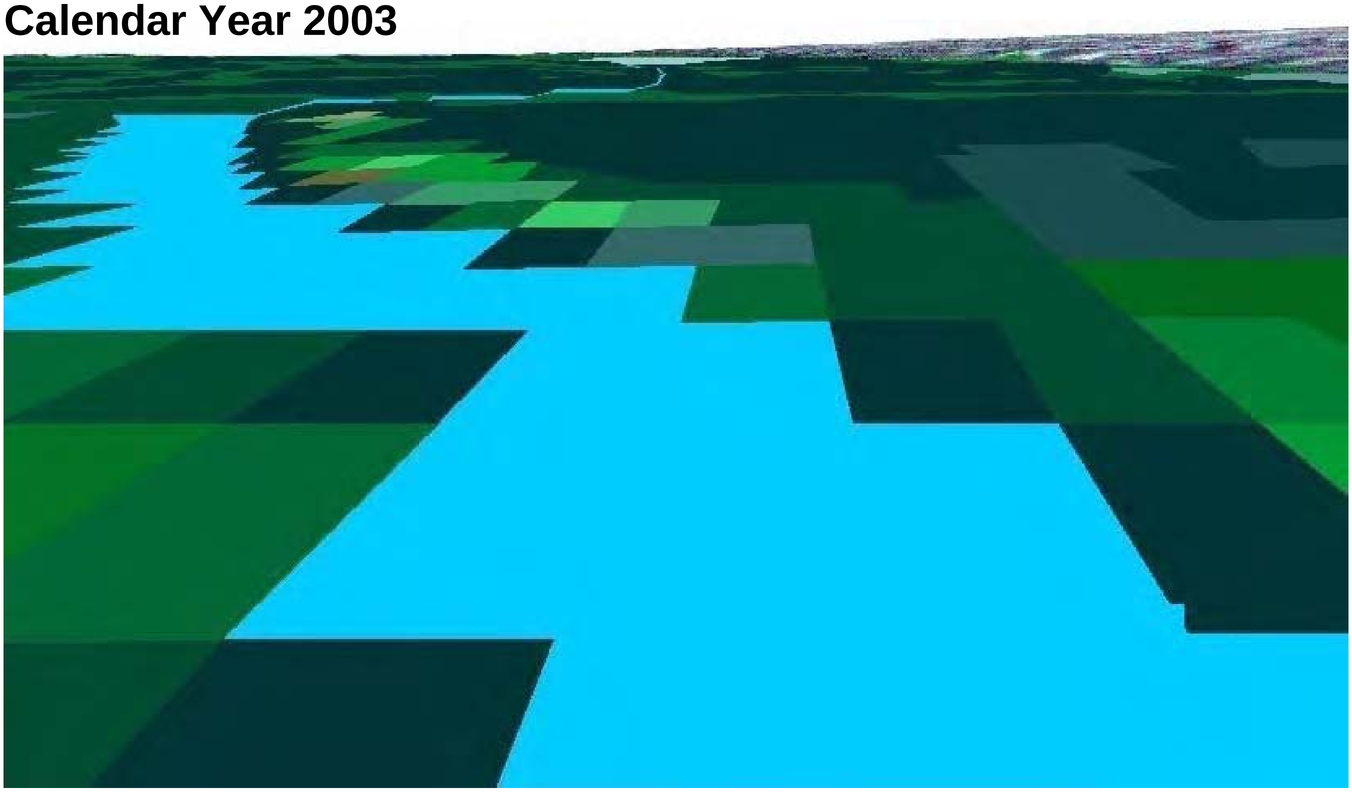
RECLAMATION
Managing Water in the West

Lower Colorado River Accounting System Evapotranspiration Calculations

Calendar Year 2003



U.S. Department of the Interior
Bureau of Reclamation

December 2004

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Calendar Year 2003

U.S. Department of the Interior
Bureau of Reclamation
Lower Colorado Regional Office
Boulder City, Nevada

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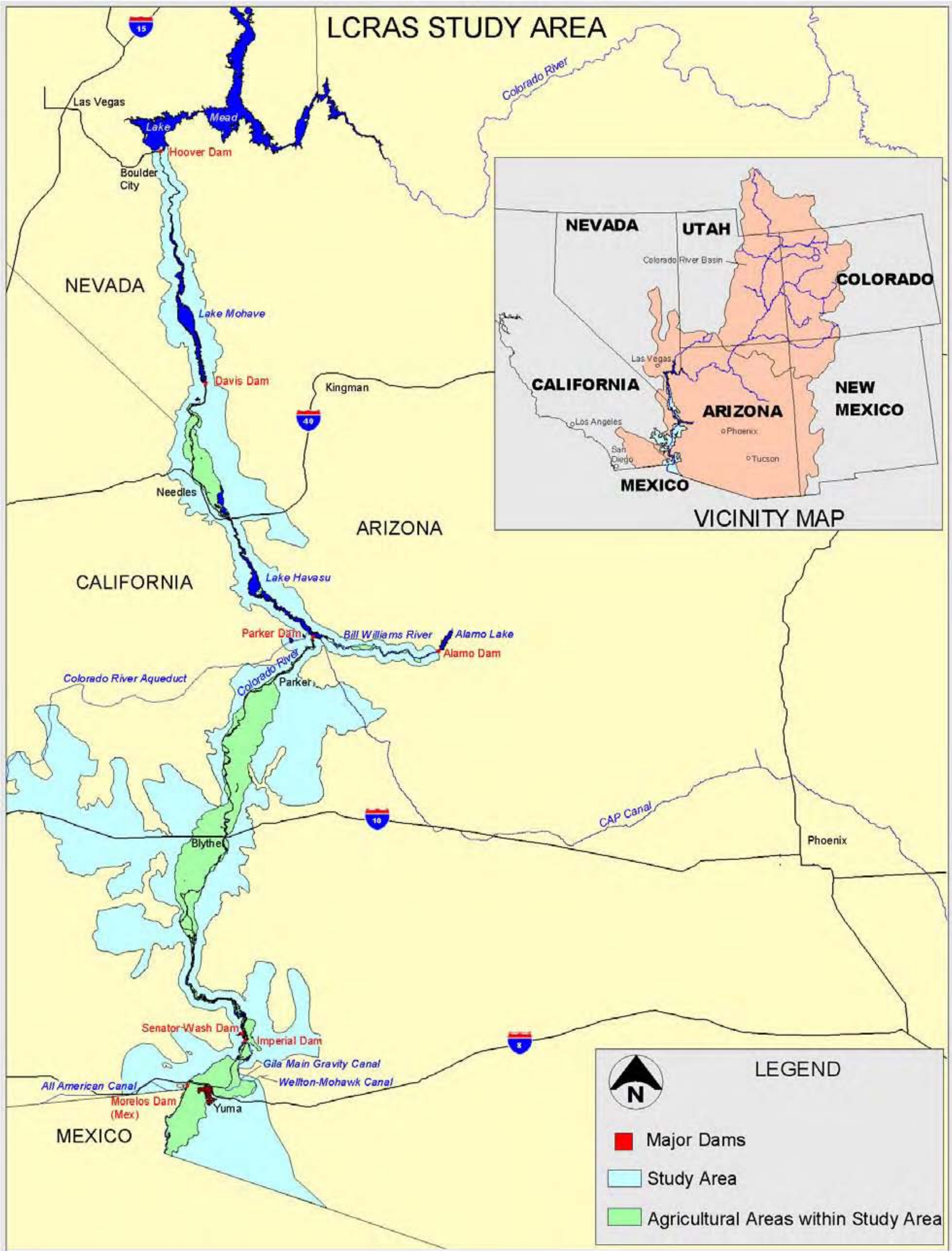
LCRAS STUDY AREA
Colorado River
Las Vegas
Lake
Mead
Hoover Dam
Boulder City
NEVADA
Lake Mohave
Davis Dam
Kingman
Needles
ARIZONA
CALIFORNIA
Lake Havasu
Parker Dam
Bill Williams River
Alamo Lake
Alamo Dam
Colorado River Aqueduct
Colorado River
Parker
CAP Canal
Blythe
Phoenix
Senator Wash Dam
Imperial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

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Introduction

The lower Colorado River is the principal source of water for irrigation and domestic use in Arizona, southern California, and southern Nevada. Reclamation must understand the disposition of water once it is released from Hoover Dam in order to effectively manage the lower Colorado River. The Lower Colorado River Accounting System (LCRAS) provides the following information for Reclamation to use as water management tools:

1. estimates of evapotranspiration (ET) from irrigated areas for monitoring of agricultural water use;
2. estimates of ET from riparian vegetation for environmental resources assessment and management; and
3. estimates of evaporation from the channel and reservoirs of the lower Colorado River for river system resource assessment and management.

Reclamation uses these tools to monitor the current state of the river system and the potential impacts of changes to the river system, and as inputs to management decisions involving the administration of the laws, compacts, and U.S. Supreme Court decree which govern the operation of the lower Colorado River.

Results

Table 1 shows the riparian vegetation and agricultural ET for each water user along the lower Colorado River between Davis Dam and Mexico, and along the Bill Williams River from Alamo Dam to Lake Havasu for calendar year 2003. Agricultural ET is the ET from crops (crop ET) plus evaporation losses from major delivery canals used to transport the water from the river to the irrigated fields. Detailed calculations and values used to develop the results presented in Table 1 can be found in, "Lower Colorado River Accounting System Appendix: Part 1, Evapotranspiration-Rate Calculations, and Part 2, Evapotranspiration Calculations" for calendar year 2003.

Table 1 — Riparian Vegetation and Crop ET by Water User

Diverter Name	Riparian Vegetation ET	Agricultural ET
Nevada		
Lake Mead National Recreation Area	97	0
Fort Mojave Indian Reservation	5,629	1,838
State of Nevada[1]	10,219	0
Nevada Totals	15,945	1,838

[1] Includes all agricultural water use not identified with a known diverter boundary.

Table 1 — Riparian Vegetation and Crop ET by Water User		
Diverter Name	Riparian Vegetation ET	Agricultural ET
California		
Chemehuevi Indian Reservation	41	76
Fort Mohave Indian Reservation	4,884	12,948
Havasu National Wildlife Refuge	5,962	298
Moabi Park	222	0
Bernal Farm	1,209	0
Cibola National Wildlife Refuge	19,469	0
Clark Farm	131	602
Colorado River Indian Reservation	34,648	0
Imperial National Wildlife Refuge (Parker Dam to Imperial Dam)	22,855	0
Imperial National Wildlife Refuge (Imperial Dam to Mexico)	41	0
Imperial National Wildlife Refuge and Yuma Proving Ground	53	0
North Lyn-De Farm[4]	1	809
Palo Verde Irrigation District, CA.	8,470	367,813
Palo Verde Irrigation District, AZ.	571	638
Picacho State Recreation Area (Parker Dam to Imperial Dam)	5,083	0
Picacho State Recreation Area (Imperial Dam to Mexico)	1,105	0
South Lyn-De Farm	2	557
Fort Yuma Indian Reservation	12,361	4,027
Fort Yuma Indian Reservation, Indian Unit	1,421	16,825
Fort Yuma Indian Reservation, Bard Unit	882	22,754
Fort Yuma Indian Reservation and Picacho State Recreation Area	1,421	0
Fort Yuma Indian Reservation and Yuma Proving Ground	877	0
Yuma Proving Ground	8,669	41
State of California (Other uses, Davis Dam to Parker Dam)	19,443	298
State of California (Other uses, Parker Dam to Imperial Dam)	28,783	985
State of California (Other uses Imperial Dam to Mexico)	2,773	6,249
California Totals	181,377	434,920
Arizona		
Lake Mead National Recreation Area (Davis Dam to Parker Dam)	355	0
Fort Mojave Indian Reservation	32,470	37,719
Havasu National Wildlife Refuge	49,259	0
Havasu State Park (Windsor Beach)	3,458	0
Mohave Valley Irrigation and Drainage District	31,535	21,429
Arkelian Farms	2,512	0
Bill Williams National Wildlife Refuge (Bill Williams River)	10,638	0

[4] A portion of North Lyn-De farm is within Colorado River Indian Reservation diverter boundary.

Table 1 — Riparian Vegetation and Crop ET by Water User		
Diverter Name	Riparian Vegetation ET	Agricultural ET
Bill Williams River (Alamo Dam to Bill Williams National Wildlife Refuge)	24,444	2,677
Cibola Valley Irrigation and Drainage District	7,728	14,095
Cibola National Wildlife Refuge	47,326	7,534
Colorado River Indian Reservation	136,924	335,719
Ehrenberg Farm	0	2,376
Imperial National Wildlife Refuge (Parker Dam to Imperial Dam)	35,586	0
Imperial National Wildlife Refuge (Imperial Dam to Mexico)	6,297	210
Fort Yuma Indian Reservation and Homesteads	3,066	1,236
Fort Yuma Indian Reservation, Mittry Lake State Wildlife Area and Yuma Proving Ground	907	0
Hillander "C" Irrigation District	0	7,098
Mittry Lake State Wildlife Area	10,612	150
North Cocopah Indian Reservation	767	674
West Cocopah Indian Reservation	6,514	5,438
North Gila Valley Irrigation District	2,105	20,045
Sturges Gila Monster Ranch	849	5,923
Unit "B" Irrigation and Drainage District	0	6,334
University of Arizona Agricultural Station	0	185
Yuma Irrigation District	1,109	31,464
Yuma Mesa Irrigation and Drainage District	0	68,152
Yuma Proving Ground	656	0
Yuma County Water Users Association	11	130,789
State of Arizona (Other users, Davis Dam to Parker Dam)	3,751	0
State of Arizona (Other users, Parker Dam to Imperial Dam)	22,548	0
State of Arizona (Other users, Imperial Dam to Mexico)	13,605	08,743
State of Arizona – Limitrophe Section	4,717	2,401
State of Arizona – Down gradient of the Yuma Mesa Irrigation and Drainage District	0	35,217
Arizona Totals	459,749	745,608
Davis Dam to Mexico (including Bill Williams below Alamo Dam)Totals	657,071	1,182,366

Table 2 provides a Summary of ET and evaporation results along the lower Colorado River from Davis Dam to Mexico, and the for the Bill Williams River from Alamo Dam to Lake Havasu (included in Davis Dam to Parker Dam).

Table 2 — Summary of ET and Evaporation Results				
ET Category/Evaporation	Davis Dam to Parker Dam	Parker Dam to Imperial Dam	Imperial Dam to Mexico	Davis Dam to Mexico
Agricultural ET	77,283	731,128	373,955	1,182,366
Riparian Vegetation ET	202,407	373,846	80,818	657,071
Evaporation (river channel and reservoirs)	108,745	66,698	9,312	184,755

Key LCRAS ET Components

The key components of LCRAS ET calculations are these:

1. identifying crop and riparian vegetation groups, and open-water areas;
2. calculating ET for crop groups and riparian vegetation groups; and
3. calculating evaporation from open-water areas (the channel and reservoirs of the lower Colorado River, and evaporation from major delivery canals).

The following sections present a description of the key components of LCRAS ET calculations.

Identifying Crop Groups, Riparian Vegetation Groups, and Open-Water Areas

This section provides an overview of the image classification processes and Geographic Information Systems (GIS) technologies Reclamation used to identify and map crop and riparian vegetation groups, and open-water areas along the lower Colorado River below Davis Dam and along the Bill Williams River below Alamo Dam in calendar year 2003.

Overview

Remote sensing is the process of acquiring information 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 assignment of objects, features or areas based upon their appearance, using image processing programs in digital satellite imagery. Reclamation uses these techniques with GIS technologies, to determine the location and acreages of crop groups, riparian vegetation groups, and open-water areas along the lower Colorado River from Davis Dam to Mexico and along the Bill Williams River from Alamo Dam to Lake Havasu on the Colorado River. This procedure is also referred to as 'mapping' in this report. The spatial extent (location and area of coverage) of the crop groups, riparian vegetation groups, and open-water areas are stored in digital spatial databases collectively referred to as a GIS database. Reclamation uses the data generated from these processes to accurately calculate ET from crops and riparian vegetation, and evaporation from open-water areas.

When remote sensing processes are insufficient to map crop and riparian vegetation groups, or open-water areas, data collected on the ground (ground reference surveys) is also used. For example, orchards are mapped from ground survey data due to the difficulty of correctly identifying those features using remote sensing processes alone. Once the data is entered into a GIS database, programs are used to calculate the number of acres of each crop group and riparian vegetation group for each diverter, as well as the open-water areas. Acreage calculations are completed for areas located within the flood plain along the mainstream of the lower Colorado River from Davis Dam to Mexico, cropped areas upon the Palo Verde and Yuma Mesas, and for areas along the Bill Williams River from Alamo Dam to Lake Havasu.

Once Reclamation maps the crop and riparian vegetation groups, and open-water areas (discussed in the following sections), Reclamation calculates the ET from crops and riparian vegetation for each diverter and evaporation from open-water areas. Currently, this analysis does not include estimates of ET within the boundaries of domestic (non-agricultural) water users.

Collecting and Analyzing Remotely-Sensed Data

Satellite imagery is acquired by Thematic Mapper (TM) sensors mounted on the Landsat 5 and Landsat 7 satellites and sensors mounted on the Indian Remote Sensing (IRS) 1-C or 1-D satellites. For its analysis, Reclamation selects satellite images that adequately cover the study area, are cloud-free, and capture the variation in crop planting practices during the year. Table 3 shows the dates for which Reclamation purchased TM image data for analysis during calendar year 2003. Path and row designations refer to image locations based on the World Reference System[1].

[1] 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 3 — TM Image path-row designations and acquisition dates used in calendar year 2003	
Path-Row Designation	Acquisition Date
Path 38, rows 36 and 37	January 29, 2003
Path 38, row 37	March 02, 2003
Path 38, rows 36 and 37	May 05, 2003
Path 38, rows 36 and 37	July 16, 2003
Path 38, rows 36 and 37	November 21, 2003
Path 39, row 36	May 04, 2003
Path 39, row 36	July 07, 2003

Collecting Ground Reference Data

Correctly identifying and mapping crop and riparian vegetation groups using remotely-sensed data requires a thorough understanding of the spectral characteristics of vegetation types for representative (ground reference survey) sites throughout the study area. The term "spectral characteristics" refers to the amount of spectral reflectance from the Earth's surface recorded by the satellite sensors in different portions of the electromagnetic spectrum (ERDAS, 1999) for different vegetative types (i.e. crop types or riparian vegetation types). TM satellite image data contain digital values that represent the spectral reflectance values of these crop and riparian vegetation groups. Reclamation analyzes these digital values within ground reference survey sites to generate spectral statistics, or signatures (ERDAS, 1999) for specific crop and riparian vegetation groups.

Reclamation collects ground reference survey 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 survey data for image classification processing (to identify crop groups) and the remaining 35 to 40 percent to assess the accuracy of the image classifications. Reclamation selects ground reference survey sites in each major irrigated area along the mainstream of the lower Colorado River from Davis Dam to Mexico. To provide a statistically valid data set for image classification procedures, Reclamation selects irrigated fields randomly from a GIS database and adds additional fields to the random sample, where necessary, to ensure representation of all major crop groups. This sample is also stratified based upon an analysis of agricultural field size. The variability in planting and harvesting times for each crop group is a critical factor in selecting optimum image dates.

Reclamation purchases satellite images five times a year, and collects ground reference survey data four times a year to coincide with four of the image acquisition dates. Table 4 shows the crop groups sampled in calendar year 2003.

Table 4 — Crop groups sampled in calendar year 2003

Alfalfa	**Melons –** Spring and Fall (Watermelon, Honeydew, Cantaloupe, Squash, Strawberries)	**Tomatoes**	**Small Vegetables** (Carrots, Cilantro, Celery, Garlic, Dry Onions, Onions, Parsley, Radishes, Commercial flowers)
Cotton	**Grapes**	**Sudan** (includes Klein Grass, Timothy Grass, Sunflower, Sesbania)	**Root Vegetables** (Table Beets, Parsnip, Turnip and Rutabaga)
Small Grain (Oats, Rye, Barley, Millet, Wheat)	**Grass** (Bermuda, Bermuda with Rye, Clover)	**Legume and Solanum Vegetables** (Green, Dry and Garbanzo Beans; Peas, Peanuts, Fresh Peppers, Potatoes)	**Perennial Vegetables** (Artichoke, Asparagus, Guayule)
Field Grain (Field Corn, Sorghum, Milo)	**Citrus** (Young, mature, Declining)	**Crucifers** (Broccoli, Cauliflower, Cabbage, Bok-Choy, Mustard, Kale, Okra)	**Sugar Beets**
Lettuce - Spring and Fall (Head, Leaf [Red], Leaf [Green], Spinach, other)	**Idle** (Fields currently not in production, includes bare cultivated soil)	**Dates**	**Fallow**
Cane/Bamboo	**Jojoba Beans**	**Safflower**	**Moist Soil Unit**[2]
Miscellaneous Herbs (Anise, Mint, other)	**Nursery or Greenhouse** (Citrus Nursery, Native Nursery, Greenhouse, Other Nursery)	**Deciduous Orchards** (Pecans, Peaches, Almonds, Irrigated Native orchard)	**Seasonal Wetland**[3]
Rice			**Open Water** (Fish Pond, Duck Pond, Off-Stream Lake or Reservoir)

Table 5 shows how Reclamation groups riparian vegetation types.

[2] An area gradually flooded in winter to develop migratory waterfowl forage and not irrigated in summer.

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

Table 5 — Riparian Vegetation 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 riparian vegetation

Delineating 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 Davis Dam to Mexico and along the Bill Williams River from Alamo Dam to Lake Havasu (field border database). Reclamation has linked all ground reference survey data collected for image classification to this field border database. Reclamation originally created the GIS field border database by digitizing field boundaries using 10-meter Systemme Pour l’Observation de la Terre (SPOT) satellite image data as a reference. This imagery was acquired in June and August of 1992. 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 a real-world coordinate system and then are displayed or analyzed within the computer environment.

Since 1995, Reclamation has updated changes in field borders on the basis of ground reference survey data collected throughout the year. Reclamation also uses 5-meter Indian Remote Sensing (IRS) satellite images (1-C or 1-D sensors) to update field borders in areas where ground reference survey data show significant changes in field border locations. Reclamation will continue to use these two methods to update field borders.

Delineated cropped areas include all areas known by Reclamation to divert or pump water along the mainstream of the lower Colorado River from Davis Dam to Mexico, and irrigated areas along the Bill Williams River from Alamo Dam to Lake Havasu. Exhibits 1 through 8 show these areas. Exhibit 9 is an example of digitized field borders; Exhibit 10 shows an overview of the diverter boundaries; and Exhibit 11 shows the Bill Williams River from Alamo Dam to Lake Havasu. Using the analysis of remotely-sensed data, discussed previously, in conjunction with the GIS field border database, Reclamation identified the crop groups (Table 4) which were grown in each agricultural field throughout the calendar year. Post-classification accuracy assessment shows that, overall, the crop groups were mapped with an average accuracy of greater than 90 percent for each of the five image classification dates used in 2003.

Delineating Riparian Vegetation Areas

Reclamation updates riparian vegetation areas by comparing the current year Landsat TM summer 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 riparian vegetation database. Reclamation compared images from July 21, 2002, to images from July 16, 2003, to update riparian vegetation areas for calendar year 2003.

Delineating Open-Water Areas

Open water of the mainstream

An open-water GIS database contains the spatial boundaries of open-water surfaces such as reservoirs, rivers, and canals. Reclamation initially developed an open-water GIS database for calendar year 2000 and has updated this database annually using change detection techniques (described previously). For calendar year 2003, Reclamation compared TM satellite images acquired on July 16 and November 21, 2003, to the calendar year 2002 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. This analysis found no significant changes in open-water acreage between calendar years 2003 and 2002.

Open water in major delivery canals

LCRAS calculates evaporation from major canals that serve districts and Indian reservations. Reclamation initially identified bank-to-bank canal area (in acres) by digitizing canal banks using 5 meter IRS panchromatic satellite imagery as a reference for calendar year 2000. This information was added to the open-water GIS database. From this, Reclamation calculated the acreage of open water within each canal. This information is updated annually. For calendar year 2003, Reclamation compared July 16, 2003, 30-meter TM imagery to the open-water

LOWER COLORADO RIVER ACCOUNTING SYSTEM
MAP INDEX

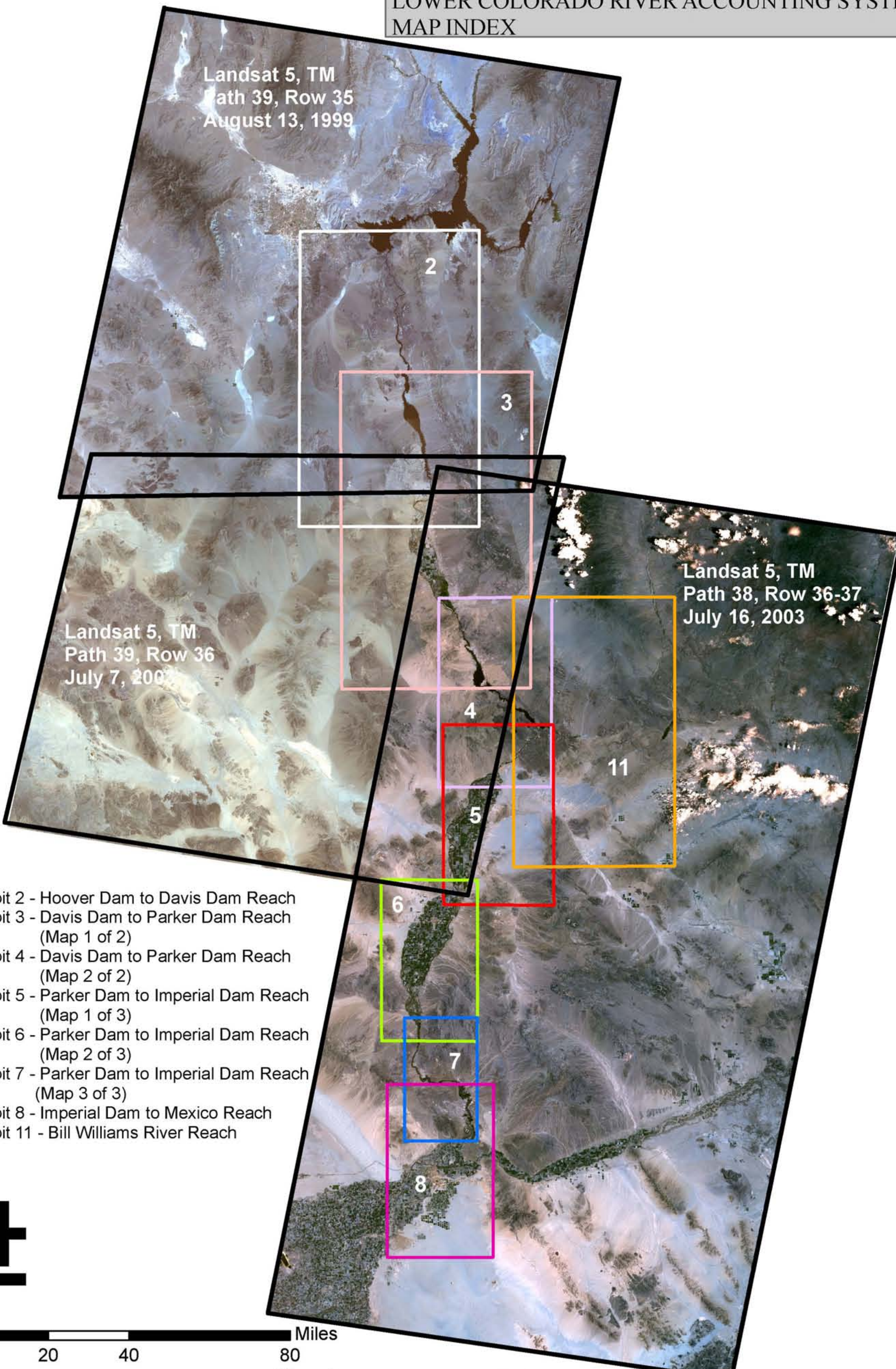
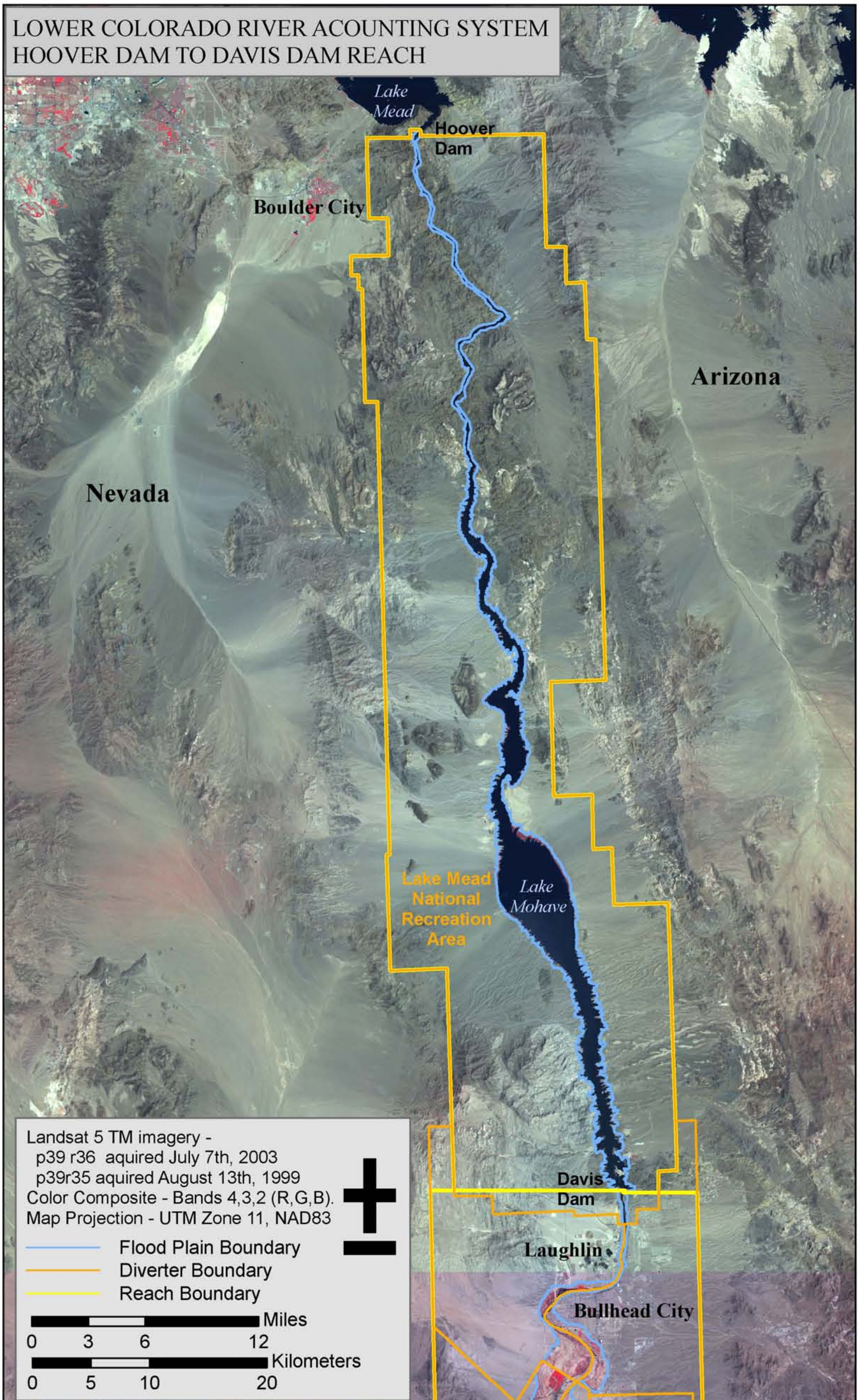


Exhibit 2 - Hoover Dam to Davis Dam Reach
Exhibit 3 - Davis Dam to Parker Dam Reach (Map 1 of 2)
Exhibit 4 - Davis Dam to Parker Dam Reach (Map 2 of 2)
Exhibit 5 - Parker Dam to Imperial Dam Reach (Map 1 of 3)
Exhibit 6 - Parker Dam to Imperial Dam Reach (Map 2 of 3)
Exhibit 7 - Parker Dam to Imperial Dam Reach (Map 3 of 3)
Exhibit 8 - Imperial Dam to Mexico Reach
Exhibit 11 - Bill Williams River Reach

Miles: 0 20 40 80

Kilometers: 0 30 60 120

Exhibit 1



LOWER COLORADO RIVER ACOUNTING SYSTEM
HOOVER DAM TO DAVIS DAM REACH
Lake Mead
Hoover Dam
Boulder City
Arizona
Nevada
Lake Mead National Recreation Area
Lake Mohave
Davis Dam
Laughlin
Bullhead City
Landsat 5 TM imagery -
p39 r36 aquired July 7th, 2003
p39r35 aquired August 13th, 1999
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM Zone 11, NAD83
Flood Plain Boundary
Diverter Boundary
Reach Boundary
Miles
0 3 6 12
Kilometers
0 5 10 20

Exhibit 2

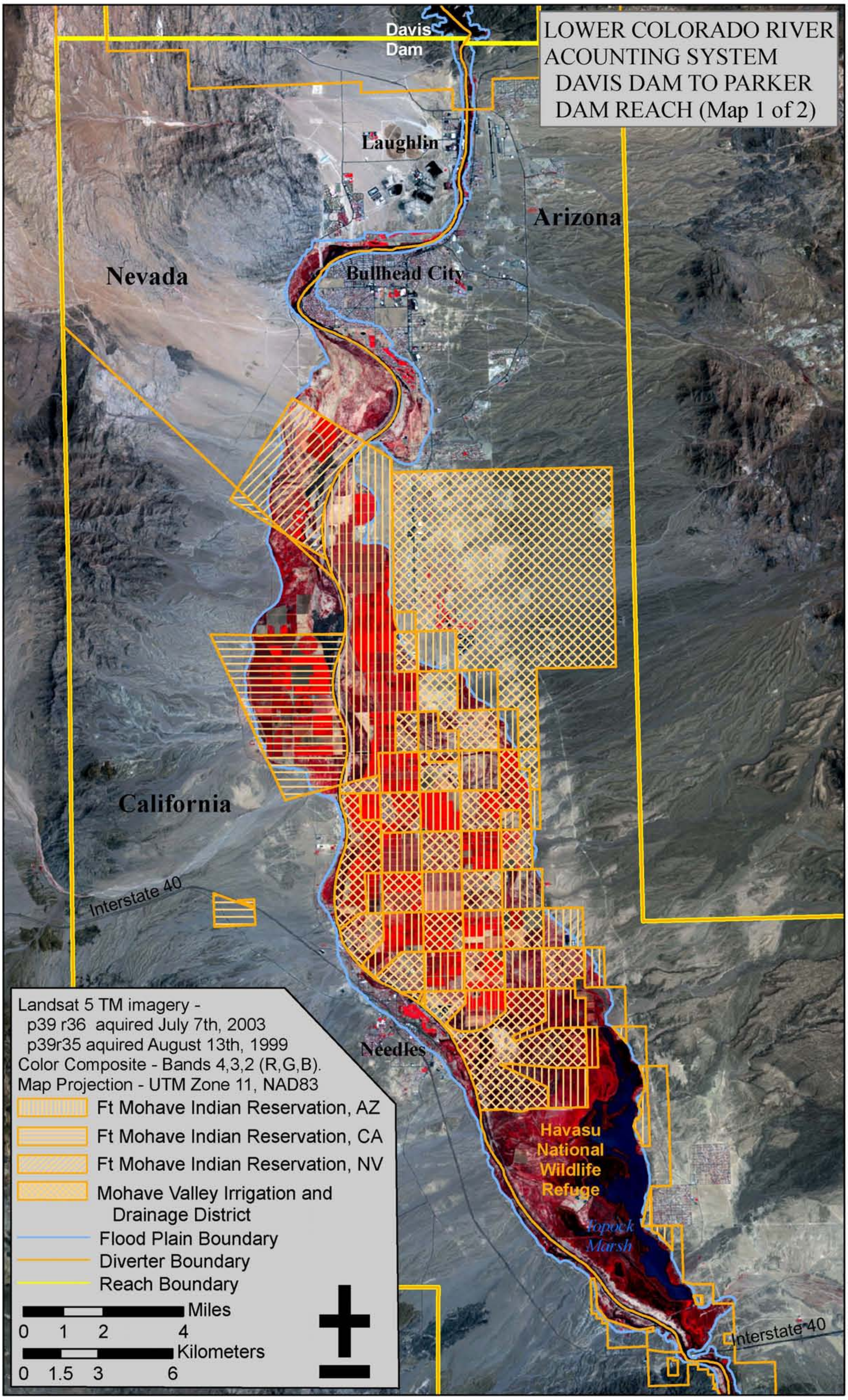
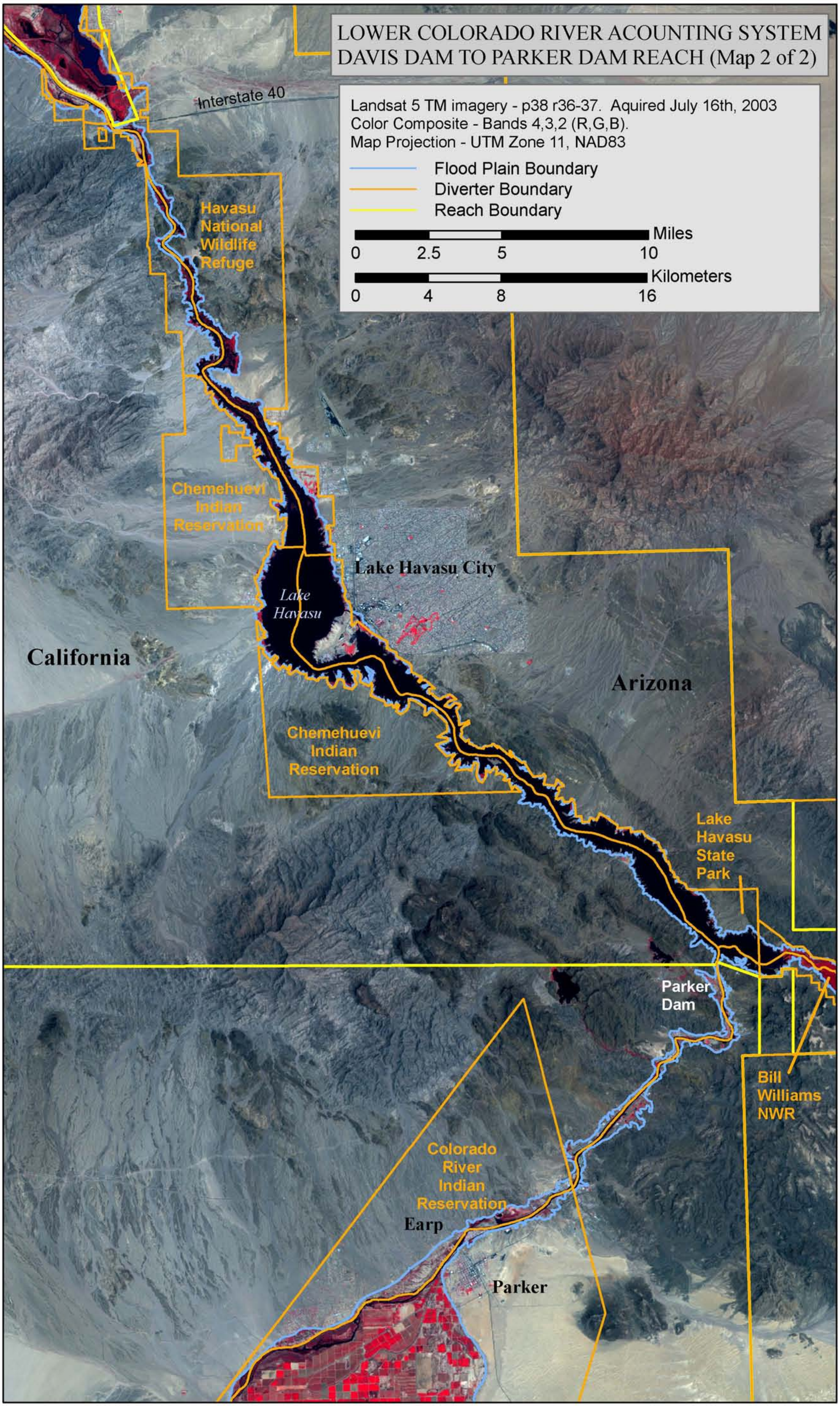

LOWER COLORADO RIVER
ACOUNTING SYSTEM
DAVIS DAM TO PARKER
DAM REACH (Map 1 of 2)
Davis
Dam
Laughlin
Arizona
Nevada
Bullhead City
California
Interstate 40
Needles
Havasu
National
Wildlife
Refuge
Topock
Marsh
Interstate 40
Landsat 5 TM imagery -
p39 r36 aquired July 7th, 2003
p39r35 aquired August 13th, 1999
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM Zone 11, NAD83
Ft Mohave Indian Reservation, AZ
Ft Mohave Indian Reservation, CA
Ft Mohave Indian Reservation, NV
Mohave Valley Irrigation and
Drainage District
Flood Plain Boundary
Diverter Boundary
Reach Boundary
Miles
0 1 2 4
Kilometers
0 1.5 3 6

Exhibit 3



LOWER COLORADO RIVER ACOUNTING SYSTEM
DAVIS DAM TO PARKER DAM REACH (Map 2 of 2)
Landsat 5 TM imagery - p38 r36-37. Aquired July 16th, 2003
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM Zone 11, NAD83
Flood Plain Boundary
Diverter Boundary
Reach Boundary
Miles
0 2.5 5 10
Kilometers
0 4 8 16
Interstate 40
Havasu National Wildlife Refuge
Chemehuevi Indian Reservation
Lake Havasu City
Lake Havasu
California
Arizona
Chemehuevi Indian Reservation
Lake Havasu State Park
Parker Dam
Bill Williams NWR
Colorado River Indian Reservation
Earp
Parker

Exhibit 4

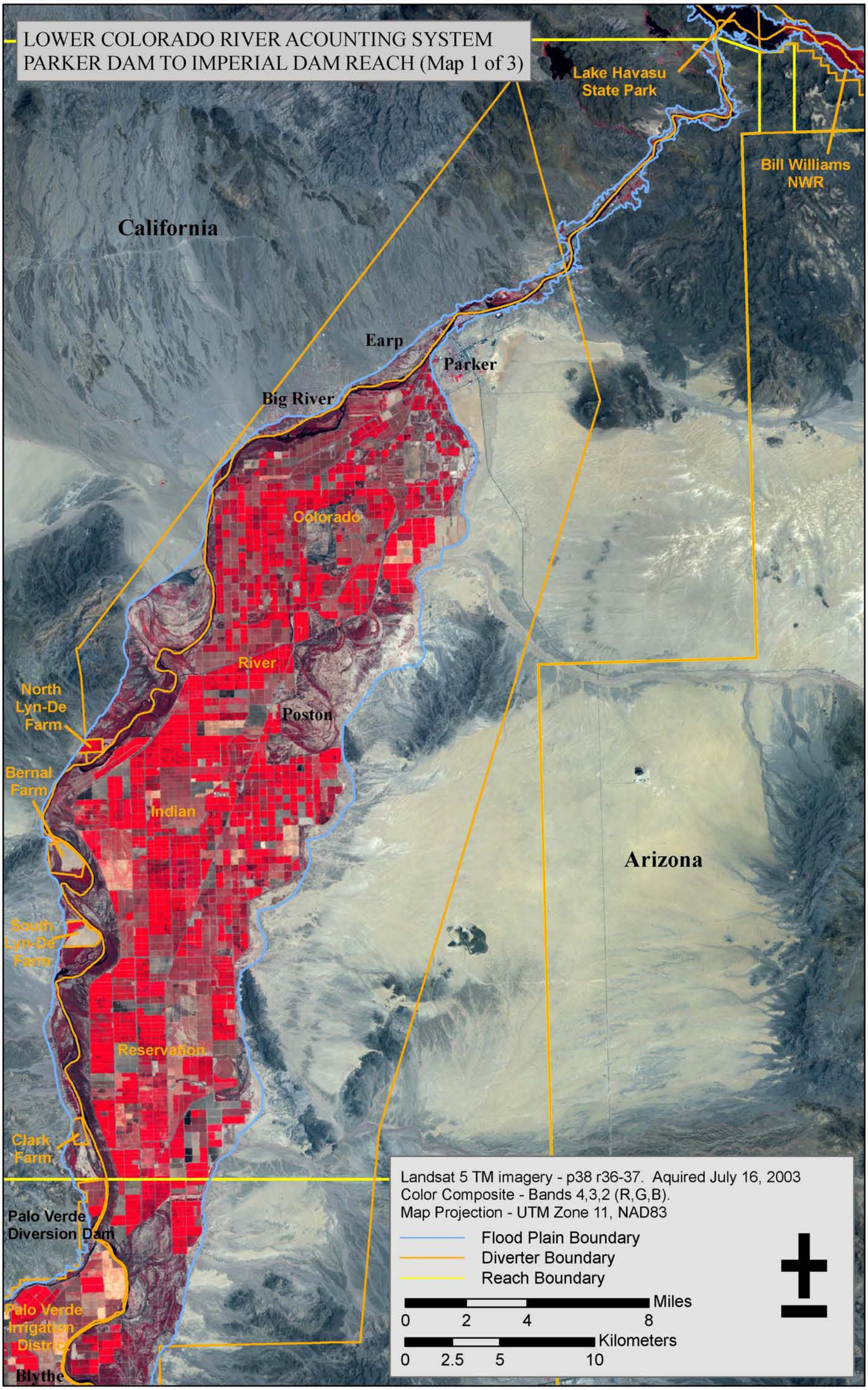

LOWER COLORADO RIVER ACOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 1 of 3)
Lake Havasu
State Park
Bill Williams
NWR
California
Earp
Parker
Big River
Colorado
River
North
Lyn-De
Farm
Poston
Bernal
Farm
Indian
Arizona
South
Lyn-De
Farm
Reservation
Clark
Farm
Palo Verde
Diversion Dam
Palo Verde
Irrigation
District
Blythe
Landsat 5 TM imagery - p38 r36-37. Aquired July 16, 2003
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM Zone 11, NAD83
Flood Plain Boundary
Diverter Boundary
Reach Boundary
Miles
0 2 4 8
Kilometers
0 2.5 5 10

Exhibit 5

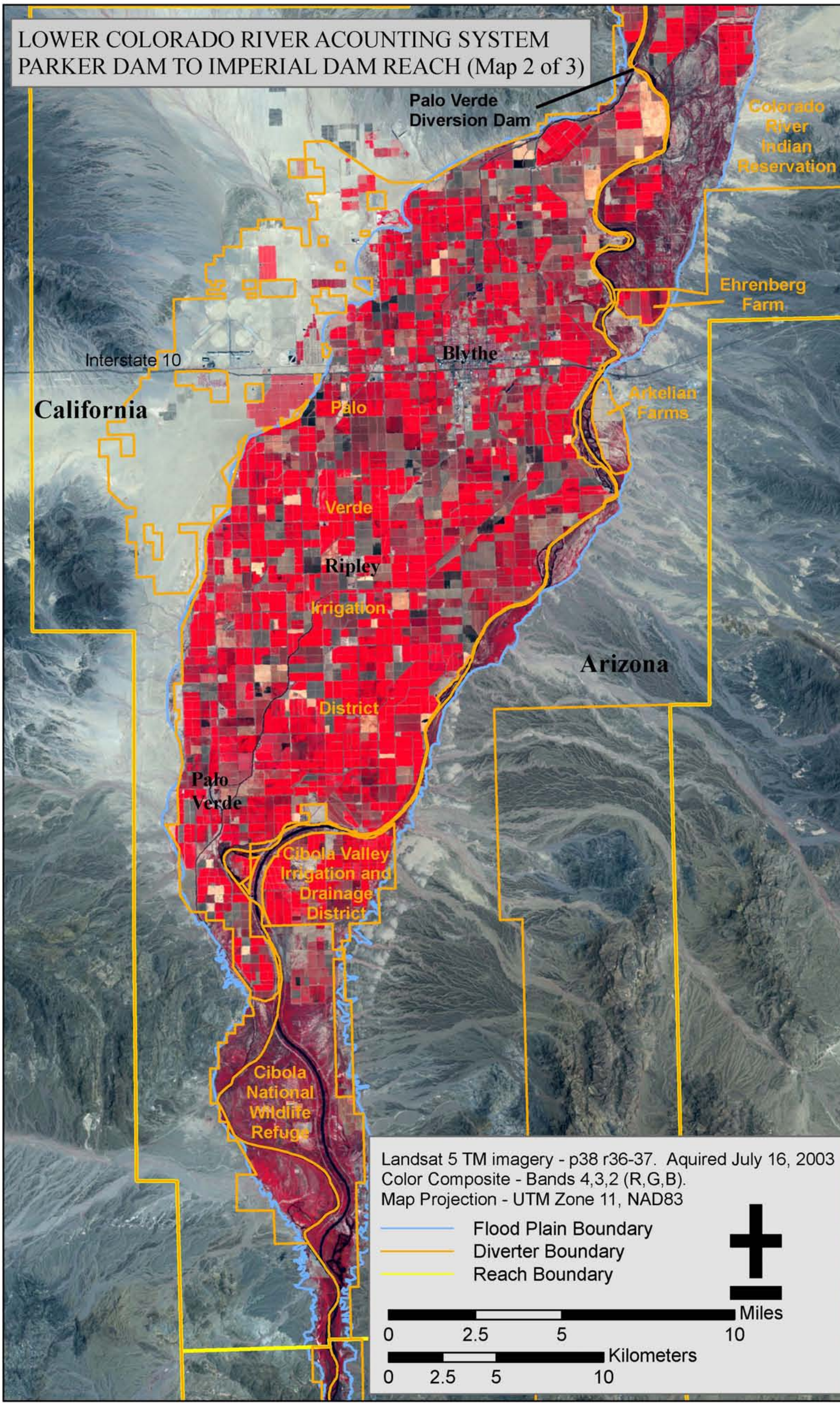
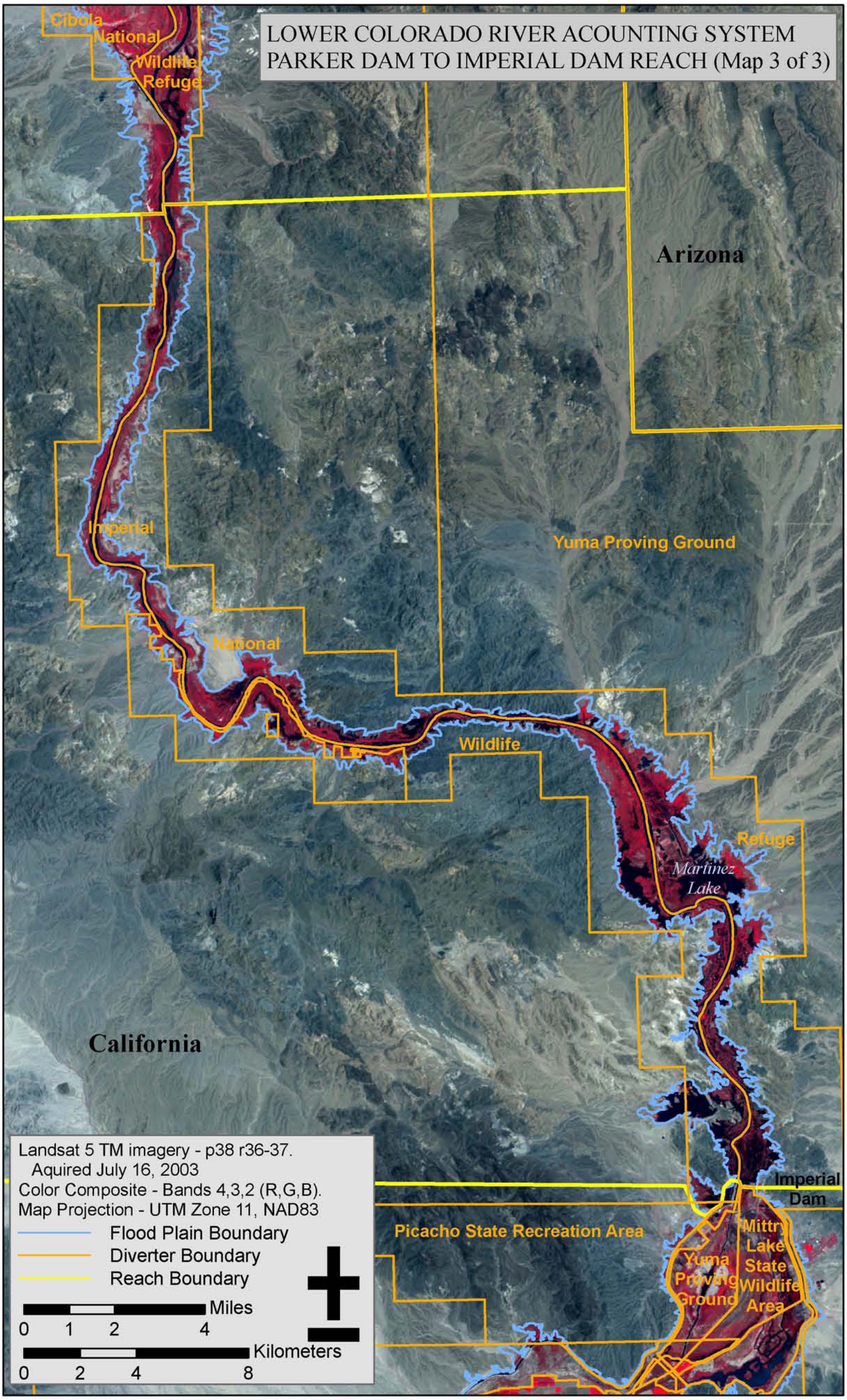

LOWER COLORADO RIVER ACOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 2 of 3)
Palo Verde Diversion Dam
Colorado River Indian Reservation
Ehrenberg Farm
Interstate 10
Blythe
California
Palo Verde Irrigation District
Arkelian Farms
Ripley
Arizona
Palo Verde
Cibola Valley Irrigation and Drainage District
Cibola National Wildlife Refuge
Landsat 5 TM imagery - p38 r36-37. Aquired July 16, 2003
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM Zone 11, NAD83
Flood Plain Boundary
Diverter Boundary
Reach Boundary
Miles
0 2.5 5 10
Kilometers
0 2.5 5 10

Exhibit 6



LOWER COLORADO RIVER ACOUNTING SYSTEM
PARKER DAM TO IMPERIAL DAM REACH (Map 3 of 3)
Cibola
National
Wildlife
Refuge
Arizona
Imperial
National
Wildlife
Refuge
Yuma Proving Ground
Martinez
Lake
California
Imperial
Dam
Picacho State Recreation Area
Yuma
Proving
Ground
Mittry
Lake
State
Wildlife
Area
Landsat 5 TM imagery - p38 r36-37.
Aquired July 16, 2003
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM Zone 11, NAD83
Flood Plain Boundary
Diverter Boundary
Reach Boundary
Miles
0 1 2 4
Kilometers
0 2 4 8

Exhibit 7

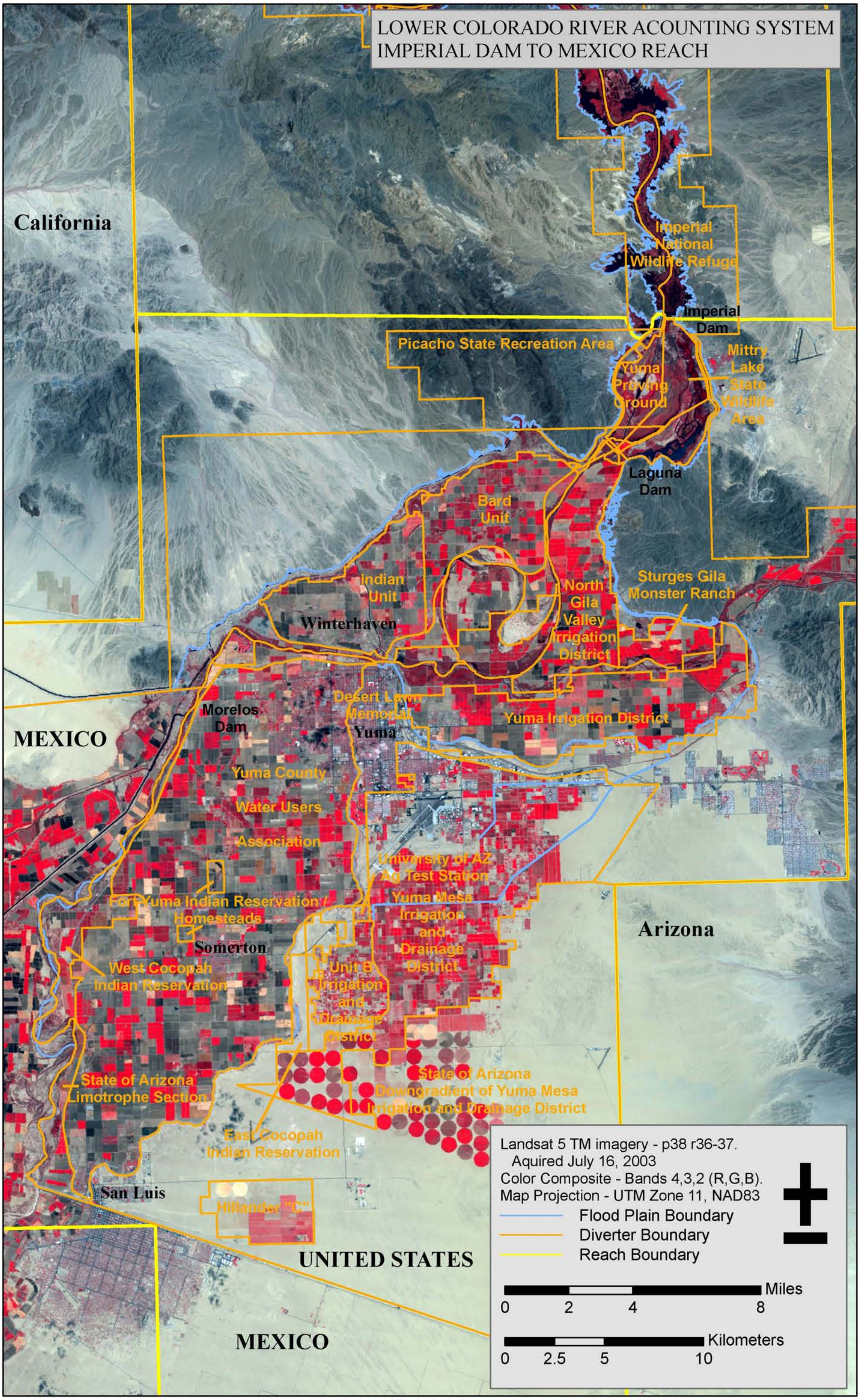
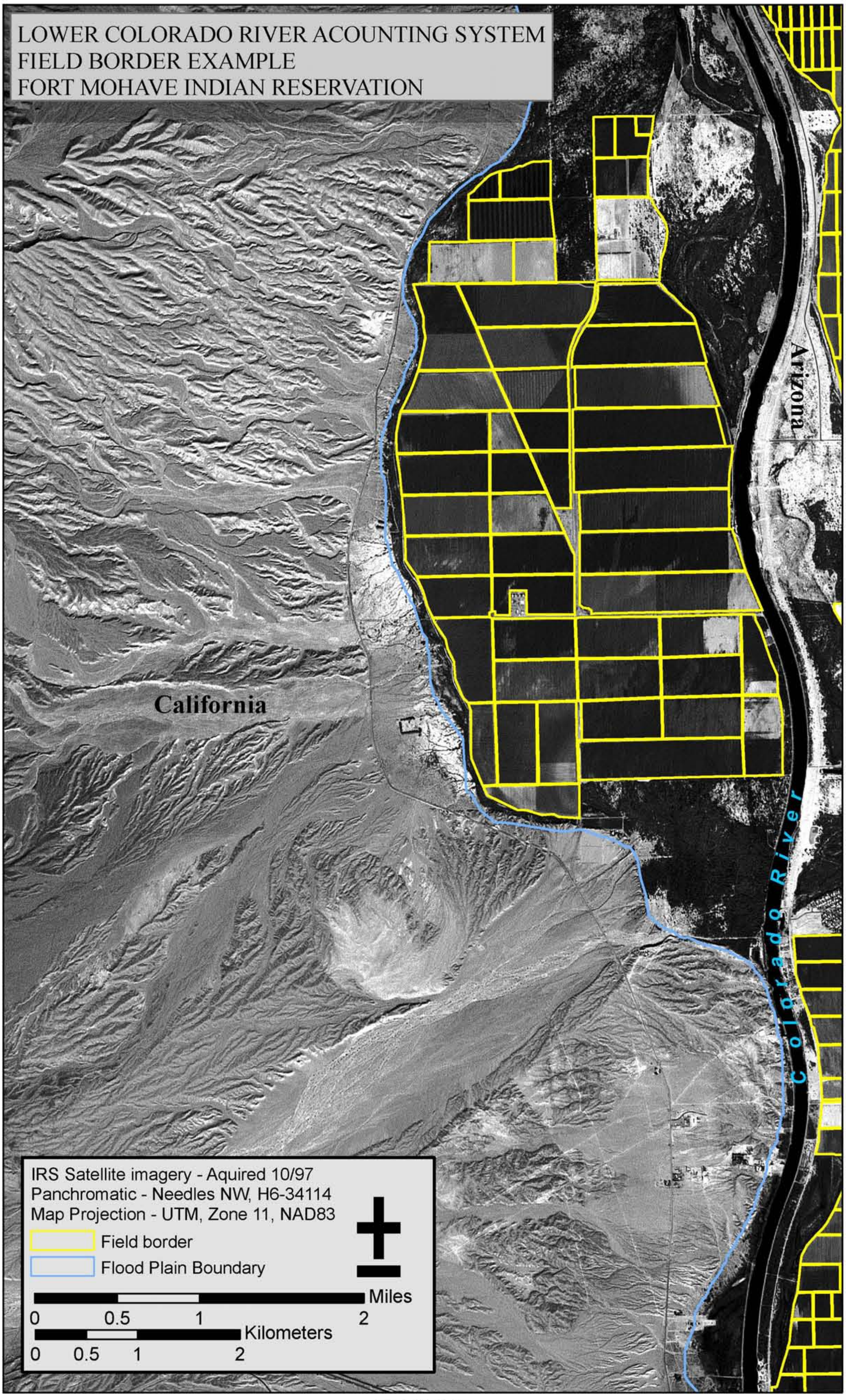

LOWER COLORADO RIVER ACOUNTING SYSTEM
IMPERIAL DAM TO MEXICO REACH
California
Imperial National Wildlife Refuge
Imperial Dam
Picacho State Recreation Area
Yuma Proving Ground
Mittry Lake State Wildlife Area
Laguna Dam
Bard Unit
Indian Unit
Winterhaven
North Gila Valley Irrigation District
Sturges Gila Monster Ranch
Morelos Dam
Desert Lawn Memorial
Yuma
Yuma Irrigation District
MEXICO
Yuma County Water Users Association
University of AZ Ag Test Station
Fort Yuma Indian Reservation Homesteads
Yuma Mesa Irrigation and Drainage District
Arizona
Somerton
West Cocopah Indian Reservation
Unit B Irrigation and Drainage District
State of Arizona Limotrophe Section
State of Arizona Downgradient of Yuma Mesa Irrigation and Drainage District
East Cocopah Indian Reservation
San Luis
Hillander "C"
UNITED STATES
MEXICO
Landsat 5 TM imagery - p38 r36-37.
Aquired July 16, 2003
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM Zone 11, NAD83
Flood Plain Boundary
Diverter Boundary
Reach Boundary
Miles
0 2 4 8
Kilometers
0 2.5 5 10

Exhibit 8



LOWER COLORADO RIVER ACOUNTING SYSTEM
FIELD BORDER EXAMPLE
FORT MOHAVE INDIAN RESERVATION
Arizona
California
Colorado River
IRS Satellite imagery - Aquired 10/97
Panchromatic - Needles NW, H6-34114
Map Projection - UTM, Zone 11, NAD83
Field border
Flood Plain Boundary
Miles
0 0.5 1 2
Kilometers
0 0.5 1 2

Exhibit 9

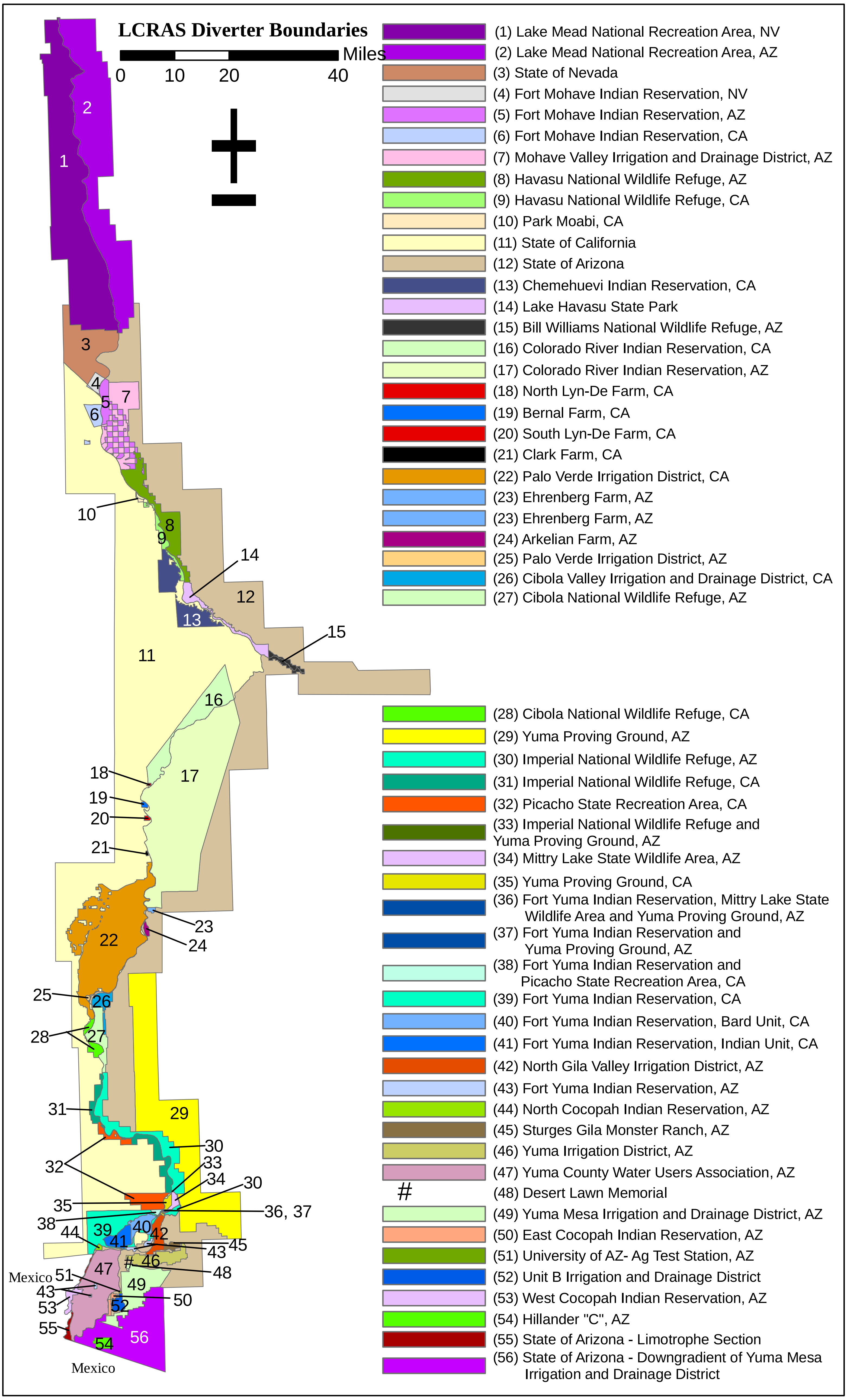

LCRAS Diverter Boundaries
Miles
0 10 20 40
Mexico
(1) Lake Mead National Recreation Area, NV
(2) Lake Mead National Recreation Area, AZ
(3) State of Nevada
(4) Fort Mohave Indian Reservation, NV
(5) Fort Mohave Indian Reservation, AZ
(6) Fort Mohave Indian Reservation, CA
(7) Mohave Valley Irrigation 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
(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
(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 Wildlife 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 Water 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 - Limotrophe Section
(56) State of Arizona - Downgradient of Yuma Mesa Irrigation and Drainage District

Exhibit 10

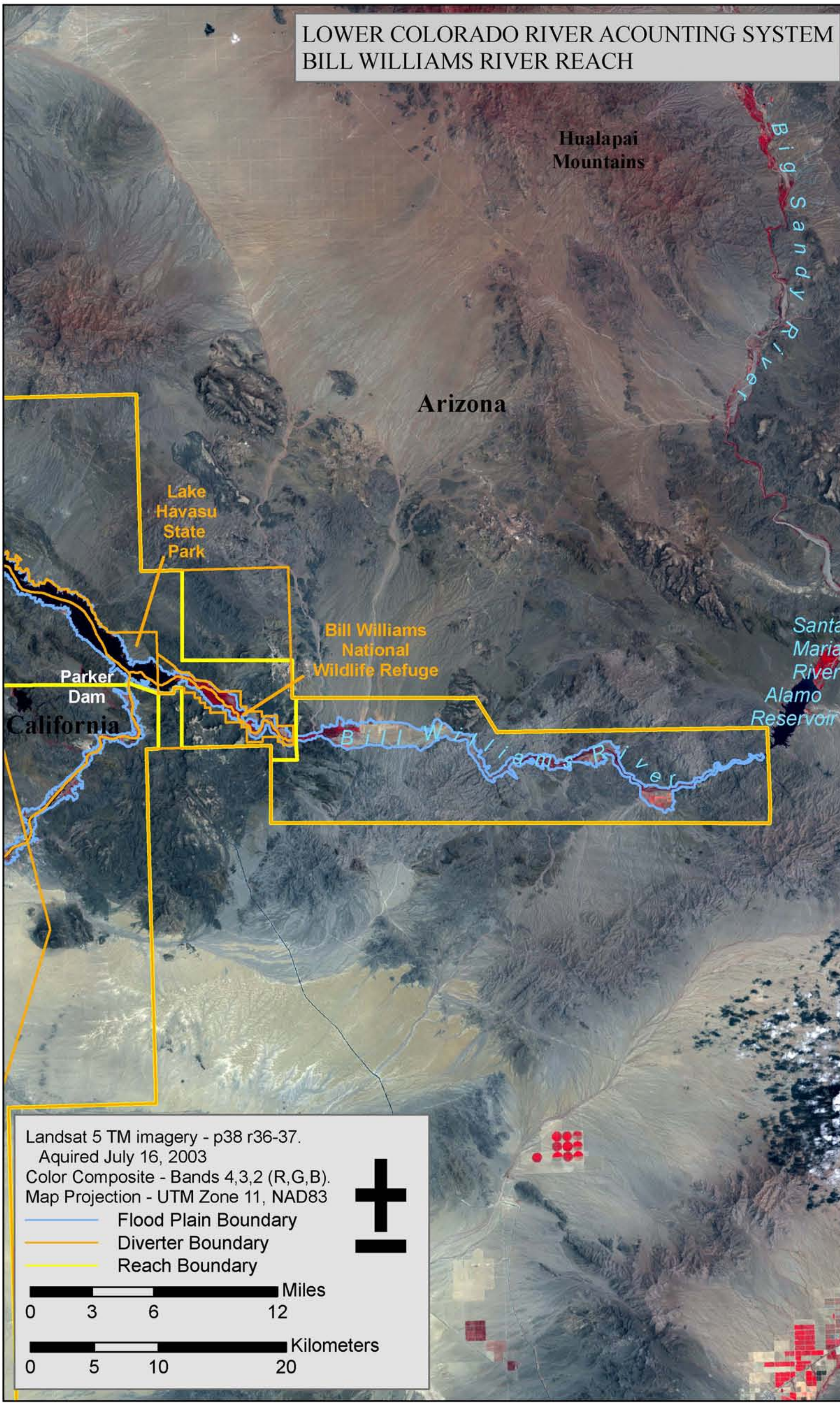

LOWER COLORADO RIVER ACOUNTING SYSTEM
BILL WILLIAMS RIVER REACH
Hualapai Mountains
Big Sandy River
Arizona
Lake Havasu State Park
Bill Williams National Wildlife Refuge
Santa Maria River
Alamo Reservoir
Parker Dam
California
Bill Williams River
Landsat 5 TM imagery - p38 r36-37.
Aquired July 16, 2003
Color Composite - Bands 4,3,2 (R,G,B).
Map Projection - UTM Zone 11, NAD83
Flood Plain Boundary
Diverter Boundary
Reach Boundary
Miles
0 3 6 12
Kilometers
0 5 10 20

Exhibit 11

GIS database used for calendar year 2002. This analysis did not identify any additional open-water areas.

Calculating ET for Crop Groups and Riparian Vegetation Groups

Reclamation calculates ET from crop and riparian vegetation groups found along the lower Colorado River flood plain, on the Palo Verde and Yuma Mesas, and the flood plain of the Bill Williams River from Alamo Dam to Lake Havasu.

ET calculations require the following items:

1. Reference ET;
2. ET coefficients for each crop and riparian vegetation group;
3. Number of acres covered by each crop and riparian vegetation 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 the rate of water use by vegetation (in linear units, such as inches) to which the rate of water use of all types of vegetation (as well as the rate of 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 (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 Davis 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.

The AZMET and CIMIS networks report reference-ET values directly; however, Reclamation has 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 equation to calculate reference ET. Calculating reference ET using the standardized equation and the climatological data provided by the AZMET and CIMIS networks eliminates this disparity in reference ET values reported by the networks. The use of the standardized equation leaves only site conditions, equipment calibration, and micro-climatic differences as sources of site-to-site variations in reference-ET values.

Reclamation develops area-specific reference-ET values for the Mohave Valley, the Parker and Palo Verde Valleys, and the Yuma Area by averaging reference-ET values calculated using the standardized equation and data collected by the AZMET and CIMIS stations sited within these areas. Figure 1 shows the reference-ET and precipitation values used to develop the ET-rate estimates used by this report to calculate ET from crop and riparian vegetation groups.

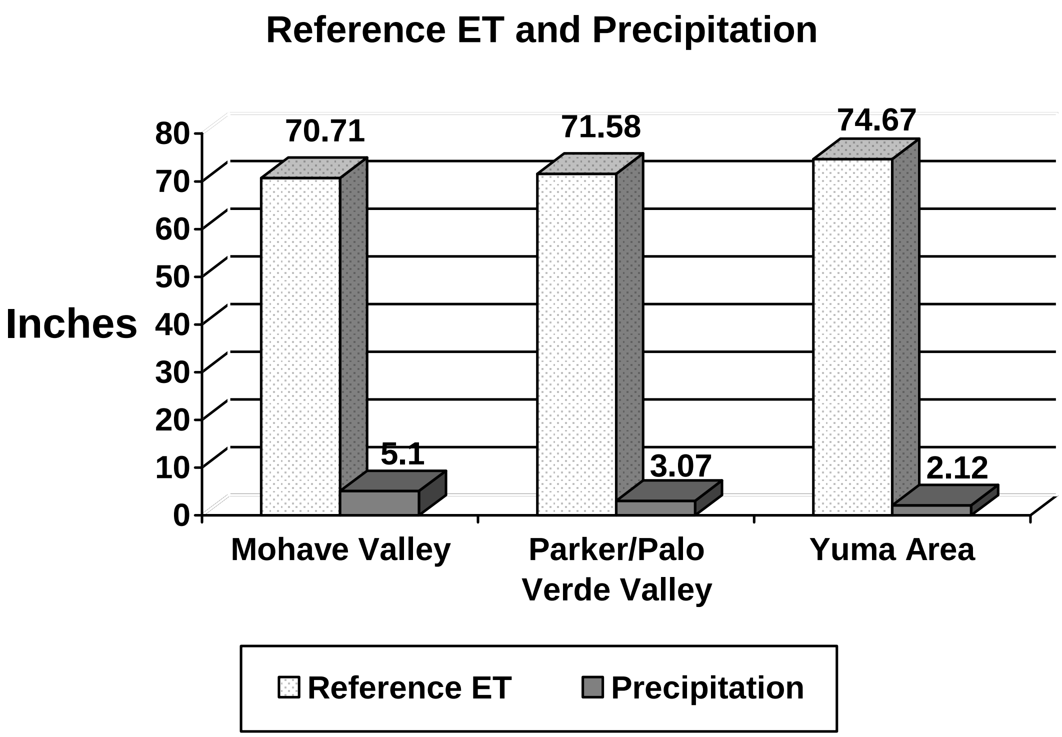


Figure 1 — Reference ET and Precipitation

Refining ET Coefficients for Crop and Riparian Vegetation Groups

ET coefficients are the values that relate reference ET to the ET rate of specific crop and riparian vegetation groups (as well as the evaporation rate from a water body). Jensen (1998) presents the rationale used to develop the original crop and riparian vegetation groups and ET coefficients for each group used by the LCRAS program. Jensen (2002) presents the adjustments made to the crop and riparian vegetation groups and the ET and evaporation coefficients used in this report.

Calculating the Number of Acres of Each Crop and Riparian Vegetation Group

The number of acres of each crop and riparian vegetation group are required to calculate ET. Reclamation calculated the number of acres of each crop and riparian vegetation group by applying the analysis previously described in "Identifying Crop Groups, Riparian Vegetation 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 that of 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 those operated by the National Weather Service (NWS) along the lower Colorado River record precipitation. Reclamation developed a single daily precipitation value for the Mohave Valley, the Parker and Palo Verde area, and the Yuma area by averaging precipitation measured at the AZMET, CIMIS, and NWS stations in each area. Jensen (1993) contains the documentation for the effective precipitation coefficients used in this report. Reclamation uses the following equation to calculate effective precipitation:

Effective Precipitation = Daily Precipitation H Monthly Effective Precipitation Coefficient

The amount of precipitation the lower Colorado River Valley received in calendar year 2003 ranged from 1.02 inches, measured by the Yuma Citrus NWS station, to 6.93 inches, measured by the Palo Verde II CIMIS station. The correction to the ET rate for precipitation is very small, as can be discerned from an examination of Figure 1 which shows annual reference ET and annual precipitation.

Calculating Crop ET

To calculate ET from 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 coefficient (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) for each crop group.

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 determines this acreage by using GIS technologies, remote sensing, and field survey data described previously.

With the ET rates for, and number of acres covered, by each crop group described previously, Reclamation calculates the ET of each crop group (in acre-feet) grown within each diverter boundary, by multiplying the ET rate for each crop group by the area covered by each crop group (acres) within each diverter boundary, and divides by 12 (inches/foot). These calculations are performed monthly and the results summed to produce annual agricultural ET values within each diverter boundary. Table 4, previous, lists the crop groups used for this report.

The following example illustrates an ET calculation for cotton:

$$ET\ cotton = n\ [(ET_0 \times K\ cotton) - Effective\ PPT]\ AC\ cotton \div 12$$

Where:

ET cotton = Monthly or annual ET by cotton for the diverter in question (acre-feet)

n = Summation for n time (monthly)

ET_0 = Daily reference ET (inches)

K cotton = Daily ET coefficient specific to cotton (dimensionless)

AC cotton = Acreage of cotton for the diverter in question (acres)

Effective PPT = Effective precipitation (inches)

Calculating ET from Riparian Vegetation

Reclamation calculates ET from riparian vegetation for this report the same way it calculates agricultural ET, except that Reclamation makes no correction to the ET rates of riparian vegetation for effective precipitation. The sum of the ET from all riparian vegetation groups within a diverter boundary yields the riparian vegetation ET for an individual diverter.

Reclamation analyzed remotely-sensed data and aerial photography to develop the original acreage values for each riparian vegetation group used to calculate ET from riparian vegetation for 1995. Beginning with calendar year 1996, and continuing through calendar year 2003, Reclamation has updated riparian vegetation acreage values using change detection methods (described previously) and by field verifying major changes (usually due to fire or development). Table 5 (previous) lists the riparian vegetation groups used in this report.

Calculating Evaporation

Calculating evaporation from the mainstream

Reclamation calculates mainstream evaporation from Lakes Mohave and Havasu, and Senator Wash reservoir, and the open water of the Colorado River and adjacent backwaters (such as Topock Marsh and Mittry Lake) from Davis Dam to Mexico. 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 the result in (4) 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; and
7. Sum the monthly evaporation for all months of the year to yield an annual evaporation in acre-feet.

Reclamation verified the open-water area for this report by analyzing satellite images acquired on July 16, 2003.

Calculating evaporation from major delivery canals serving irrigation districts and Indian reservations

Reclamation calculates evaporation from major delivery canals using the same technique used to calculate evaporation from the mainstream, except that the open-water area is that of the major delivery canals. 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 or Indian reservations (shared canals). The Colorado River Indian Reservation Main Canal is an example of a single user canal, and the All American Canal is an example of a shared canal.

Reclamation calculates the proportionate use of a shared canal using a process described by the following paragraphs:

1. Calculate a single diversion point distance from the canal headworks 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 headworks and weighing these distances by the diversion amount 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 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.

LCRAS Improvements for Calendar Year 2003

Reclamation reviews each application of LCRAS and incorporates "lessons learned" into subsequent reports. Reclamation also modifies each application of LCRAS in response to information provided by water users and as modified processes become available after analysis of long-term questions and issues.

The following paragraphs describe improvements to crop and riparian vegetation identification and ET calculations made since the issuance of the 2002 LCRAS Demonstration of Technology report, and potential improvements under active consideration during the past year.

Improving ET Estimates for Riparian Vegetation

Reclamation continues a cooperative study initiated in fiscal year 2001 with the Nevada District of the US Geological Survey to improve estimates of ET from riparian vegetation. The study's objective is to refine ET estimates for the most common riparian vegetation communities found along the lower Colorado River using parameters measured by three micro-meteorological stations placed above riparian vegetation stands in Topock Marsh. The micro-meteorological stations will collect data for at least 2 years. The study plan includes,

1. Producing estimates of ET from riparian vegetation,

2. Comparing these estimates with estimates of ET from riparian vegetation calculated using ET coefficients and reference ET currently used by LCRAS, and

3. Assessing adjustments that may be needed to the riparian vegetation ET coefficients.

Adjusting Diverter Boundaries

Reclamation consults with irrigation districts, Indian reservations, and other diverterss within defined service areas to resolve discrepancies between Reclamation's understanding of diverter boundaries and diverter's understandings of their boundaries. Reclamation uses this information and other information that may become available to update diverter boundaries used by LCRAS. Such information sharing and gathering is an ongoing process. No adjustments were made to diverter boundaries in 2003.

Determining Accuracies of ET Estimates based on Remote Sensing and GIS Procedures

Reclamation continues a study with an independent statistician to quantify the effects of remote-sensing-based crop classification error on accuracies of ET estimates.

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