinely used available aerial photography as an ancillary data set to help in image 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, which identify spectral difference between image dates (i.e. July 2001 and July 2002), and focuses remapping efforts in areas of spectral change.

Collecting Ground Reference Data

Reclamation collects ground reference data to train the image classifier to identify phreatophytes in the same way it collects this data to identify crops. Reclamation staff collect data throughout the project area to adequately sample the variety of phreatophytes and to ensure a good geographic distribution of ground reference data. The exact location of sites are determined by using GPS technology. At each site, staff record a unique site number, GPS information, type of vegetation, percent crown closure by type of vegetation, moisture conditions, basic soil types, and any other pertinent information. Plots with image backdrops and preliminary unsupervised image classifications (ERDAS, 1999) aid navigation and ensure that spectral variability is captured during ground reference data collection.

Mapping phreatophytes requires a somewhat different approach than that used for mapping crops because satellite image pixels of phreatophytes often consist of a mixture of plant types rather than a single plant type typical of crops (e.g., an irrigated field with one crop). Reclamation generates unsupervised classifications consisting of unlabeled spectral classes before ground reference data collection and staff takes plots of these unlabeled spectral classes into the field to help establish correlation between particular phreatophyte groups and the satellite image.

Because phreatophyte groups typically change more gradually than crop groups, staff often have the opportunity to revisit the area as needed during the classification process. Reclamation must collect field data and satellite data during the same season. After staff collect ground reference data, Reclamation generates a GIS database of data collection sites from the GPS data and uses this GIS database to develop spectral signatures for the phreatophyte image classification.

Classification Strategies

Reclamation evaluated the following satellite image band combinations to determine the optimum combination to classify phreatophytes:

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.

The initial phreatophyte classification, completed in 1994, used a May 1994 TM 6-band image. The presence of additional bands did not appear to help distinguish phreatophyte groups any better than the TM 6-band image. Reclamation classifies each satellite image using both supervised and unsupervised image classification algorithms (ERDAS, 1999). Reclamation merges and analyzes signature files from the classifications using statistical clustering algorithms.

Image Preparation

Reclamation masks portions of the satellite images to isolate phreatophyte areas (as it does for classifying crops), and creates Normal Difference Vegetation Index (NDVI) (ERDAS, 1999) images to separate vegetated from non-vegetated areas for classification purposes. This process tends to reduce classification error in deeply shadowed areas and reduces error caused by high-variance “barren” pixels.

Spectral Signature Generation, Analysis, and Image 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 (1) "informationally" unique spectral signatures (spectral signatures that always represent the same phreatophyte group in the landscape) (2) spectrally similar signatures that represent different phreatophyte groups in the landscape (spectrally confused groups), and (3) spectral signatures (from ISODATA) that are 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 (preliminary error matrices) also allow the analyst to see how well the signature set classifies the training sites. (Training sites used to generate signatures should be classified 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 pixel classification (each pixel in the imagery is given a phreatophyte label) is complete, Reclamation uses these data to label spectrally derived polygons.

Generating and Labeling spectrally Derived Polygons

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

Reclamation "overlays" the spectrally derived polygon boundaries with the phreatophyte pixel classification, and generates a histogram showing the distribution of phreatophyte pixel groups within each polygon. Reclamation then assigns a phreatophyte label to each polygon by applying labeling rules (based on the classification system) that account for the relative percentages of phreatophyte pixel groups within each polygon. The result is a GIS database containing the location and distribution of phreatophyte groups.

Editing the Polygon Phreatophyte GIS Database

Once Reclamation labels the polygons, Reclamation edits the polygon phreatophyte GIS database to correct error from the classification process. 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. As discussed previously, photography is the principle ancillary data source for editing purposes.

Updating the Phreatophyte GIS Database

Reclamation updates the phreatophyte GIS database annually using change detection methodologies and Landsat satellite images. This process involves comparing satellite images of the same areas from different dates to locate changes in land cover.

Reclamation first co-registers the satellite images (i.e. spatially aligns the two images so they overlay each other properly) from each date to reduce apparent change due to misregistration between the two images. Then, Reclamation normalizes the images in order to reduce effects caused by differences in atmospheric conditions, illumination conditions, and sensor calibration between images acquired on different 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).

Once the imagery is coregistered and normalized, Reclamation creates a difference image by subtracting the values in one image from the other image using various image subtractions with different band combinations to determine the optimum band combinations for this application. Reclamation analyzes the image subtraction test results by examining the image subtraction outputs in combination with imagery, field notes, maps, and aerial photography, and chooses an appropriate image subtraction method based on these results.

Reclamation then categorizes the difference image into the five general groups shown below based on all available ancillary data:

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

Reclamation makes field visits to areas of change to verify the change as well as to indicate the general nature of the change (i.e. change due to fire, dozer activities, etc.), and uses this data to remap areas of significant phreatophyte change using classification processes previously described for phreatophytes or manual photo interpretation techniques. Reclamation then incorporates remapped areas into the existing phreatophyte GIS database as an update. Accuracy assessment work is ongoing for phreatophyte updates in conjunction with Reclamation's Lower Colorado Regional Office, Resource Management Office, in Boulder City, Nevada, which is also mapping phreatophyte communities.

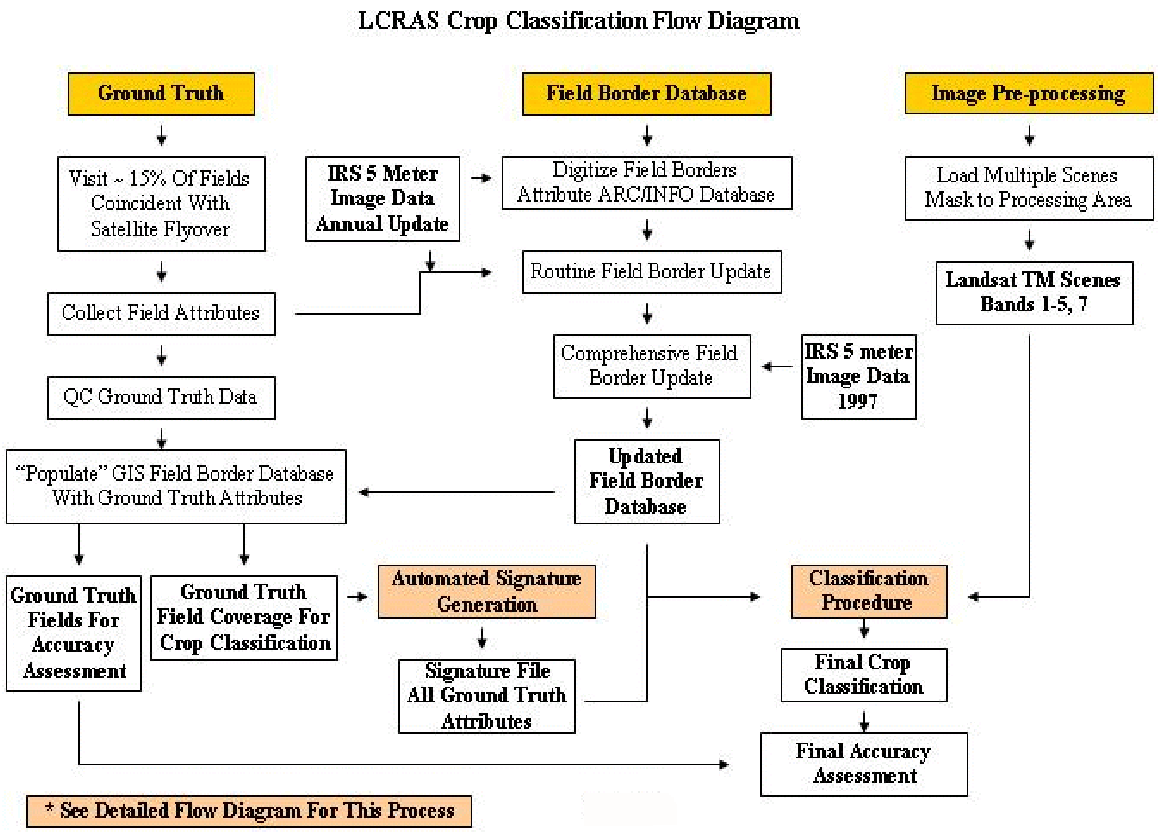

Figure 6.4 — LCRAS Crop Classification Flow Diagram, Ground Truth, Field Border Database, and Image-Preprocessing.

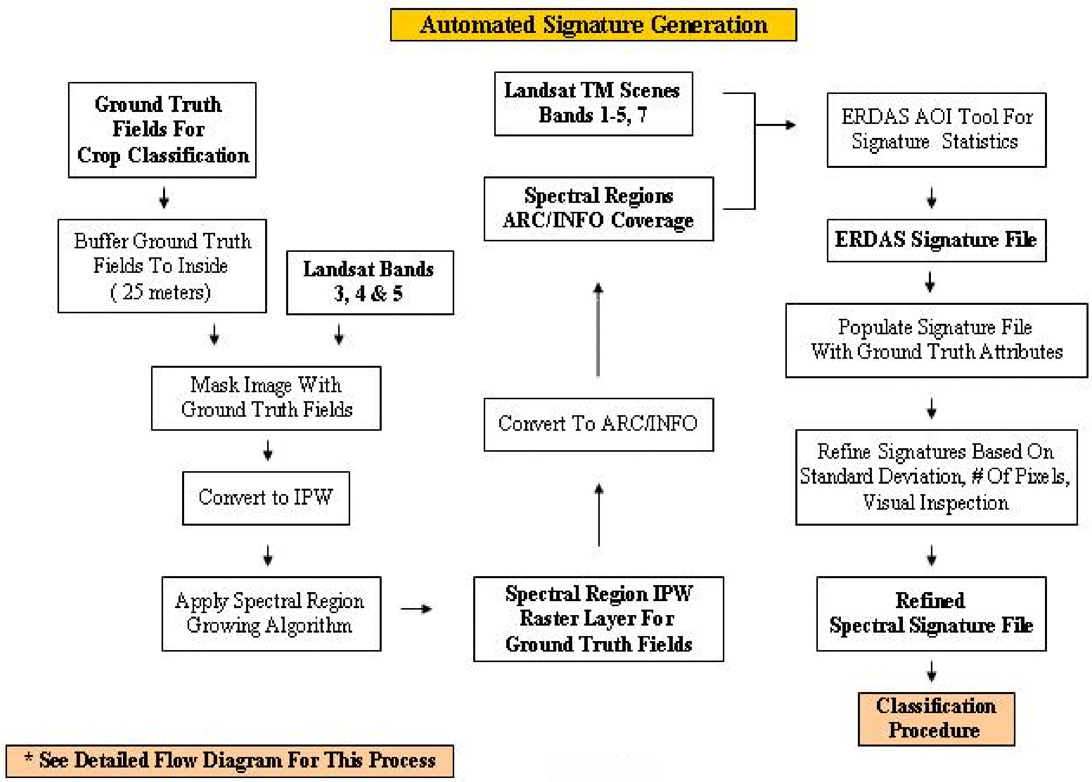

Figure 6.5 — LCRAS Crop Classification Flow Diagram, Automated Signature Generation.

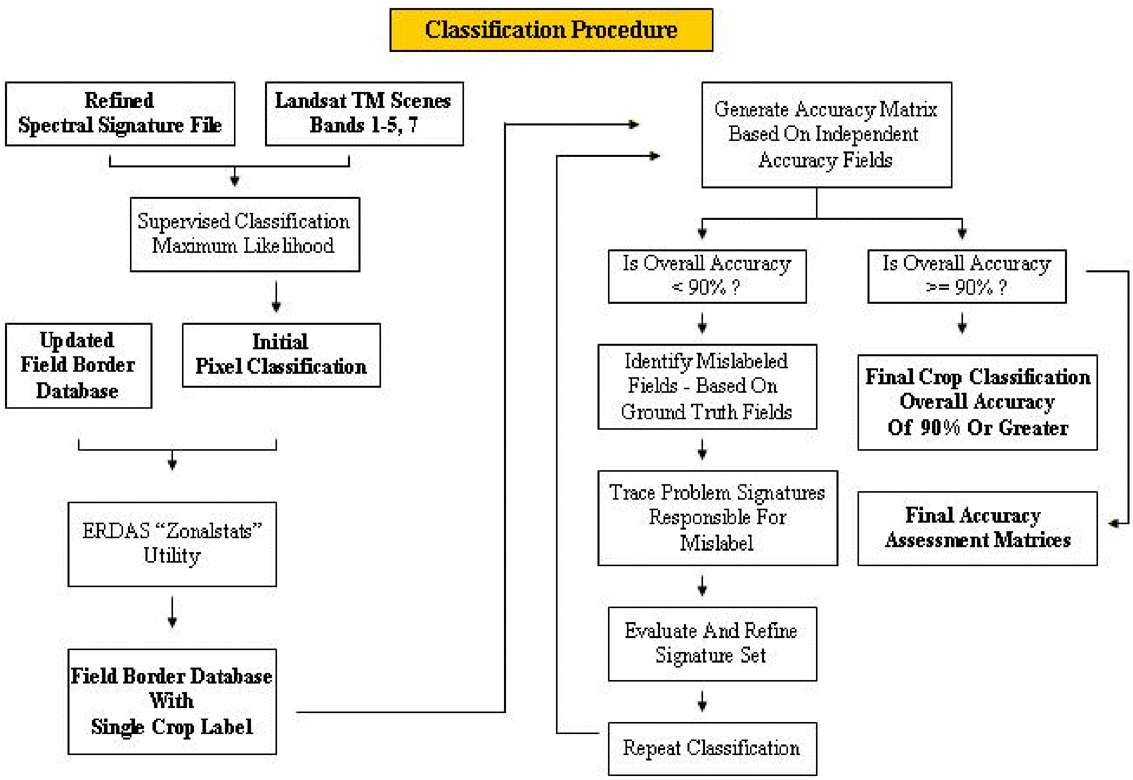

Figure 6.6 — LCRAS Crop Classification Flow Diagram, Classification Procedure.

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 the Southerly International Boundary (SIB), as discussed briefly in chapter 2. This underflow results from the application of water diverted from the Colorado River, which percolates to the groundwater table. Reclamation derives the contribution fractions from a particle tracking study performed by Reclamation's 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).

As discussed previously in this report, the Lower Colorado River Accounting System (LCRAS) is a water balance tool currently being tested to improve calculations of consumptive use for the decree accounting report[1]. Reclamation performs calculations of consumptive use for LCRAS based on 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 that 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 focuses on the fractions of water pumped from drainage wells and water that appears in drainage ditches, which originated from excess irrigation within the irrigation 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 groundwater not water diverted directly from the surface stream of the Colorado River. This groundwater pumped by Hillander "C" and the south Yuma Mesa wells is excess irrigation from applications of water diverted directly from the surface stream of the Colorado River which recharges the aquifer up gradient from Hillander "C" and the south Yuma Mesa wells.

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 contributed by each district that applies water diverted from the Colorado River at Imperial Dam.

Process to Identify the Fraction of the Underflow to Mexico at SIB That Comes From Excess Irrigation with Water Each District Diverted from the Colorado River at Imperial Dam

The goal of this process is to identify the fraction of the underflow to Mexico at SIB that comes from excess irrigation of water each district diverted from the Colorado River at Imperial Dam. This chapter refers 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 manner 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 refers to Hillander "C" and the south Yuma Mesa as dependent components.

The particle tracking study identifies and quantifies (in acre-feet) the components of the underflow to Mexico at SIB and identifies the pumping by the Hillander “C” and the south Yuma Mesa wells. Tables 9, 15, 16, and 17 of particle tracking study provide the data used in this assessment.

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.

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 doing the following:
   - 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).

This process described above 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.

At this time, Reclamation chooses not to use the particle tracking study to address the underflow to Mexico across the limitrophe section because the particle tracking study itself concludes 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 tables 7.2, 7.3, and 7.4.

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

This chapter provides background and rationale, and displays 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 for LCRAS using one of the following four methods:

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 2000 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 will add an estimate of the evapotranspiration by the vegetation that makes up the landscape to the domestic use calculated as the population multiplied by an annual per-capita domestic use factor of 0.14 acre-feet per capita, or
4. Other methods unique to the specific circumstances of an individual domestic diverter.

Deriving the 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],

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[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 consumptive use as defined by the 1964 U.S. Supreme Court decree in *Arizona* v *California* 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 a measured return flow, and an unmeasured return flow calculated from information supplied by the Colorado River Board of California.

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

Figure 8.1 shows the domestic consumptive use factors, from table 8.1, for each of the four cities and the Robert B. Griffith Water Project. As figure 8.1 shows, 0.6 appears to be a useable domestic consumptive use factor that falls near the average of the information available. Reclamation will continue to use a consumptive use factor of 0.6, or a similar value, until additional information becomes available to suggest a more appropriate value.

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.

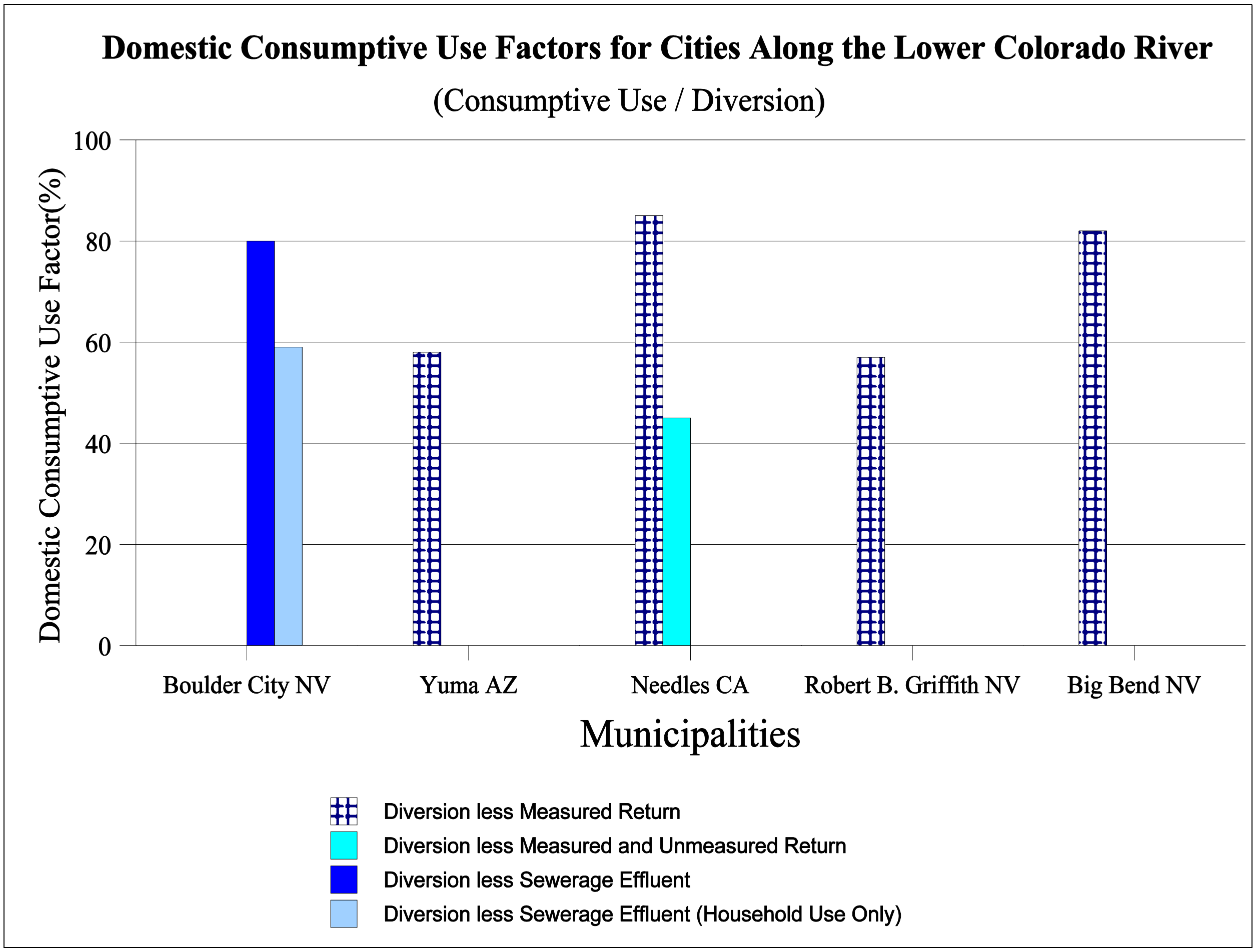

Figure 8.1 — Domestic Consumptive Use Factors for Cities with Measured Returns

Deriving Per-Capita Consumptive Use Factors

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 diversion from the surface stream of the Colorado River (no private wells), and from which all the domestic water returns to a sewer system (no septic tanks). Also, the population of Boulder City is not affected by large seasonal visitation as are 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 (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, which is not true of many communities along the lower Colorado River. To account for this, 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).

Estimating 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 for calendar years 1989-1992, with an average of 0.32 acre-feet per capita (table 8.2). These values do not include the water delivered to municipal parks and the golf course for turf irrigation but 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, and 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

Estimating 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 (when landscape irrigation is at or near minimum), and extrapolating the January water use rate for an entire year. This analysis yielded an annual household per-capita consumptive use of 0.14 acre-feet per capita. Reclamation will use this annual household per-capita consumptive use 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 show 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 (tables 8.3 and 8.4),
2. Approximate the annual amount of water delivered for household use with minimal landscape irrigation by multiplying 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 (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:	283.7	
Less Average January Municipal Landscape Use:	22.6	
Less Average January Waste Water:	106.7	
Equals Average January Household Consumptive Use:	154.4	(283.7 - 22.6 - 106.7)
Extrapolated Annual Household Consumptive Use Based On Average January Household Consumptive Use:	1852.8	(154.4 x 12)
Average Annual Diversion for Household Consumptive use:	3133.2	((283.7 - 22.6) x 12)
Average Annual Consumptive Use Factor for Household Use (dimensionless):	0.59	(1,852.8 ÷ 3,133.2)
Average Annual Per-Capita Household Consumptive Use(acre-feet per capita):	0.14	(1,852.8 ÷ 12,815)

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