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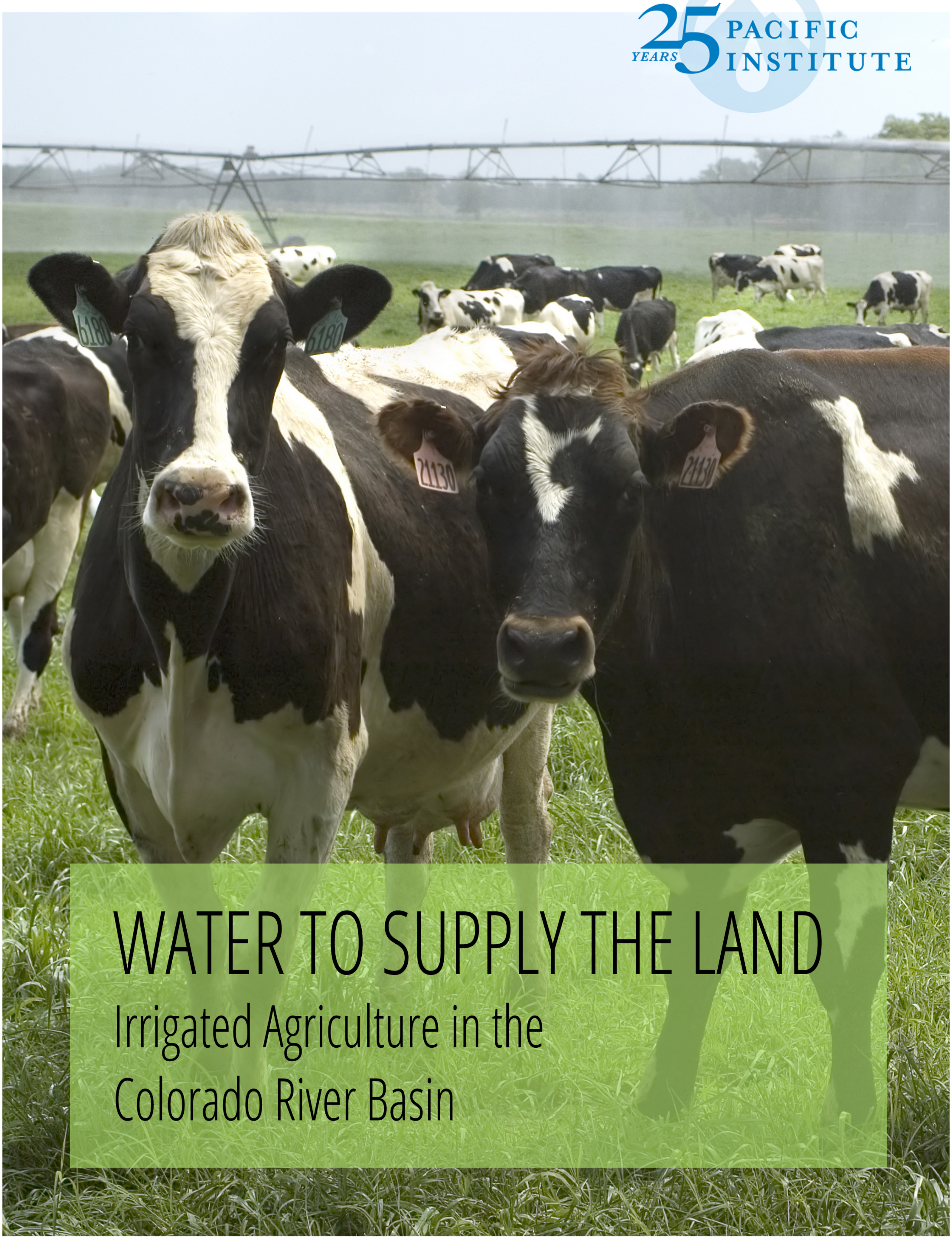

WATER TO SUPPLY THE LAND

Irrigated Agriculture in the Colorado River Basin

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Executive Summary

The Colorado River basin covers 256,000 square miles in the western United States and parts of northwest Mexico (see Figure ES-1). Much of the basin is extremely arid, in some areas receiving less than three inches of precipitation per year. Irrigation and agriculture are closely linked in the Colorado River basin. More than ninety percent of pasture and cropland in the basin receives supplemental water to make the land viable for agriculture. This irrigated land extends across some 3.2 million acres within the basin, while water exported from the basin reportedly helps irrigate another 2.5 million acres in Colorado, Utah, New Mexico, and southern California. Irrigating this much land requires a lot of water, consuming roughly 70 percent of the basin's water supply (not including evaporation or exports).

As shown by the recent Colorado River Basin Water Supply & Demand Study, limited supply, climate change, and growing demand for water challenge the basin. Irrigators were among the first to divert and put water from the basin to beneficial use, securing legal rights to the use of that water. With some of the oldest and largest water rights in the basin, irrigators face increasing pressure from urban interests to sell or relinquish some of these water rights.

This report has two goals. First, improve understanding of crop acreages and water use in the basin. Second, having assessed irrigation methods and cropping patterns, develop a set of plausible scenarios in which some of the water currently devoted to irrigation could be conserved and used for other purposes without reducing the amount of land in production.

This report focuses on the last decade (2000 to 2010) and addresses land irrigated by Colorado

Figure ES- 1. The Colorado River Basin

River basin water, including water diverted from the river's mainstem, from tributary water, or pumped from groundwater in the basin. The report includes districts within the basin as well as those outside the basin that import basin water for at least a portion of their water supply and for which information was available. The data in this report come from federal and state sources, primarily the Bureau of Reclamation, the USDA/NASS Census of Agriculture, and the USGS estimate of water use. We performed no new measurements or surveys for this report.

Part I – Irrigated Acreage Inventory

About 90 percent of the pastureland and harvested cropland in the Colorado River basin is irrigated. This report highlights several important points about this irrigation:

1. More than half of the land and water use in the Colorado River basin is dedicated to feeding cattle and horses;
2. The Upper and Lower basins exhibit very different trends in the extent of irrigated acreage over the last decade and the types of crops grown;
3. Irrigation water use trends are less clear; and
4. State and federal agencies frequently report inconsistent irrigated land and water use information for areas within the Colorado River basin, obscuring key basin issues and hampering efforts to reconcile the basin's water supply and demand challenges.

Irrigated pasture and forage crops, used primarily to feed beef and dairy cattle and horses, cover about two million acres (60 percent) of the irrigated land in the Colorado River basin. We estimate that irrigated pasture and forage in the basin consume more than five million acre-feet of water each year. Alfalfa, planted extensively from Wyoming to the delta in Mexico, alone covers more than a quarter of the total irrigated acreage in the basin. Arizona, California, and Mexico have more crop diversity than the other states in the basin, with hundreds of thousands of acres in vegetables, wheat, and cotton. Nevertheless, Arizona, California, and Mexico's 750,000 acres of forage crops and pasture in the basin consume roughly three million acre-feet of water each year.

Trends in irrigated acreage reveal clear geographic differences. In Upper Basin states, the amount of irrigated acreage fell in the early part of the last decade, only to recover or surpass previous acreages by decade's end. In contrast, the amount of irrigated acreage in Mexico's portion of the basin remained relatively flat while the Lower Basin saw continued declines in irrigated acreage over the decade. The conversion and transfer of irrigation water to urban uses in all three Lower Basin states led to this reduction of total Lower Basin water use generally and reductions of irrigated land and water use for irrigation more specifically.

One of the most unexpected revelations of this study is the marked disparity in the different state and federal agencies' reported extents of irrigated acreage and volumes of irrigation water use. The agencies report different aspects of irrigation water use, complicating efforts to compare their reported values. Despite these limitations, the available information provides a revealing overview of recent land and water use in the Colorado River basin.

Part II – Conservation and Efficiency Options

Consuming more than 70 percent of the developed water supply in the Colorado River basin, irrigated agriculture is an obvious candidate for water conservation. Given available information on agricultural water use, we estimate potential water savings based on various conservation scenarios involving regulated deficit irrigation, crop shifting, and advanced irrigation technologies, without taking land out of production. We note that reductions in water use in the irrigation sector for transfer to municipal use should be contingent upon prior implementation of aggressive municipal conservation and should be on a voluntary basis only.

Table ES-1 on the next page shows the potential water savings, in both total applied water and in consumptive use, for the three general water conservation strategies explored in this report. With the exception of the conversions from flood to sprinkler irrigation, these strategies could generate large volumes of transferable conserved water at relatively low cost. This is very encouraging. We assume that other interests (such as municipal water agencies or wildlife agencies) would compensate irrigators for implementing the changes, so total costs would need to be negotiated and presumably would include some additional incentive payments to irrigators. We estimate that one of the least expensive options could reduce consumptive use by more than 800,000 AF.

We note that not all consumptive water use savings may be available for transfer, due to state legal restrictions, water rights limitations, and other challenges. We acknowledge that water rights holders are under no obligation to transfer their water to urban or instream uses: we assume that all such transfers would be voluntary and would be compensated. Furthermore, when considering crop switching or deficit irrigation, there are implications related to demands for specific crops that will affect individual producer's decisions.

Typically, only consumptive-use savings can be transferred. However, total reductions in applied water (and more broadly in total withdrawals) could offer significant benefits for general water quality, stream health, and (in the case of groundwater extraction) the sustainability of local aquifers.

Table ES- 1. Summary of Scenarios

Scenario	Description	Applied water savings (AF)[a]	Consumptive use savings (AF)	Base costs
Scenario 1a: Basin-wide RDI	Applied to alfalfa in the entire basin	>970,000	970,000	$81/AF
Scenario 1b: Lower Basin RDI	Applied to alfalfa in the Lower Basin only	>834,000	834,000	$62/AF
Scenario 2a: Decreased cotton, increased wheat	70,000 acres of cotton substituted by wheat	>90,000	90,000	$112/AF
Scenario 2b: Decreased alfalfa, increased sorghum	74,000 acres of alfalfa substituted by sorghum	>140,000	140,000	$96/AF
Scenario 2c: Decreased alfalfa, increased cotton and wheat	74,000 acres of alfalfa substituted by 37,000 acres of cotton and 37,000 acres of wheat	>250,000	250,000	$36/AF
Scenario 3a: Basin-wide improved irrigation technology	Basin wide: 25% shift from flood to sprinkler	175,000	60,000	$450-$1,500/AF[a]
Scenario 3b: Lower Basin improved irrigation technology	Counties with no return flows: 25% shift from flood to sprinkler	60,000	60,000	$470 - $1,600/AF[a]

Notes: RDI - regulated deficit irrigation.
(a) These are estimated costs per AF reduction in total applied water savings, not base costs per AF consumptive use savings.

Conclusions and Recommendations

Irrigation and agriculture are closely linked in the Colorado River basin. The total volume of water diverted from surface sources and pumped from the ground for irrigation in the Colorado River basin as a whole (including Mexico) reportedly exceeded 18.5 million acre-feet in 2005, while the total consumptive use by irrigation in the U.S. portion of the basin that year was about half as much. Yet even this massive volume of water, equivalent to more than half of the river's annual flow, was insufficient to meet the total demand for irrigation in the basin, as shown by various estimates of agricultural water shortages. As John Wesley Powell stated more than a century ago, there is not sufficient water to supply the land.

This report clearly describes the large amount of land and water in the Colorado River basin devoted to growing pasture and crops used to feed livestock. Shorter growing seasons and cooler climates, as well as limited upstream water storage and water availability, account for lower irrigation water consumption (per acre) in the Upper Basin than in the Lower. In fact, about four times more water is delivered to Lower Basin and Mexican fields than to Upper Basin fields. Excluding Mexico, in 2005 irrigated agriculture in the Lower Basin (including the Salton Sea watershed) consumed three times more water from the Colorado River basin than it did in the Upper Basin. These disparities demonstrate that irrigated acreage does not represent the volume of basin water use, and underscore the differences between Upper and Lower basin irrigation.

As noted in the *Colorado River Basin Study*, in the context of rising municipal demand, the need for healthy stream flows and climate-change's projected impact on supply over the next half-century, it is informative to consider ways to reduce irrigation water demand while maintaining a healthy agricultural sector and rural economies. The projected savings under the various scenarios evaluated in Part II of this report provide encouragement, with consumptive water use savings of almost a million acre-feet achieved by irrigating alfalfa less frequently. Other scenarios, such as shifting from water-intensive to less water-intensive crops, also yield impressive water savings at relatively low cost, without reducing the total amount of irrigated acreage in the basin. The magnitude of the potential water savings and the range of costs associated with these changes suggest considerable potential for reducing irrigation while keeping agricultural land in production.

Recommendations

The magnitude of the potential consumptive water use savings generated under this report's scenarios – especially by applying regulated deficit irrigation to alfalfa acreage in the Lower Basin and by shifting a small portion of alfalfa acreage to other, less water-intensive field crops – compels in-depth, site-specific analyses. So long as the already high demand for water in the basin and adjacent areas continues to grow and those with growing demands have already implemented aggressive water conservation measures of their own, relatively low-cost, high-yield programs such as regulated deficit irrigation and shifts to less water-intensive crops should be developed and implemented.

As we described in our companion *Municipal Deliveries* report (Cohen 2011), growing municipal demand should first be addressed by improving municipal water conservation. It makes little sense to pursue deficit irrigation of alfalfa unless municipal water agencies and their ratepayers have implemented their own aggressive water conservation measures. As cities improve their water conservation rates, regulated deficit irrigation may be implemented most appropriately as a drought response measure, keeping land in production while transferring some portion of the irrigation water requirement to cities struggling with significant shortages and to streams facing greatly diminished flows and threatened aquatic species. Crop shifting could also be implemented in the context of projected water shortages, incentivizing willing producers to plant less water-intensive crops and transfer a portion of the resultant water savings to improve supply predictability for cities or other irrigators.

Given the surprisingly disparate accounts of irrigated acreage and irrigation water use provided by the different state and federal agencies, we recommend that the relevant agencies develop and implement better and more consistent approaches to tracking and quantifying annual irrigation data. We encourage the Bureau of Reclamation to confer with other state and federal agencies and with state water agencies and irrigation districts to coordinate measurement and reporting of irrigation and cropping patterns and to clearly explain any differences that may arise in their respective reports. As noted in the recent *Colorado River Basin Water Supply & Demand Study*, rising demand and diminishing supply frame the future of the basin. The luxury of not measuring or compiling information on water use and irrigated land can no longer be afforded. Greater effort must be made to resolve these data challenges.

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Tables and Figures

Abbreviations and Acronyms

AF	Acre-feet
Agricultural census	USDA/NASS Census of Agriculture
AZ DWR	Arizona Department of Water Resources
CA DWR	California Department of Water Resources
CAP	Central Arizona Project
CDSS	Colorado's Decision Support Systems
CO DWR	Colorado Division of Water Resources
CONAGUA	*Comisión Nacional del Agua*
CRB	Colorado River Basin
CULR	Reclamation's semi-decadal Consumptive Uses and Losses Reports
CWCB	Colorado Water Conservation Board
CVWD	Coachella Valley Water District
FRIS	Farm and Ranch Irrigation Survey
IBWC	International Boundary and Water Commission
IID	Imperial Irrigation District
KAF	1,000 acre-feet
LB	Lower Basin
LCRAS	Reclamation's *Lower Colorado River Accounting System* reports
MWD	Metropolitan Water District of Southern California
M&I	Municipal and Industrial
NASS	National Agricultural Statistics Service
NMOSE	New Mexico Office of the State Engineer
OEIDRUS	*Oficinas Estatal de Información para el Desarrollo Rural Sustentable*
PVID	Palo Verde Irrigation District
SAGARPA	*La Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación*
SIB	Southerly International Boundary
SWSI	Colorado's 2010 Statewide Water Supply Initiative
UB	Upper Basin
USBR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UT DWR	Utah Division of Water Resources
WY SEO	Wyoming State Engineer's Office

Conversions

Length

1 mile	1.609 km

Area

1 acre	4047 m^2
1 acre	0.4047 ha
1 square mile	640 acres
1 square mile	259.0 ha
1 square mile	2.590 km^2

Volume

1 acre-foot	435,600 ft^3
1 acre-foot	325,851 gallons
1 acre-foot	1,233 m^3
1 KAF	1.233×10^6 m^3

1 Introduction

Irrigated agriculture in the Colorado River basin has a long, rich history. In central Arizona, the Hohokam diverted water from the Gila River to irrigate fields of corn and beans more than 1,500 years ago; by one estimate, the Hohokam irrigated more than 200,000 acres of land.[1] Today, irrigated agriculture extends across some 3.2 million acres of land within the basin as a whole (including the drainages in Mexico and the Salton Sea watershed in the U.S.), while water exported from the basin helps irrigate another 2.5 million acres in Colorado, Utah, New Mexico, and southern California. This irrigation requires a lot of water – nearly 90 percent of consumptive use in the Upper Basin.[2]

Irrigation – the artificial supply of water to land – is critical in the Colorado River basin. As the Colorado Supreme Court recognized 130 years ago in *Coffin v. Left Hand Ditch Co.* (1882), “The climate is dry, and the soil, when moistened only by the usual rainfall, is arid and unproductive; except in a few favored sections, artificial irrigation for agriculture is an absolute necessity” (in Fleck 2012). Water – especially in the Upper Basin – is the resource that limits the amount and productivity of agriculture.[3]

Limited water resources and growing demands challenge the basin, as documented in the new *Colorado River Basin Water Supply and Demand Study* (Basin Study). Irrigators, among the first to divert and put water from the basin to beneficial use and so secure legal rights to the use of that water, face increasing pressure from urban interests to sell or relinquish some of their water rights. There is already an active market in water rights in parts of the basin. In California, a large, complex water transfer will ultimately move 200,000 acre-feet[4] of water per year from agriculture in the Imperial Valley to urban users in San Diego County, a transfer that continues to be litigated more than nine years later. More than a century ago, John Wesley Powell foresaw this contention, stating in a presentation to an irrigation conference in Los Angeles, “I tell you gentlemen you are piling up a heritage of conflict

[1] Layperson’s Guide to Arizona Water, 2007, p.2.

[2] Exclusive of reservoir evaporation and exports. Source: Bureau of Reclamation (USBR) *Consumptive Uses and Losses* 2001-2005 report. The Upper Basin includes land in Arizona, Colorado, New Mexico, Utah, and Wyoming. The provisional 2006-2010 *Consumptive Uses and Losses* report states that the irrigated agriculture category is responsible for 67 percent of consumptive uses and losses excluding reservoir evaporation but including exports.

[3] In 2005, when Colorado River flows were 13 percent above the long-term average, USBR estimates that Upper Basin irrigators would have consumed an additional 117 KAF of water had it been available. Data from USBR’s Table UC-9, “Upper Colorado River Basin Agricultural Water Shortage Estimates, 2001-2005,”Consumptive Uses and Losses Report 2001-2005 and CURRENT natural flow data 1906-2008.

[4] An acre-foot is the conventional unit of measurement for water in the West. One acre-foot is equivalent to 325,851 gallons of water.

and litigation over water rights for there is not sufficient water to supply the land."[5]

This report has two goals. The first is to describe the extent and nature of irrigated agriculture in the Colorado River basin as a whole, to improve understanding of recent crop acreages and uses of water in the region. The second goal is to assess recent irrigation methods and cropping patterns and develop a set of plausible scenarios in which some of the water currently devoted to irrigation could be conserved and used for other purposes. This report includes two main parts: the first is a description of irrigated agriculture in the basin, at the basin level, and, because the individual states manage water within their own borders, at the state level. Part I also includes a description of recent irrigated acreage and crop types in Mexico. Part II of this report describes various scenarios in which water could be conserved – including regulated deficit irrigation, crop shifting, and irrigation technology improvement – without taking irrigated agriculture out of production.

Study Objective

The purpose of this study is to create an inventory of land irrigated with water from the Colorado River basin and to estimate the total volume of transferable water conservation[6] that could be achieved over a 50-year timeframe from such land, assuming an unlimited budget for investments, and assuming the goal is to keep existing acres of irrigated agriculture in production.

Scope

The scope of this report includes land irrigated by water from the Colorado River basin. This includes land irrigated by water diverted from the Colorado River mainstem, by tributary water, and by groundwater. It includes districts within the basin as well as those outside the basin that import basin water for at least a portion of their water supply and for which information was available. The geographic scope therefore includes the full extent of the Colorado River basin (see **Figure ES- 1**) broadly defined here to include lands where the river discharged historically, including the Salton Sea basin and the Mexicali Valley. This study also includes some areas adjacent to the Colorado River basin, such as the Front Range in Colorado and portions of southern California, that import water from the basin for irrigation, for which data are available. This study focuses on the years 2000 to 2010, because the recent decade reflects current conditions and generally has better data availability, particularly from state agencies, than previous decades.

Data Sources and Limitations

All values in this report come from other sources: we did not perform any new measurements or surveys to acquire the data included in this report. Instead, we obtained data from a variety of existing sources, including published reports and from information on file with various local, state, and federal agencies. Please see the References section for the complete list of sources. Table 1 shows the major data sources for this report. These sources vary in scope and frequency, as shown in the table below. The U.S. Bureau of Reclamation (USBR) and the U.S.

[5] Quoted in Donald Worster, 1992, Rivers of Empire: Water, Aridity, and the Growth of the American West, Oxford University Press, p. 132.

[6] We define "transferable water conservation" to mean a quantifiable volume of consumptively used water that is saved or otherwise not used due to extraordinary measures, such as changes in crop type, avoiding a scheduled irrigation, or implementation of more efficient irrigation technologies where return flows are not diverted, and where the water that is saved can be put to use by another diverter or contracted for another use, such as instream flow augmentation.

Geological Survey (USGS) both provide irrigated land and water use estimates, as does the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS)'s Farm and Ranch Irrigation Survey (FRIS). However, the USDA/NASS Census of Agriculture (agricultural census) does not measure or estimate water use. USBR's Lower Colorado River Accounting System (LCRAS) reports provide detailed information on crop types and acreages and water use for diverters of Colorado River water operating along the river's mainstem and for several major off-stream irrigation districts. The agricultural census is the primary source of information on crop types and extents basin-wide. For Mexico, we relied on data reported by the *Comisión Nacional del Agua* (*CONAGUA*) and the *Oficinas Estatal de Información para el Desarrollo Rural Sustentable* (*OEIDRUS*). In Table 1, "UB" refers to the Colorado River's Upper Basin and "LB" refers to the Lower Basin (See Figure ES-1).

Table 1. Data Sources and Scope

Source	Title	Subject	Scope	Frequency
USBR	Consumptive Uses and Losses report	consumptive use, irrigated land	UB, LB, exports, by state & basin	5-yr report with annual data
	Decree Accounting[7]	diversions, returns, consumptive use	LB mainstem by state & contractor, deliveries to Mexico	annual
	LCRAS	consumptive use, crop type, irrigated land	LB mainstem, CVWD, IID, and PVID, by state & contractor	annual
	Basin Study	future demands	UB, LB, exports, by state & region	2015 projection
USDA/NASS	Agricultural Census	crop type, irrigated acreages, livestock	U.S., watershed, state & county level	2002, 2007
	FRIS	irrigation extent & type	UB, LB	2003, 2008
	Annual crop reports	crop type, irrigated acreages, livestock	by state	annual
USGS	Estimated Use of Water in the United States	withdrawals, irrigated acreage, irrigation type	county, state	2000, 2005
State & Local	State water reports	withdrawals or depletions, land	sub-basin	various
	County agriculture reports	crop type, crop acreage	county	annual
	Irrigation district reports	crop type, crop acreage, diversions & deliveries	district	annual
CONAGUA	Estadísticas agrícolas de los distritos de riego	diversions, crop type, acreage	district	annual
OEIDRUS	Series Históricas Agrícolas	Crop type, acreage	county-equivalent in Mexico	annual

[7] USBR's "*Colorado River Accounting and Use Report: Arizona, California, and Nevada*," commonly known as the Decree Accounting Reports, are posted at http://www.usbr.gov/lc/region/g4000/wtracct.html#decree.

Agency Methods

The reporting agencies use a variety of methods to obtain and compile the information we use in this report. Some agencies compile self-reported data, some measure land areas and water use directly, while others derive data from other sources and from climate records and assumptions about water use requirements. For example, the agricultural census attempts to collect information from all farming and ranching operations with at least $1,000 of agricultural sales per year, via detailed reports submitted by operators themselves.[8] The Farm and Ranch Irrigation Survey (FRIS) is a statistical sample, not a census, of farming and ranching operations, reporting irrigation practices at the state and hydrologic region level, but not at the county or sub-basin level.[9] The semi-decadal USGS water use estimates reports compile data from a variety of different sources, including the agricultural census and FRIS, plus state and local sources.[10] State and local reports use a variety of different methods to obtain and compile information on cropping patterns and water use, including direct measurements, remote sensing data, and surveys.

USBR calculates irrigated acreage and water use for its consumptive uses and losses reports from the agricultural census reports, supplemented by spatial datasets showing irrigated acreage from some of the basin states. USBR's Decree Accounting reports use streamgage data and tabulations from individual water users and a variety of reporting agencies. LCRAS calculates acreage, crop type, and consumptive use from remote sensing data and local climate stations. Because the USBR records are central to this report's description of irrigated acreage and consumptive water use, Appendix A quotes USBR's methodology from its *Consumptive Uses and Losses* report.

Data Limitations

The data reported by the different agencies are not consistent, and in many cases are not directly comparable. For example, the agricultural census, FRIS, and the USGS water use estimates are each conducted every five years, but never in the same year.[11] Some agencies report water use information by water year rather than by calendar year. Some areas, notably California, provide detailed annual data describing the extent of irrigated agriculture and total water withdrawals. Some California irrigation districts provide even more detailed information, listing annual withdrawals, conveyance losses, and volumes delivered to farms and to other users. Other areas, and some states generally, do not track total irrigated acreage or agricultural consumption at all, by state or by basin. In some parts of the basin, the most recent state-reported information available may be a decade or more out of date. These and other challenges hampered our ability to identify trends within or across states or other boundaries.

The infrequency of federal data collection is a further limitation. Despite the growing emphasis on improved irrigation management in the arid West, comprehensive annual data on irrigation practices are not collected by federal agencies (Frisvold and Deva 2011a). The five-year reporting intervals of the agricultural census, FRIS, and USGS hamper the determination of

[8] The full description of the USDA/NASS Census of Agriculture methodology is posted here.
[9] The full description of the USDA/NASS FRIS methodology is posted here.
[10] The guidelines used to develop the USGS water use estimates are posted here. See also Dickens et al. (2011).

[11] NASS also publishes annual agricultural statistics for Arizona and other states, though these do not match the agricultural census' level of detail. The Arizona District of the USGS produces an annual water use estimate, including agricultural data, for all counties in Arizona outside of the Active Management Areas.

annual trends, especially since the data collected by the different agencies are not directly comparable. Additionally, the 2002 agricultural census was conducted in a notable drought year that witnessed limitations on surface water diversions in the Upper Basin, limiting the utility of that census for determining trends and variability in land and water use.

USBR's *Consumptive Uses and Losses* reports offer the most consistent summary of water use and irrigated acreages in the Colorado River basin. Unfortunately, these reports take many years to compile. To date, they only offer provisional data for 2006-2010 for the Upper Basin; Lower Basin values for these years have yet to be released. Since several states include land in both basins, this means that provisional data through 2010 is only available for Colorado and Wyoming, with limited information for 2006-2010 for Utah, New Mexico, and Arizona, and no information as yet for California or Nevada. USBR's Lower Basin Decree Accounting reports show detailed water use data for mainstream contractors in Arizona, California, and Nevada for these years, but not tributary uses in these states.

Determining irrigated acreage by individual crop type often is not possible, limiting the scope of the inventory of irrigated land. For individual crops, the agricultural census reports crop acreages as well as total irrigated cropland and total irrigated pastureland. For irrigated acreage, the agricultural census and FRIS count each acre only once regardless of the number of times it is irrigated or harvested. Total crop acreage often exceeds total irrigated acreage, because a small percentage of crops in the basin (less than 10 percent overall) is not irrigated, and because the same parcel of land can be used to grow more than one crop in a given year. This means that total irrigated acreages and total crop acreages are rarely equivalent. Further, the agricultural census suppresses some information to protect individual growers' privacy, so in some instances

Water Use Terms

Agricultural water use efficiency - crop yield per unit of applied water.

Applied water - the quantity of surface and groundwater delivered to the farm; equivalent to withdrawals minus conveyance losses.

Consumptive use - water that is unavailable for reuse in the basin from which it was extracted, due to soil evaporation, plant transpiration, incorporation into plant biomass, seepage to a saline sink, contamination, or export from the basin. In the Lower Basin, "consumptive use" has a specific legal definition: "diversions from the stream less such return flows thereto as are available for consumptive use in the United States or in satisfaction of the Mexican Treaty obligation."

Conveyance losses - seepage or evaporation from reservoirs and canals; the difference between the volume diverted or extracted and the volume delivered to the farm.

Depletion – consumptive use.

Irrigated land - includes all land watered by any artificial or controlled means, such as sprinklers, flooding, furrows or ditches, sub-irrigation, and spreader dikes. This includes supplemental, partial, and pre-planting irrigation.

Non-consumptive use - water that is available for reuse within the basin from which it was extracted, through return flows or other means.

Water use - a generic term employed in this report to refer to any use of water, including consumptive, applied, or withdrawals. Note that this is not the USGS definition of the term, which specifically refers to withdrawals.

Withdrawal - groundwater and/or surface water taken from a source for a specific purpose, such as for public supply, domestic use, or irrigation.

there are large gaps in reported acreages.[12] An additional challenge related to describing irrigated acreage by crop type is that crop categories, such as "forage" or "field crops" or "vegetables," can include different specific crop types when reported by different agencies, challenging efforts to compare these values.

The various reporting agencies often use different terms to measure water or refer to water use. Terms such as withdrawals, diversions, use, consumptive use, applied water, and depletions mean different things. The text box on the previous page, "Water Use Terms," defines water terms as used in this report. Figure 1 is a simple schematic that places some of these water use terms in context relative to one another. Defining these terms is important because agencies report different aspects of water use. As shown in Figure 1, withdrawals refer to the total amount of water diverted from the surface and pumped from the ground. These withdrawals are then conveyed to the field, typically via pipes or canals. In some cases, such conveyances may extend hundreds of miles; in others, an irrigator may pump water from directly beneath the land or divert water from an adjacent stream. The length of these conveyances directly affects the volume of water lost via evaporation and seepage. Additional reductions may occur due to operational losses, as may occur when an irrigator cancels a water order or other factors. The difference between the total volume of withdrawals and the volume of conveyance and operational losses is the volume of water applied to the field. Depending on location, some of the conveyance and operational losses, as well as a portion of the water applied to the field, may return to the system for subsequent use. These "return flows" may be substantial, but are not reflected in records of withdrawals or of applied water use.

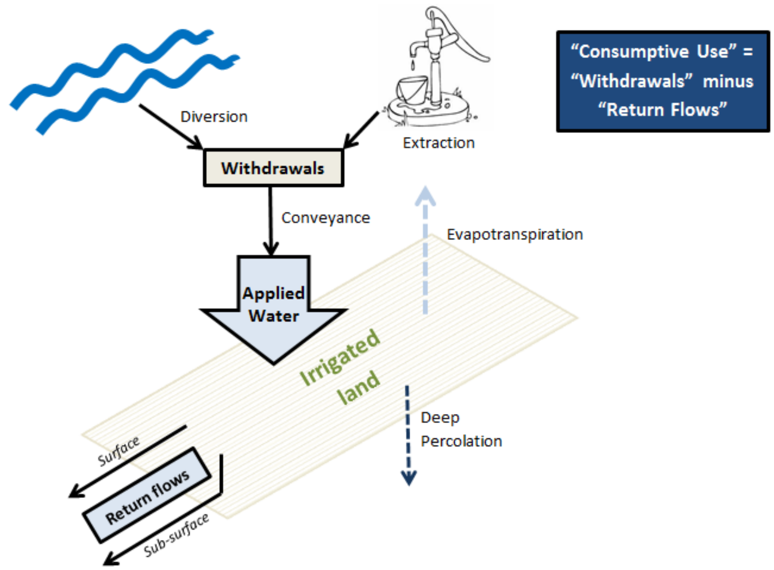

Figure 1. Irrigation Schematic

Return flows highlight the difference between consumptive and non-consumptive water uses. Consumptive use refers to water that is unavailable for reuse in the basin from which it was extracted, due to soil evaporation, plant transpiration, incorporation into plant biomass, seepage to a saline sink, or contamination. Non-consumptive use refers to water that is available for reuse within the basin from which it was extracted. USBR reports consumptive uses, while USGS and many state agencies report total withdrawals, which reflect a combination of both consumptive and non-consumptive uses. Both types of use are important, but they are not interchangeable.

[12] The USDA/NASS Census of Agriculture suppresses "any tabulated item that identifies data reported by a respondent or allows a respondent's data to be accurately estimated or derived." Typically, this suppression affects tabulations for acreages for individual crop types but not for county-level irrigated acreage as a whole.

This report focuses on irrigated acreage. This can be a deceptive unit of measurement. Reports of irrigated acreage may reflect the maximum number of acres irrigated in a year, but in some cases (especially for data obtained from LCRAS reports for Arizona and California) represent an average number of irrigated acres for the year. In higher elevation areas, the frost-free growing season may be four months or less, while in parts of the Lower Basin and Mexico, the frost-free growing season is year-round, where two or more crops may be grown and harvested each year. As reported in the following, the total irrigated acreage is roughly 50 percent higher in the Upper Basin than it is in the Lower Basin. If we were to use a unit of measurement such as irrigated acre-days and average those for the year, Lower Basin acreage would decrease only slightly while Upper Basin acreage would decrease by more than half, reflecting the much shorter growing and irrigation seasons in the Upper Basin.

In summary, the various agencies that report water and land use information for the Colorado River basin use a host of different terms that are often not comparable. The frequency and timing of many of these measurements are rarely synchronized. Despite these limitations, the available information offers an important and revealing overview of recent land and water use in the Colorado River basin. This report offers the first such broad overview of basin agriculture incorporating values reported by different sources and highlights the need for better coordination and consistency among reporting agencies.

2

Irrigated Acreage Inventory

Basin Overview

The Colorado River basin covers more than a quarter of a million square miles in the inter-mountain West, stretching from high in western Wyoming to the Gulf of California, from the Coachella Valley in the west to Rocky Mountain National Park in the east, from 14,000-foot peaks to the shores of the Salton Sea, more than 232 feet below sea level. Temperatures regularly exceed 110° F in the Imperial Valley and regularly fall below -10° F in high mountain pastures in Colorado. Much of the basin is extremely arid, with areas receiving less than three inches of total precipitation annually. USBR reports the size of the Colorado River basin in the United States as 241,900 square miles, plus an additional 1,200 square miles of drainage in Mexico above the Southerly International Boundary (SIB), for a total of 243,100 square miles.

USBR considers the Salton Sea watershed to be outside of the Basin, at least partly because water diverted into the Salton Sea watershed does not return to the mainstem for subsequent use in the U.S. portion of the basin or for delivery to Mexico. The legal definition of consumptive use for Colorado River basin accounting has displaced the hydrologic definition of the basin. Including the hydrologically connected Salton Sea watershed and other areas in Mexico that do not drain to the mainstem above the SIB, the total extent of the basin is on the order of 256,000 square miles. Figure 2 shows this full extent of the Colorado River basin, including the watersheds for the basin's historic discharge points in the Salton Sea and Laguna Salada.

Figure 2. Colorado River Basin

Most of the basin receives insufficient precipitation to grow crops, so irrigation is required. The agricultural census indicates that some 90 percent of the harvested cropland in the basin is irrigated. Table 2 shows irrigated acreage in the Colorado River basin as reported by the agricultural census in 2002 and 2007 and by the Farm and Ranch Irrigation Survey (FRIS) in 2003 and 2008 for the corresponding hydrologic regions, and by *OEIDRUS* for Mexico for 2002 and 2007. The census data also reports irrigated

Table 2. Irrigated Acreage in the Colorado River Basin, by Basin

Acres (1000)	Ag Census[a]		FRIS	
	2002	2007	2003	2008
Upper Basin	1,155	1,357	1,366	1,360
Lower Basin	1,020	947	897	936
Upper + Lower	2,175	2,305	2,264	2,296
Salton Sea watershed	558	452	n/r	n/r
Total US Basin	2,733	2,757		
Mexico[b]	501	501		
Total Basin	**3,234**	**3,258**		

(a) The agricultural census data, reported by region for Hydrologic Unit Codes (HUCs) 14 & 15, have been adjusted to reflect actual Colorado River basin boundaries by excluding HUC 140402, the Great Divide Closed Basin in Wyoming, from Upper Basin total irrigated acreage, and by excluding HUCs 150801-150803, the three sub-basins in southern Arizona that drain into Mexico rather than into the Colorado River, from Lower Basin total irrigated acreage. In 2007, the total irrigated acreage in these four excluded sub-basins was about 50,300, representing 2.1% of total basin acreage.
(b) Mexico values as reported by OEIDRUS.
"n/r" – not reported

acreage for the Salton Sea watershed, shown in the table above. FRIS does not report irrigated acreage in the Salton Sea watershed as a separate unit.

Table 2 shows two interesting differences between years and between basins. The first is that the amount of Upper Basin irrigated acreage was relatively stable in 2003, 2007, and 2008, but was almost 200,000 acres (15 percent) lower in 2002, when the third-lowest runoff year in the historic record dramatically reduced the availability of surface water for diversions.

Figure 3 plots USBR's reconstructed Colorado River flows at Lees Ferry, showing the volume of water that would have flowed if there were no anthropogenic depletions or diversions as a percentage of the reconstructed 100-year average. As shown in the figure, the year 2002 saw dramatically reduced run-off – the third-lowest volume in the past 100 years. Flows remained below 75 percent of average until 2005, limiting the availability of run-of-the-river diversions prevalent in the Upper Basin and dramatically reducing the volume of water in storage.

The second key difference between the basins is that there was much greater inter-annual change in the amount of irrigated acreage in the Lower Basin than in the Upper. Interestingly, the greatest amount of irrigated acreage in the Lower Basin occurred in 2002, the drought year that saw the 15 percent decrease in Upper Basin acreage. The Salton Sea watershed, like the Lower Basin, saw much higher irrigated acreage in 2002 than in 2007. The combination of higher totals in the Lower Basin and in the Salton Sea watershed largely offset the rise in Upper Basin acreage from 2002 to 2007, so that the Colorado River

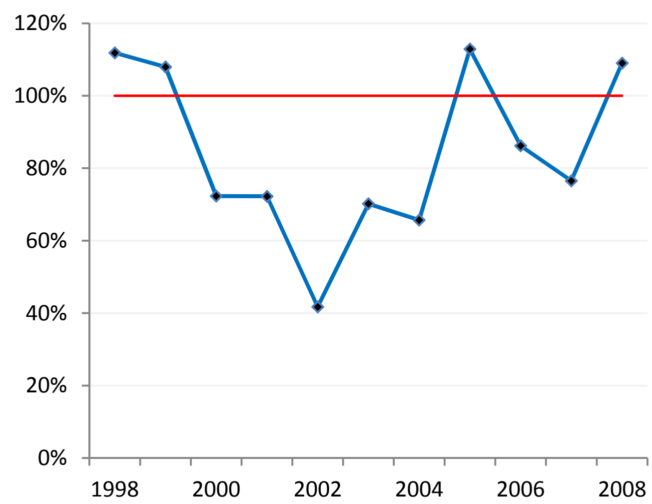

Figure 3. Colorado River "Natural Flow" at Lees Ferry 1998-2008 as Percent of Average
Source: USBR's **CURRENT natural flow data 1906-2008** updated 1/26/2011. Natural flow average for the period 1906-2008 reported as 15,023,000 acre-feet. Natural flow data reconstruct the flow of the river that would have occurred absent any diversions or consumptive uses. They are provisional and subject to change.

Basin in the U.S. as a whole showed a less than one percent change from 2002 to 2007. Total irrigated acreage in Mexico, as reported by agencies in Mexico, showed negligible change between 2002 and 2007.

While basin boundaries offer an informative means of categorizing acreage and comparing trends, the individual states manage water rights and transactions within their boundaries and so offer another important unit of measurement. Colorado River water allocations are divided both by areas of the basin – such as the Upper/Lower division in the 1922 Compact – and by individual state allocations. Although states typically are classified as being either Upper or Lower division,[13] Arizona, New Mexico, and Utah all have land in both basins. Table 3 shows irrigated acreage for the counties within the Colorado River basin as reported in 2007 by the agricultural census and as reported in 2005 by USGS. This table also shows irrigated acreages at the state level as reported by USBR for 2007, and as reported by the individual states, typically at the basin level, for 2007.

The total basin-level irrigated acreage as reported by the agricultural census in Table 2 is 63,000 acres (2.3 percent) less than the county-level irrigated acreage shown in Table 3, reflecting differences in study boundaries. USBR records for 2007 are about 1.2 percent greater than the total reported by the agricultural census in Table 2, reflecting similar basin boundaries.

Table 3. Irrigated Acreage in the Colorado River Basin, by State, 2007

	Source			
Acres (1000s)	USBR[a]	Census	USGS[b]	State
Wyoming	304	342	171	335
Colorado	754	643	695	822
Utah	368	322	321	351
(Upper)	343			332[c]
(Lower)	25			18
New Mexico	80[d]	102	103	108
(Upper)	80	78	80	80
(Lower)	[d]	24	23	28
Arizona	716[e]	876	949	n/r[f]
(Upper)	0.5			0.4
(Lower)	182[g]			502
Nevada	19[b]	33	21	n/r[f]
California	549	504[h]	504[i]	587
(Mainstem)	97			96
(SS basin)	452	452		490
U.S. Total	2,791[d]	2,820	2,765	2,704[d]
MEXICO	494	501		
(headwaters)		2		
(delta)	494	499		
Total	3,286	3,321		

Notes for Table 3 on the following page.

[13] The upper division states are Colorado, New Mexico, Utah, and Wyoming; the lower division states are Arizona, California, and Nevada.

Notes from Table 3:
In Table 3, the values listed under the agricultural census (abbreviated "census") and USGS represent the sum of county-level irrigated acreage, except for California. Please see individual state sections in Part I for the sources of individual state reports. Arizona does not report the total irrigated acreage within the state; the value listed in Table 3 only reflects the state's reported irrigated acreage within the Active Management Areas, for the year 2006. Please see the individual state discussions in the following sections for a detailed discussion of the differences between these reported values and a discussion of irrigated agriculture within each state more generally.
We made the following adjustments to reported data in an effort to approximate 2007 acreage. USBR's values are taken from the provisional 2006-2010 *Consumptive Uses and Losses Report*, supplemented by LCRAS-reported values for areas along the mainstem and the Salton Sea watershed. USBR's data for Arizona represent acreage reported in 2005 for the state, plus reported mainstem and Upper Basin acreage for 2007. USBR's reported acreage for the Lower Basin in Utah is from 2005, while the Upper Basin data are from 2007. The reported agricultural census data reflect census-reported acreage for Imperial County, plus self-reported acreage for CVWD and PVID, both in Riverside County. Reported values for Mexico in the 'USBR' column are from *CONAGUA* for the 2007-08 crop year, while those reported under the NASS column are from *OEIDRUS* for the 2006-07 crop year (crop years run from October to September; *CONAGUA* 2006-07 data were not available).
(a) USBR 2007 values are from *Consumptive Uses and Losses* report and are provisional. Reported acreage for Nevada and the Lower Basin acreage for Utah are from 2005, the most recent available. USBR acreages for California are from USBR's LCRAS report for 2007.
(b)2005 data
(c) As described in the Utah section, the state surveys and reports irrigated acreage in the four different planning areas in the Colorado River basin on a rotating six-year schedule. Values reported for the Upper Basin in Utah therefore are a mix of 2006 irrigated acreage in the Uintah Plan Area and 2005 acreages for the West Colorado River and Southeast Colorado River Plan Areas.
(d) incomplete
(e) The value shown for Arizona is the sum of USBR's reported Lower Basin 2005 acreage plus reported provisional Upper Basin 2007 acreage plus 2007 acreage as reported by USBR's LCRAS report for the mainstem (not included as part of the acreage reported by the USBR *Consumptive Uses and Losses* report for the Lower Basin).
(f) "*n/r*" – not reported
(g) USBR's reported 2007 acreage for Arizona only includes the mainstem
(h) The agricultural census reports irrigated acreage on the county level, including 376,535 acres in Imperial County. The census also reports about 168,000 irrigated acres in Riverside County; more than 41,000 of these acres (about 25 percent) lie outside the basin.
(i) Imperial County only.

As noted in the following sections, state-reported acreage is typically higher than that reported by other sources; the lower total shown in Table 3 reflects the absence of statewide reporting by Arizona and Nevada. Interestingly, the agricultural census county-level irrigated acreage and the USGS county-level irrigated acreage for Arizona are much higher than those reported by USBR.

Table 4 lists major crops grown in the Colorado River basin, as reported by the agricultural census. The crops listed account for roughly 90 percent of the irrigated acreage in the basin; others, such as sorghum, barley, corn, sugar beets, and seed crops, each comprise less than 2 percent of total irrigated area and are not listed in Table 4.

As shown in Table 4, 60 percent of the land in the basin is planted in forage and pasture. Alfalfa – a type of forage crop used to feed livestock – alone occupies more than a quarter of all irrigated land in the Colorado River basin. Alfalfa provides an important food source for the dairy industry. While the dairy industry is not the only consumer of alfalfa grown in the Colorado River basin, a brief examination of the recent trends in the industry in the seven basin states points to some similar trends in the numbers of dairy cattle and alfalfa acreage. Appendix B summarizes dairy industry trends to provide some background for the extent of alfalfa acreage in the basin.

Table 4. Colorado River Basin Major Crops and Acreages

Acres (1000s)										
Crop	AZ	CA	CO	NV	NM	UT	WY	US Total	Mexico	CRB Total	% total
Total Forage	307	289	332	17	37	124	208	1,315	79[a]	1,394[a]	41%
Alfalfa hay	257	181	157	-	29	104	55	783	79	863	26%
Other tame hay	28	97	119	-	0.2	10	21	285	-	275	8%
Pasture	53	2	263	8	15	153	131	628	23	651	19%
Wheat	86	43	41	-	-	0.1	-	169	250	420	12%
Vegetables[b]	138	96	4	-	11	0.1	-	250	30	280	8%
Cotton	171	22	-	-	-	-	-	193	60	253	8%
subtotal	754	452	641	25	64	277	339	2,555	443	3,077	89%
Total Irrigated	876	504	697	25	99	322	342	2,868	499	3,367	

Source: Agricultural census in 2007[c]

Notes: Acreages listed in Table 4 are total harvested crop acreages, rather than irrigated crop acreages. Some of this land is multi-cropped, so total crop acreages can exceed total listed irrigated acreage, especially in the Lower Basin where multi-cropping is prevalent.

With the exception of "Total Irrigated," Table 4 shows crop acreages, rather than irrigated acreages. Table 4 excludes crops with less than 5% total acreage, such as sorghum, barley, corn, sugar beets, and seed crops, so totals do not sum to 100%

(a) Incomplete information.

(b) Includes melons and potatoes.

(c) Data shown reflect summaries of county-level data, except California crop data calculated as agriculture census-reported data for Imperial County, plus CVWD and PVID self-reported crop data. Unfortunately, the agriculture census summaries by watershed only list selected crops and are not reported by the crop types listed in the table.

In some states in the basin, such as Wyoming and Nevada, pasture and forage crops constitute almost all reported acreage. In Table 4 and in the tables in the individual state sections, we report both total forage acreage and the acreages of one or more of the major forage crop types. To clarify the difference between pasture and forage crops, and the definitions of other crop types, please see the adjacent text box. A key difference between pasture and forage crops is that the latter are harvested, while animals graze pasture in the field.

Several states export water from the Colorado River basin for irrigation in areas outside of the basin. In some cases, such basin exports are used only for irrigation, but in many cases, such as the Colorado-Big Thompson project, the San Juan-Chama project in New Mexico, and the Colorado River Aqueduct in California, water is exported for agricultural and non-agricultural purposes. Typically, such exports supplement or mix with local water supplies prior to delivery to the end user, challenging efforts to quantify the volume of basin water exported for irrigation and the amount of land outside the basin irrigated with basin water. Based on available information, we were unable to quantify the acreage outside the basin irrigated with Colorado River water, or determine the types of crops grown on such land. According to information the states submitted to the Basin Study, total irrigated acreage in these adjacent areas is projected to be about 2,565,000 acres in 2015, almost 90 percent of the total irrigated acreage within the basin.[14] According to the Basin Study, total agricultural demand for

Crop Terminology

Forage - grasses, legumes, and other crops used as feed for livestock, such as alfalfa, hay, silage, or green chop.

Harvested Cropland - land from which crops were or will be harvested at any time during the year; this also includes any land with fruit, nut trees, vineyards, orchards, citrus groves, and greenhouse crops regardless of whether or not any quantity was harvested (except for abandoned orchards).

Hay - a crop which has been cut and cured by drying for storage; principally legumes, grasses, or grain crops.

Hay, other tame dry hay - hay harvested from clover, fescue, lespedeza, timothy, Bermuda grass, Sudangrass, sorghum hay, and other types of legumes (excluding alfalfa) and tame grasses (excluding small grains).

Hay, wild dry - hay harvested that was predominately wild or native grasses, even if it had some fill-in seeding of other grasses.

Irrigated acreage - includes all land watered by any artificial or controlled means, such as sprinklers, flooding, furrows or ditches, subirrigation, and spreader dikes; includes supplemental, partial, and preplant irrigation.

Pasture - an enclosed area of untilled ground covered with vegetation and grazed by animals.

Sources: USDA/NASS agricultural census and USDA/NASS "Terms and Definitions"

[14] We have adjusted these values to include the Salton Sea watershed within the Colorado River basin, shifting 551,000 acres from the Basin Study's "adjacent area" back into the basin.

Table 5. Water Use in the Colorado River Basin, by State, 2005

	Withdrawals (KAF)	Cons. Use (KAF)	Cons. Use (KAF)	Withdrawals (KAF)
State	USGS	USBR	State	State
Wyoming	610	315	396	1,191
Colorado	5,521	1,220	1,593	5,679
Utah	1,238	661		
Upper		572		
Lower		89		
New Mexico	441	223		433
Upper	294	210		295
Lower	146	13		139
Arizona	5,387	3,374		4,500
Nevada	89	66		
California	3,136[a]	3,463	3,227	3,777
Mainstem		389	423	623
SS Basin		3,074	2,764	3,113
U.S. subtotal	16,421[b]	9,320		
Mexico	2,126[c]			
Total	18,547[b]			

Notes: The year 2005 is shown in Table 5 because USBR's consumptive use records are still provisional post-2005 and to allow for comparison between USGS withdrawals reported for that year and USBR consumptive use volumes.
(a) Imperial County only
(b) incomplete
(c) source - *CONAGUA*

Colorado River water in these adjacent areas could be almost four million acre-feet in 2015, nearly 50 percent of the agricultural demand projected for lands within the basin.[15]

Table 5 shows irrigation water use within the Colorado River basin in 2005, as reported by USGS, USBR, and individual state agencies, reflecting the variability in reported values. USGS reports total withdrawals for irrigation, while USBR reports consumptive use, which can be defined as withdrawals less return flows. Note that the total reported withdrawals, including Mexico, sum to more than 18,500 thousand acre feet (KAF) (records for California are not complete), about 1,000 KAF less than the total virgin flow of the Colorado River in 2005 (USBR 2011). Although this may appear to mean that

[15] We have adjusted these values to include the Salton Sea watershed within the Colorado River basin, shifting about 3,230 KAF of agricultural demand from the Basin Study's "adjacent area" back into the basin.

irrigation diverts almost the entire flow of the river, in reality it reflects the multiple diversions and returns of Colorado River water, as well as other diversions of tributary waters and extraction of groundwater in the basin. Comparisons between USGS withdrawals and USBR consumptive use should recognize the different accounting methods used by the two agencies, but such a comparison does give a general sense of the relative magnitude of the two types of water use. Figure 4 shows the total volume of applied water by basin, as reported by FRIS; the water agencies in the Salton Sea watershed (not reported by FRIS for the Lower Basin); and by Mexico's water agency. The volume of applied water, i.e., the volume of water actually delivered to the field, falls between the total volume of withdrawals reported by USGS and the volume of consumptive uses reported by USBR: these are all separate and distinct terms and volumes. Mexico's water agency reports a volume more akin to withdrawals than to applied water, so the volumes shown for Mexico in the figure are greater than they would be if reported as applied water.

Figure 4 shows the sharp increase in applied water volumes from 2003 to 2008 in every region except the Salton Sea basin. The roughly 20 percent increase in Upper Basin applied water over this period likely reflects the supply limitations imposed by the lingering effects of the 2002 drought and continued below-average run-off in 2003 (see Figure 3). This is supported by the FRIS reports, which show a 25 percent increase in Lower Basin applied water use from 2003 to 2008. In both years, total Lower Basin applied water use (including the Salton Sea watershed) was roughly 50 percent higher than the combined water use of the Upper Basin and Mexico.

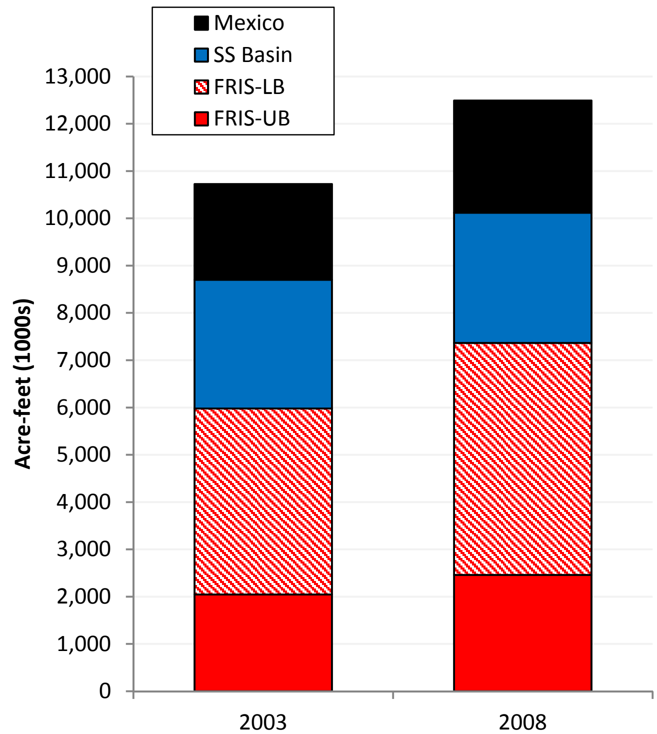

Figure 4. Water Applied for Irrigation in the Colorado River Basin, 2003 and 2008

Sources: FRIS, IID, CVWD, and *CONAGUA* (Mexico)[a]

Notes:

(a) Values shown reflect volumes of water applied to the field ("Delivered to farms" for IID and CVWD), except for Mexico, which are only defined as "Deliveries" and include total diversions and groundwater extractions. Total water withdrawals can be 21 percent higher than the applied water volumes shown for the U.S. portions of the basin.

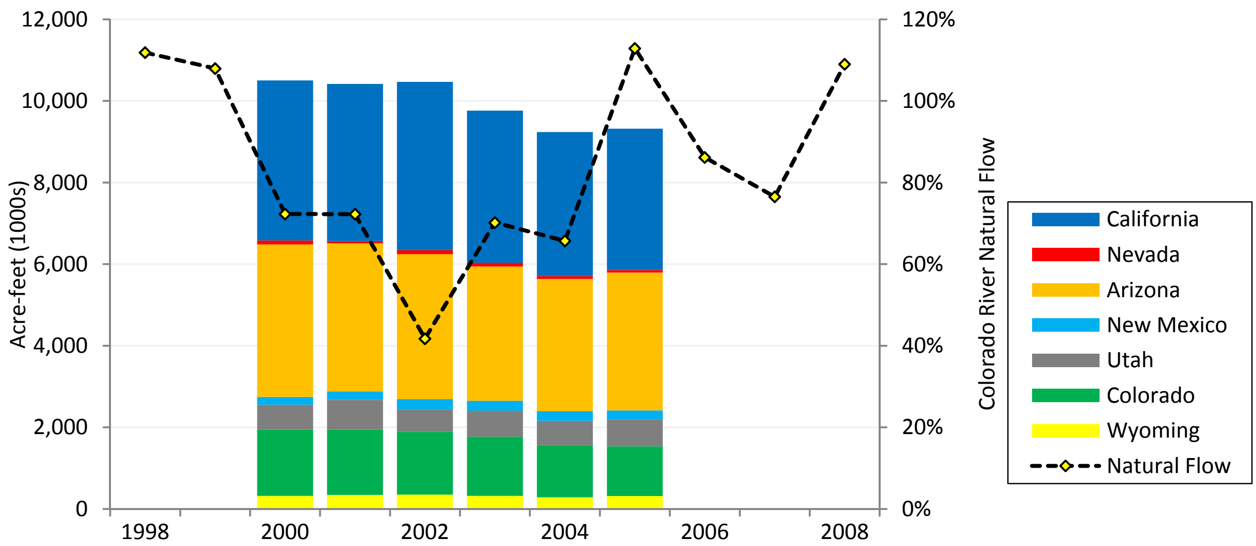

Figure 5. Consumptive Uses for Irrigation by U.S. Basin States, 2000-2005
Source: USBR (2011)

Figure 5 shows the volumes of consumptive use by irrigation within the basin reported by USBR for the seven basin states for the years 2000-2005 (the most recent available for the Lower Basin), showing annual changes in use over time. For context, the figure also shows USBR's estimated natural (undepleted, undiverted) flow of the Colorado River at Lees Ferry for the years 1998-2008, showing the above-average flows at the end of the last century that filled system reservoirs and insulated total consumptive uses – especially in the Lower Basin – from the multi-year drought that began at the end of 1999.

Figure 5 clearly shows the decline in use that began in 2003 and the roughly 11 percent decrease in consumptive use from the early to the middle part of the decade, reflecting sharp declines in Lower Basin consumption.[16] Figure 5 also depicts the relative irrigation uses by the different basin states, dominated by California and Arizona and with much smaller volumes consumed by Nevada, New Mexico, and Wyoming. In most years, the combined total irrigation use of Colorado River basin water by these three states is lower than that of Utah, the next lowest state. The following sections describe irrigated agriculture in the basin for each of the individual basin states and for Mexico.

Wyoming

Wyoming, home of the headwaters of the Green River and the northernmost of the basin states, contains 17,125 square miles of land within the Colorado River Upper Basin (WY State Engineer's Office (WY SEO) 2010). Average annual precipitation near Pinedale is about ten inches, and about an inch less near Green River. The average frost-free growing season in Pinedale is 132 days and is 175 days in Green River (Pochop et al. 1992). Irrigated agriculture in Wyoming's portion of the Upper Colorado River basin – known as the Green River Basin – occurs predominantly in river valleys, at elevations ranging from about

[16] Consumptive use by irrigation in the Lower Basin states fell by 666 KAF from 2002 to 2003, a decline of more than 9 percent in one year.

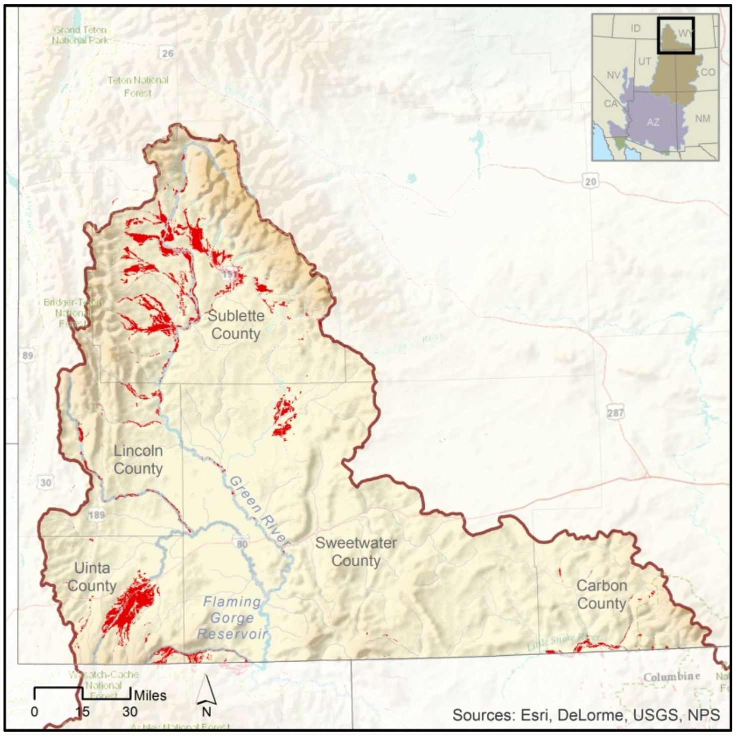

Figure 6. Agricultural Lands (in red) in Wyoming's Green River Basin

Source: USGS

Notes: Figure 6 shows the differences between county and watershed boundaries, important here because several agencies report data by political rather than hydrologic units. Sublette and Sweetwater counties lie predominantly within the basin; Uintah and Lincoln counties contain irrigated land within the Colorado River basin, but also contain an additional 63,900 acres in the Bear River basin (*Bear River Basin Report* 2001). Carbon County includes some 15,000 acres in the Colorado River basin, but lies predominantly outside of the basin. For the county-based reports (USGS and NASS), we included Lincoln and Uintah counties as part of the Colorado River basin total, but not Carbon County, and then adjusted the total acreage downward by 49,000 acres (=63,900-15,000) for these two county-based sources, to reflect lands outside the basin.

6,100 feet near the City of Green River, to more than 7,500 feet in several areas of the basin. The average elevation of all irrigated lands in the basin is over 7,000 feet. Figure 6 shows agricultural land within the basin in Wyoming.

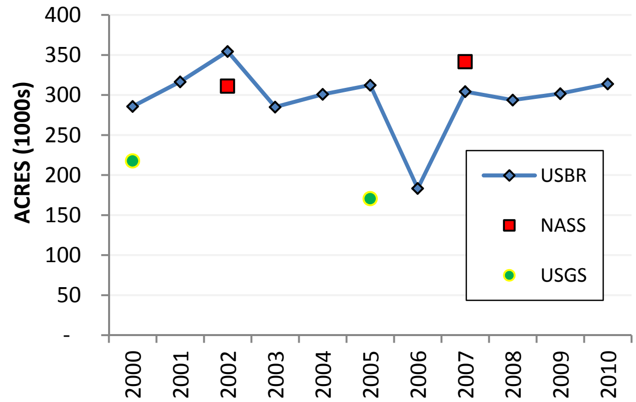

Figure 7. Irrigated Acreage in the Colorado River Basin in Wyoming, 2000-2010

Sources as shown in legend;[a] USBR 2006-2010 data are provisional and subject to change.

Notes:

(a) NASS county data for Lincoln, Sublette, Sweetwater, and Uintah counties, plus 15,000 acres in Carbon County minus 63,900 acres in Lincoln and Uintah counties that actually lie within the Bear River basin.

Figure 7 shows the extent of irrigated acreage in the Green River basin in Wyoming for the years 2000-2010, as reported by the various sources. Interestingly, USBR's data shows the highest irrigated acreage in 2002,a year that saw roughly half the average annual flow in the Green River (USBR 2011). With the exception of an anomalous low in 2006, USBR data have varied from year to year but show no overall trend. The agricultural census acreages show a slight increase from 2002 to 2007, but with only two data points, it is hard to draw robust conclusions. Both the USBR and agricultural census data are fairly consistent, while USGS acreages are very low relative to other sources. We could not determine the reason for the anomalous acreage USBR reported for 2006; this may simply be a result of the provisional 2006-2010 data and may be changed in USBR's final report. USGS reported half the amount of irrigated acreage in 2005 that the agricultural census reported for the same counties in 2007; average irrigated acreage as reported by USGS was at least a third lower than that reported by any other agency. According to

USBR, the amount of irrigated acreage in the basin decreased by 51,000 (14 percent) from 2002 to 2007, while the agricultural census reports a 31,000 acre (10 percent) increase between the two years. USGS reports a roughly 20 percent decline in irrigated acreage from 2000 to 2005, while USBR reports a 9 percent increase in that period. The state of Wyoming reports an average estimate of 334,500 irrigated acres[17] in the basin (*Green River Basin Report* 2010).

According to 2002 and 2007 agricultural census data, about two-thirds of the total irrigated acreage is in forage crops, and another third is irrigated pasture that is grazed but not cut or harvested. These pasture and forage crops are closely linked to the state's livestock industry. According to the agricultural census, there were about 150,000 cattle and calves, and about 84,000 sheep and lambs, in the four counties in the basin in 2007. As Wyoming's *Green River Basin Report* (2010) states:

> Water supply and growing season are the factors most often given for the predominance of grasses under irrigation. In this sense, irrigated agriculture is tied very closely to the livestock industry because the only viable use for the hay is as forage. Typically the forage is used by the producers' herds although some is disposed through local sale or export from the Basin.

Like most of the basin, there is not sufficient precipitation in Wyoming to grow crops without irrigation. According to Wyoming's *Green River Basin Report* (2010), monthly records of diversion structures show five-to-six months of surface-water diversions throughout the basin. The annual duration of diversions is highly variable, dependent on weather and water supply. Although most irrigators would like to irrigate in the fall to increase soil moisture, many do not have water available.[18] The disparity between the growing season and the irrigation season occurs because irrigators initiate diversions before the start of the growing season, to moisten the soil and recharge shallow aquifers. Irrigators continue diversions after the harvest, to maintain a shallow water table[19] and to maintain late season pasture.

Water use estimates for Wyoming's portion of the Upper Basin are highly variable. According to the state's Green Basin Water Plan (2010), for example, Wyoming's total Upper Basin depletions were 604 KAF annually,[20] including about 398 KAF by irrigated agriculture and livestock, 120 KAF from in-state reservoir evaporation, and about 80 KAF by municipal and industrial uses.[21] Wyoming's State Engineer's Office (WY SEO) reports average annual irrigation depletions at 396 KAF, although it does not report depletions for individual years. WY SEO estimates annual average groundwater depletions in the Green River basin at about 8

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[17] Wet and dry years see some ten percent more or less irrigated acreage in the basin, respectively. The Wyoming State Engineers Office (SEO) has completed three irrigated lands surveys over the last 12 years using aerial and Landsat imagery. Though the number of irrigated acres varies each year due to water supply, the SEO reports an average of 334,500 acres irrigated over these three surveys. The SEO maintains that its reported acreage is accurate and acreages reported by the federal agencies are incorrect.

[18] Source: Steve Wolf, Colorado River Coordinator, Interstate Streams Division, Wyoming State Engineer's Office, personal communication, 12/18/2012.

[19] Source: Eric Peterson, Retired Extension Educator, Sublette County and now Manager, Sublette County Conservation District, personal communication, 10/11/2012.

[20] USBR's provisional Consumptive Uses & Losses report states that Wyoming's total average annual consumptive use of Colorado River basin water for the years 2006-2010 was 382 KAF, including some in-state reservoir evaporation.

[21] Wyoming exports an annual average of 17 KAF (2006-2010) from the Green River basin to M&I users in the Cheyenne area. There are three other very small agricultural exports from the basin, and one very small agricultural import to the basin. All together they account for less than 1 KAF per year on average.

KAF, while USGS reports about 55 KAF per year in groundwater withdrawals for irrigation in the four counties in the basin. Even accounting for the differences in scope and measurement, these are very different values. Wyoming's own reported depletions for irrigated agriculture in the basin are about a third higher than USBR's reported average consumptive use. This works out to about 10 percent higher in terms of consumptive use or depletions per irrigated acre.

Figure 8 shows total estimated water use for irrigation as reported by USBR and USGS. While USGS reports a roughly 25 percent decline in withdrawals for irrigation from 2000 to 2005, USBR reports a less than 2 percent decline in consumptive use over that period. USBR does report a roughly 10 percent decline in consumptive use from 2000 to 2010, interesting given the roughly 10 percent *increase* reported in total irrigated acreage over that period.

Summary

The reported extent of irrigated land in the Colorado River basin within Wyoming ranged from a low of about 170,000 acres in 2005 (USGS) to a high of 354,500 acres in 2002 (USBR), with no clear trend over the past decade. For the period 2000-2010 as a whole, USBR records give an average value of about 296,000 irrigated acres, lower than the 334,500 reported by Wyoming itself. Almost all of this land is in irrigated pasture and forage, to feed livestock. USGS reported 774 KAF of withdrawals for irrigation in 2000, while USBR reported an average of about 303 KAF of consumptive use for irrigation over the decade, with a general decline from about 320 KAF to 280 KAF from 2000 to 2010. For the Basin Study, Wyoming does not project any significant changes in the amount of irrigated acreage in the basin in the next fifty years.

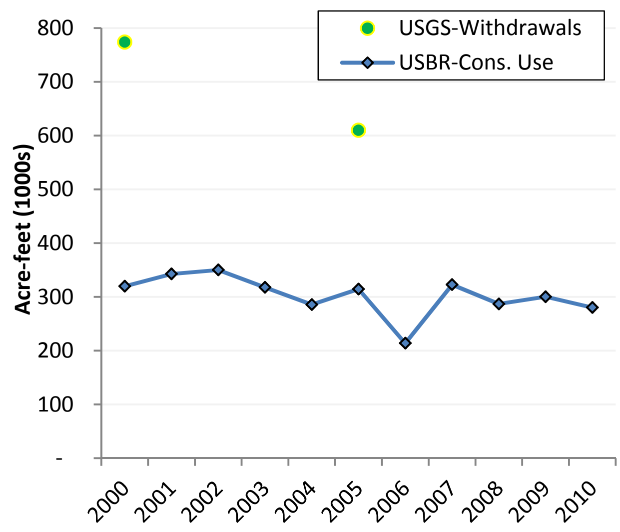

Figure 8. Irrigation Water Use in Wyoming's Portion of the Colorado River Basin, 2000-2010

Note: Values for 2006-2010 are provisional and subject to change.

Colorado

Colorado is home to the headwaters of the Colorado River and to the headwaters of several of the river's major tributaries. About 38,500 square miles of the Upper Basin lie in Colorado, generating more than 50 percent of the river's total virgin flow at Imperial Dam.[22] Figure 9, from Colorado's *State Water Supply Initiative 2010* report (CWCB 2011), shows Colorado's portion of the Upper Basin in blue and eastern drainages in green. Colorado divides its portion of the Upper Basin into four administrative divisions, named Gunnison, Colorado River, Yampa/White, and San Juan/Dolores[23]; the "Colorado River" here refers

[22] Source: USBR (2011)

[23] The CO DWR designation of Division 7 ("San Juan/Dolores") only includes part of the Dolores watershed, as shown in the map posted at http://water.state.co.us/DivisionsOffices/Pages/default.aspx. The CWCB and CDSS designated Division 7, also named "San Juan/Dolores," includes the full Dolores watershed, as shown in the map posted at http://cdss.state.co.us/basins/Pages/BasinsHome.aspx.

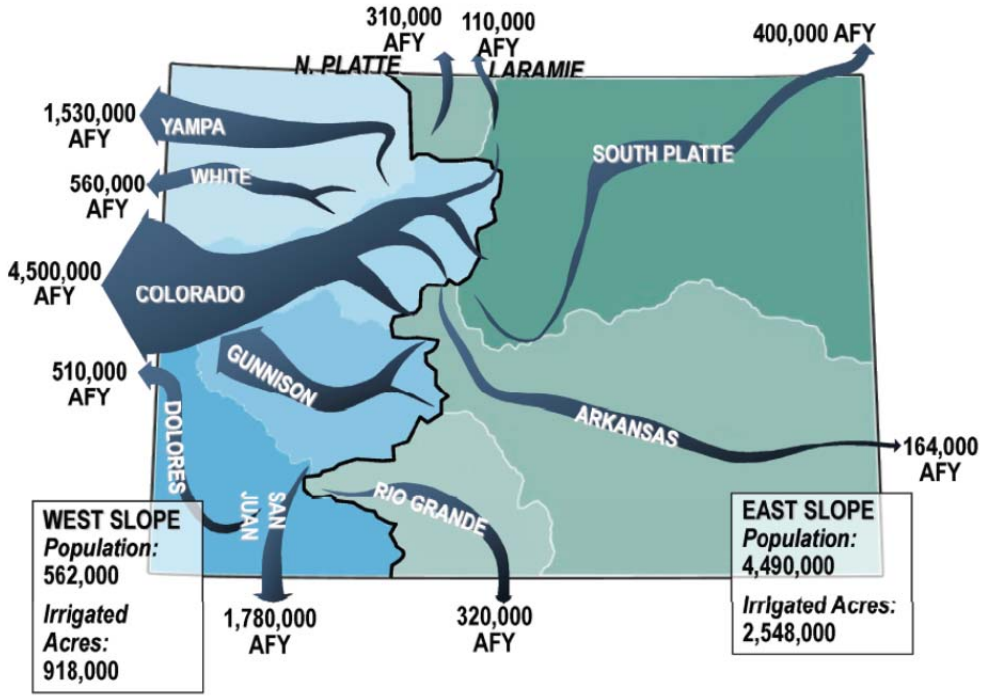

Figure 9. Colorado's River Basins and Yields
Source: CWCB 2011

to the river's mainstem, though all four divisions are part of the basin as a whole.[24] Some 80 percent of the state's total surface water yield occurs west of the continental divide, in the Colorado River basin, while 80 percent of the state's population lives east of the divide (CWCB 2011).

Much of the basin in Colorado is mountainous or forested land, unsuitable for irrigated agriculture. For example, both USGS and the NASS agricultural census reported no irrigated agriculture at all in southwestern Colorado's San Juan County (see Figure 10). Colorado's portion of the Upper Basin includes a host of 14,000-foot peaks along the Continental Divide, falling in elevation to about 4,600 feet in Grand Junction and about 4,100 feet near Cortez, at the Utah border. The frost-free growing season lasts about 228 days near Grand Junction, and less than three months at high elevation sites, typically used for irrigated pasture and grazing. There are hundreds of thousands of irrigated acres in the basin, concentrated in large river valleys such as the Uncompahgre and the Grand, in the western and southwestern portions of the state.

Figure 11 on page 23 shows total irrigated acres in the basin in Colorado, as reported by the three federal sources and Colorado's Division of Water Resources (CO DWR). The average irrigated acreage reported by CO DWR and by USBR for the period 2000 to 2007 differs by only about 55,000 acres (7 percent), much greater agreement than with the county-based irrigated acreage reported by the agricultural census[25] (NASS, in the figure) and USGS data. The vast majority of the irrigated acreage occurs in counties included in the summary data shown in the figure.[26]

[24] CO DWR's Division 6 and CDSS' Division 6, both called the "Yampa/White," both include "District 47," the North Platte basin, which is not part of the Upper Colorado River Basin; it lies to the east of the continental divide.

[25] Although the agricultural census suppresses data that could allow any particular producer to be identified, the county-level data summarized in the figure do not appear to have been affected by these data suppression efforts.

[26] We included the following counties in the basin list: Archuleta, Delta, Dolores, Eagle, Garfield, Grand, Gunnison, Hinsdale, La Plata, Mesa, Moffat, Montezuma, Montrose, Ouray, Pitkin, Rio Blanco, Routt, San Juan, San Miguel, and Summit. We did not include Saguache County, because most of the county falls within the Rio Grande basin. The 2007 agricultural census reported 103,292 irrigated acres in Saguache County as a whole, but does not disaggregate those data by basin. According to a GIS analysis of the state's CDSS data, 8,900 acres of irrigated Saguache County land lie within the Colorado River basin; roughly 93,000 irrigated acres in Saguache County lie in the San Luis Valley, in the Rio Grande basin.

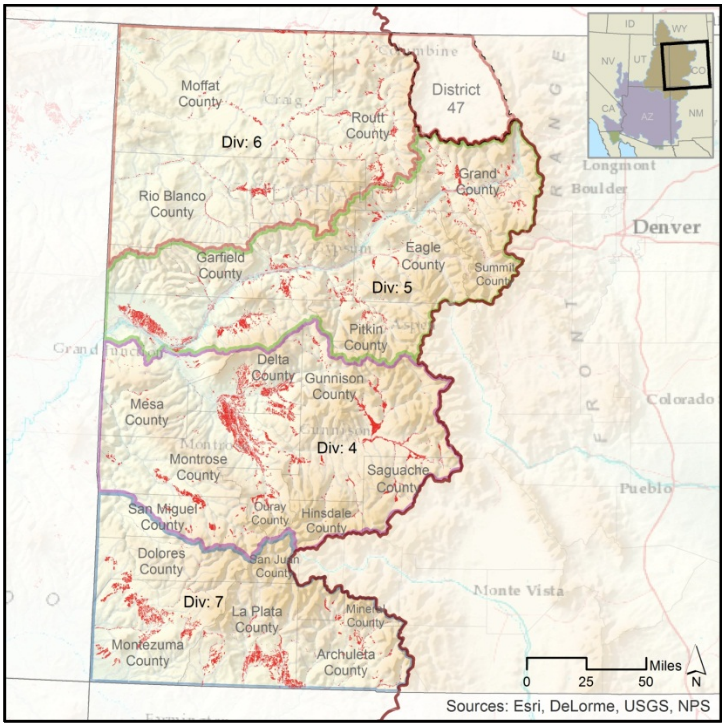

Figure 10. Colorado's Agricultural Lands (in red) in the Colorado River Basin
Source: USGS.

The State of Colorado's Division of Water Resources and the related Decision Support System (CDSS)[27] report different irrigated acreages for the state's portion of the Upper Basin. CO DWR reports irrigated acreage for each administrative division, compiled from data submitted by individual irrigators.[28] Through 2007, annual reports[29] from CO DWR provided irrigated acreage for each division. CDSS reports total irrigated acreage for each division based on remote-sensing imagery, for the years 2000 and 2005.[30] As shown in the figure, in 2000 the CDSS-reported irrigated acreage in the basin was more than 6 percent lower than that reported by CO DWR. In 2011, the Colorado Water Conservation Board (CWCB) released its *Statewide Water Supply Initiative* (SWSI), projecting future irrigation demands and consumptive use for each water district based on climatic records and constant acreages for each district over the period 1997-2006. SWSI's historic irrigated acreages differ from both the CO DWR self-reported acreages and from the CDSS image-based acreages.[31]

USBR's reported acreages vary across the period shown in Figure 11, reflecting the dependence of parts of the basin on run-of-the-river diversions, rather than deliveries from storage. Unlike irrigators in the Lower Basin who rely on mainstem water delivered from storage, many Upper Basin irrigators, especially those with more junior water rights, are dependent on average or above-average run-off to irrigate their fields. There is some inconsistency in the data but overall trends are consistent. CO DWR, reporting water-user-supplied records, notes an almost 25 percent decline in irrigated acreage from 2001 to the 2002 drought year, greater than the 7 percent decline reported by USBR. USBR records suggest that Colorado irrigated acreage did not recover from the 2002 drought for more than five years. Records from CO DWR, however, suggest that irrigated acreage within the state had largely recovered within three years.

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[27] CDSS "provides a water management system that supports the missions of both the CWCB and DWR by providing information and tools to users, enabling them to make better management decisions related to Colorado's limited water resources." See http://cdss.state.co.us/Pages/WhatisCDSS.aspx.
[28] CO DWR will no longer report user-supplied acreage, but will rely on CDSS work in the future.
[29] Source: *Cumulative Yearly Statistics of the Colorado Division of Water Resources.*

[30] CDSS expects to release its irrigated acreage data for 2010 in spring 2013.
[31] For example, for the year 2005, CDSS reports total irrigated land in Division 7 as 216,075 acres while SWSI reports it as 259,000 acres.

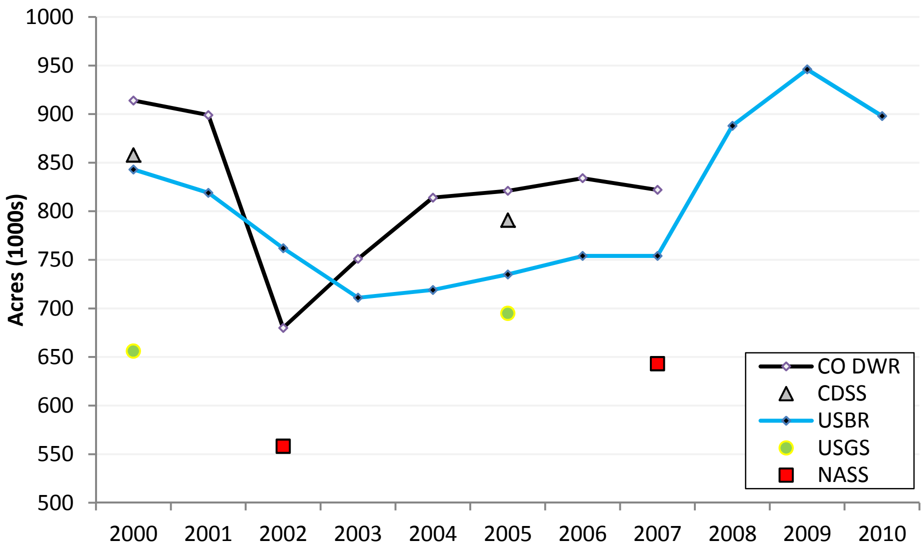

Figure 11. Irrigated Acreage in Colorado's Portion of the Basin 2000-2010 , by Reporting Agency

Notes: CO DWR values from *Cumulative Yearly Statistics of the Colorado Division of Water Resources*, showing data for the irrigation year (November through October) rather than calendar year. These acreages are reported by the water users themselves. Acreages are only provided through the 2007 irrigation year. We have adjusted the totals reported for Division 6, the "Yampa/White," to remove the acreage reported for District 47, the "North Platte," which is not part of the Colorado River basin. CDSS values were taken from GIS data sets, showing irrigated land and other coverages for the individual divisions, posted at: http://cdss.state.co.us/GIS/Pages/GISDataHome.aspx. These values were also adjusted to remove the acreage reported for District 47. Unfortunately, the CDSS data is only reported for the years 1993, 2000, and 2005; 2010 data is being compiled for release this spring. USGS and agricultural census (NASS) values do not include approximately 9,000 irrigated acres in Saguache County, which includes about 93,000 irrigated acres in the Rio Grande basin.

Figure 12 depicts annual irrigated acreage in the four water divisions within the basin in Colorado, as reported by CO DWR. Note the significant decline in reported acreage shown in three of the four water divisions in 2002 – the third driest year on record in the basin, when run-of-the-river diversions were curtailed severely – and the lack of any change at all reported for the Gunnison division that year, or in the several years following. In fact, reported acreage in the Gunnison division is effectively constant for the entire period, suggesting that irrigators keep all land in production and simply reduce the volume of irrigation or that reported annual acreages for the Gunnison division might not reflect actual irrigated acreage in the division.[32] In comparison, the agricultural census numbers (not shown in the figure), which like the CO DWR data rely on reports of irrigated acreage submitted by the irrigators themselves, show a 12.7 percent increase in irrigated acreage from 2002 to 2007 for representative counties in the Gunnison Division,[33] while the CO DWR data shows a 2 percent decline over this period. As reported by CO DWR, three of the four divisions had the same irrigated acreage in 2006 as reported in 2005. CO DWR reports that three of the four divisions experienced major declines in irrigated acreage in 2002. Of these, the Yampa/White had largely recovered by 2005, but the San Juan/Dolores only returned to about 90 percent of its previous maximum acreage and the Colorado River division only returned to about 83 percent of its previous maximum.

[32] Note that these acreages are reported by the water users themselves. The irrigated acreage reportedly did not change on the County Assessor's roles.

[33] Delta, Gunnison, and Montrose counties represent about 62 percent of total irrigated acreage in the Gunnison Division as reported by CO DWR for 2007.

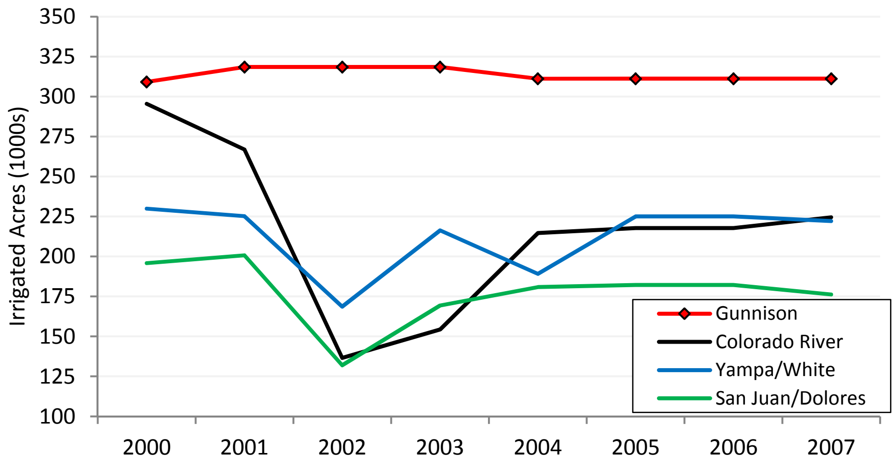

Figure 12. Irrigated Acreage by Division in Colorado, 2000-2007
Source: *Cumulative Yearly Statistics of the Colorado Division of Water Resources* and CWCB data from spreadsheets, via email.

Table 6 lists reported crop and pasture acreages for counties in the basin. Note that the sum of forage and pasture acreages represents more than 85 percent of total reported agricultural land in production in Colorado's portion of the Upper Basin. A single crop – alfalfa – alone accounts for almost a quarter of the acreage. As in Wyoming, forage and pasture are closely tied to the livestock industry. In 2007, the agricultural census reported 313,300 cattle and 150,600 sheep in Colorado's counties in the Upper Basin.

Note that percentages refer to total harvested cropland rather than irrigated land and are rounded.

Precipitation varies dramatically throughout the Upper Basin in Colorado. Some high elevation areas such as Crested Butte receive more than 24 inches of precipitation annually, distributed fairly uniformly over the year, while lower elevation areas such as the Uncompagre Valley near Delta receive as little as 8 inches annually.

Table 6. Colorado Crop Acreage in the Basin, 2007

Crop	Acres	
Forage	332,299	48%
Alfalfa[a]	*157,495*	*23%*
Pasture	263,748	38%
Wheat	40,532	6%
Dry beans	20,770	3%
Corn	16,571	2%
Vegetables	3,977	1%
Sunflower seed	7,065	1%
Peaches	1,806	0.3%
Oats	1,323	0.2%
Apples	1,087	0.2%
Total	695,981	

Source: Agricultural Census
Notes: We used agricultural census county-level acreages here, excluding Saguache County, because most of that county's agriculture lies outside of the Colorado River basin. The table lists total crop acreages because irrigated acreage is not listed for most of these crops. Total irrigated acreage in these same counties is about 8.5 percent lower; that is, about 8.5 percent of crops in Colorado's portion of the Upper Basin are not irrigated.
(a) Alfalfa is a type of forage, shown here to highlight the acreage dedicated to this single crop

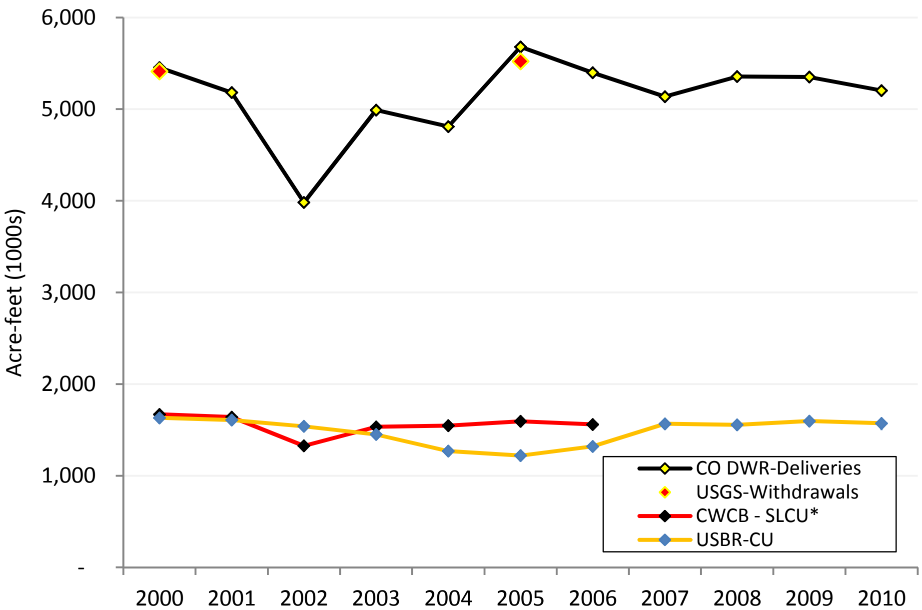

Figure 13. Irrigation Water Use in Colorado's Portion of the Basin 2000-2010, by Reporting Agency

Notes: USBR-CU values show consumptive use for irrigation only. *"Supply-limited consumptive use."[a]

(a) CWCB has reconstructed consumptive use by estimating crop use based on detailed climate records, though these estimates all assume constant irrigated acreage. One of the key themes of the *Crop Consumptive Use* reports for each basin is that crop irrigation requirements are not met, due to limited water availability: "The percent of irrigation water requirement not satisfied averaged 17 percent over the study period. Shortages averaging 17 percent from 1990 through 1996 are consistent with normal average flows. Shortages increased to a 22 percent average over a period in the early 2000s due to drought conditions. Shortages reached a maximum in 2002 of approximately 36 percent" (Leonard Rice Engineers 2009).

To be productive, farmers typically must irrigate their crops and pasture. Figure 13 shows volumes of water used for irrigation in the basin over time, as reported by the different agencies. Note that USBR reports consumptive uses, USGS reports withdrawals, CO DWR reports deliveries, and CWCB reports "supply-limited consumptive use."[34] Figure 13 shows several key points. Despite the range of irrigated acreage reported by the different agencies, USGS's total withdrawals closely mirror CO DWR's "deliveries," while USBR- and CWCB-reported consumptive uses are generally consistent. For the period 2000-2006, USBR-reported consumptive use is about 8 percent lower than that calculated by CWCB.

Figure 13 also shows some important differences between the water uses reported by the agencies. USBR reported a roughly 4 percent decline in consumptive use from 2001 to 2002, while CO DWR reported a roughly 25 percent decline in total diversions in that period. Colorado reports that total diversions rose markedly in 2003 and by 2004 had roughly returned to pre-drought volumes, while USBR reports total consumptive use continuing to decline through 2005 and not approaching pre-drought levels until 2007. USBR's consumptive use numbers do not reflect the variability in deliveries reported by CO DWR.

Irrigators in Colorado's portion of the Upper Basin have very limited dependence on groundwater: USGS reports groundwater withdrawals at about 0.5 percent of total withdrawals. USGS and USBR both report very limited water use for livestock, from either groundwater or surface water.

USBR reports the state's total annual average consumptive use of basin water as 2,197 KAF for the period 2000-2010, for all uses. According to USBR's *Consumptive Uses and Losses* reports, from 2000 to 2010 Colorado exported an average of 544 KAF per year to the east, out of the basin, for agricultural and municipal uses. Slightly less than half of this water is exported by the Colorado-Big Thompson project, which provides some of the water used to irrigate some 630,000

[34] CWCB asserts a higher consumptive use co-efficient for acreage above 6500' than does the USBR, as described in reports such as Leonard Rice Engineers, Inc, 2009, *Historic Crop Consumptive Use Analysis: Gunnison River Basin*, prepared for the Colorado Water Conservation Board. Colorado officials disagree with USBR's method and approach to determining consumptive use for the state.

acres of land in northern Colorado, and also goes to thirty different cities along the Front Range and farther east.[35]

Colorado's recent water supply planning report (CWCB 2011) projects that total irrigated acreage within the basin will decline by as much as 161,000 acres by 2050, due to urbanization of existing land and planned agriculture-to-urban water transfers.[36] CWCB's projections are based on adjusted 1993 acreages, which are almost 130,000 acres higher than the irrigated acreage CDSS reported for 2005, suggesting that most of the decline in irrigated acreage has already occurred or that substantial additional reductions in irrigated may still be seen in the next 40 years.

Summary

The reported extent of irrigated land in the Colorado River basin within Colorado ranged from a low of about 558,000 acres in 2002 (agricultural census) to a high of 946,000 acres in 2009 (USBR, *provisional*). USBR and the state both reported a decline in irrigated acreage in the early part of the decade and subsequent recovery in the middle and latter part of the decade. Colorado's Division of Water Resources (CO DWR) reported irrigated acreages for 2000-2007 are about 7 percent higher on average than those reported by USBR, but both are 20-30 percent higher than the irrigated acreages reported by USGS and the agricultural census. For the period 2000-2010 as a whole, USBR records give an average value of about 900,000 irrigated acres for the state. According to the agricultural census, about 86 percent of this land is in irrigated pasture and forage, to feed livestock, with the remainder in wheat, dry beans, corn, vegetables, and other crops. CO DWR and USGS reported very similar volumes of deliveries or total withdrawals for irrigation, peaking at about 5,679 KAF in 2005, with a low of 3,981 KAF in the 2002 drought year. Interestingly, USBR reported the lowest consumptive use by irrigation in 2005, at 1,220 KAF, with an average volume of 1,484 KAF over the decade. Colorado's recent water supply planning report (CWCB 2011) projects that total irrigated acreage within the basin will decline by as much as 161,000 acres by 2050, due to urbanization of existing land and planned agriculture-to-urban water transfers.

Utah

Utah, an Upper Division state, is home to the headwaters of the Duchesne River in the Upper Basin and the Virgin and Paria rivers in the Lower Basin, as well as to those of many smaller tributaries. Some 37,200 square miles of the Upper Basin lie in Utah, as well as 3,500 square miles of the Lower Basin. As shown in Figure 14, Utah has three basin planning areas within the Upper Basin and one in the Lower Basin. Utah's Division of Water Resources (UT DWR) has not published a basin plan for any of these four areas since 2000, though it continues to publish information on irrigated acreage in the individual areas on a rotating schedule.[37] St. George, in the Virgin River watershed in the Lower Basin, lies at about 2,600 feet and enjoys a seven-month frost-free growing season, with about 8.3 inches of annual precipitation. Duchesne, in the Uintah watershed in the Upper Basin, lies at about 7,100

[35] CBT water is mixed with water from other sources. According to information Colorado submitted to the Basin Study, approximately 187,000 acre-feet are exported from Colorado's Upper Basin to the South Platte basin (in the northern part of the Front Range) to supplement irrigation on 534,000 acres, and an additional 148,000 acre-feet are exported from Colorado's Upper Basin to the Arkansas basin to supplement irrigation on 198,000 acres.

[36] We calculated the reduction of 161,000 acres as the difference between the "Table 4-10 Current Irrigated Acres by River Basin" and the irrigated acres listed by basin in Table 4-13 of SWSI 2011.

[37] See Utah's water-related land use inventory reports, posted at http://www.water.utah.gov/planning/landuse/publ.htm.

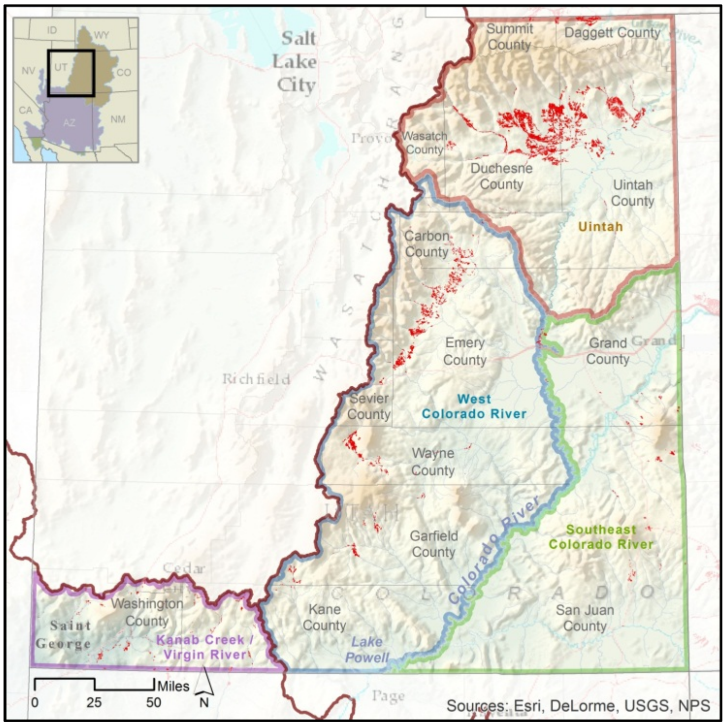

Figure 14. Utah's Basin Plan Areas and Agricultural Lands (in red).
Source: USGS

feet with about 9.5 inches of annual precipitation; in parts of the county, the growing season is only 87 days.

Utah surveys its irrigated acreage by Plan Area on a roughly six-year rotating schedule and reported total irrigated land in each basin in its 2001 state water plan.[38] The state information enables comparisons between the state's different Plan Areas and identification of trends within each area. Table 7 shows the relative size of the four planning areas, along with their irrigated acreage and estimated water withdrawals and depletions (consumptive use) as reported by individual basin reports and from the state's State Water Plan, showing data from the 1990s.[39] Note that the Uintah area has more irrigated acreage than the total combined acreages of the other three Plan Areas. As shown in Table 7 on the next page, depletions represent slightly more than half of total water withdrawals in the Uintah, West, and Southeast planning areas, but only about 40 percent of total diversions in the Virgin River planning area. Total depletions per acre are also much higher in the Virgin planning area. These water use differences are at least partly driven by climate.

USBR reported that total irrigated land within the basin in Utah in 2000 was about 303,600 acres, lower than the state's own estimate of 319,600 acres and considerably lower than the USGS reported total of 350,600 acres. This may reflect differences in accounting methods, as USBR reports irrigated acreage by basin within the state, while USGS and the agricultural census report irrigated acreage only at the state and county levels.[40]

[38] The Utah State Water Plan and individual basin reports are available at http://www.water.utah.gov/planning/waterplans.asp. Values reported in the state water plan for the state as a whole are a mix of previous years' information and do not reflect the report year.

[39] The Virgin basin report cites a 1983 study, meaning this information is now 30 years old.

[40] We included irrigated acreages for the following counties within the Colorado River basin: Carbon, Daggett, Duchesne, Emery, Grand, Kane, San Juan, Uintah, and Wayne. We also included irrigated acreages for Garfield and Washington counties, which predominantly lie within the basin.

Table 7. Utah's Basin Plan Areas and Irrigated Acreage

Basin	Area (sq. miles)	Irrigation (acre-feet)		Irrigated (acres)	Depletion (per acre)	Year
		Diversion	Depletion			
Uintah	10,890	797,610	411,310	201,120	4.0	1994
Southeast	10,900	34,950	18,430	8,929	3.9	1996
West	15,411	285,050	156,200	91,900	3.1	2000
Virgin	3,485	123,300	51,300	25,600	4.8	1983

Source: Utah State Water Plan - basin reports

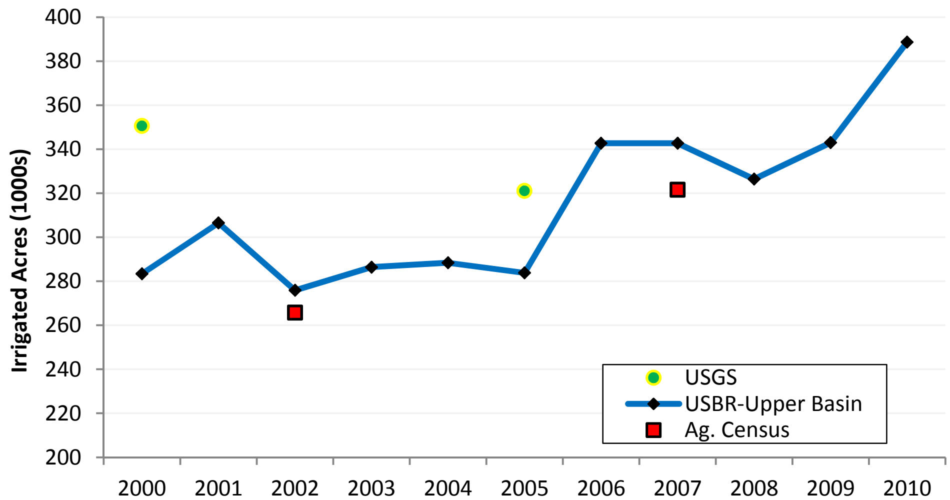

Figure 15. Irrigated Acreage in Utah's Portion of the Basin, 2000-2010, by Reporting Agency

Notes: The figure only shows Upper Basin acreage as reported by USBR, since USBR's provisional 2006-2010 *Consumptive Uses and Losses Report* only provides irrigated acreage values for the Upper Basin. For the period 2000-2005, USBR reports Lower Basin irrigated acreage as averaging 24,000.

Figure 15 shows changes in irrigated acreages over time, as reported by the different agencies. Generally, the acreages reported by the agencies fall within about 15 percent of each other. Note the upward trend in irrigated acreage in the Upper Basin reported by USBR, an increase of more than a third over ten years. USGS reports an almost 10 percent decline in irrigated acreage from 2000 to 2005 while USBR reports a slight increase in this period. The state's reported acreage for the Colorado River basin as a whole is about 5 percent higher than USBR's, though the state value is a mix of previous years' information.

On the next page, Table 8 shows data from Utah's periodic water-related land use reports, to facilitate comparisons of longer-term data. Table 8 also includes county-based data for the basin as a whole, from the 2007 agricultural census. These data show a slight increase in irrigated acreage in the northern portion of the Upper Basin – the Uintah basin planning area – while the larger but less heavily irrigated Southeast and West Colorado River basin planning areas, in the aggregate, show almost no change in irrigated acreage at all from the late 1990s to 2011. However, Utah's reports note that changes in methodology and technology have refined more recent estimates but challenge efforts to compare totals from different years.[41] Table 8 also shows the acreages of major crop types as reported in the UT DWR reports and, for 2007, in the agricultural census.

As shown in Table 8, pasture and feed crops comprise more than 90 percent of total irrigated acreage within the Colorado River basin in Utah, with very limited acreage in orchards and grains. Like Colorado and Wyoming, this reflects the close ties between irrigated agriculture and the livestock industry in the Colorado River basin. The 2007 agricultural census reports 212,200 head of cattle and 43,500 sheep in Utah's counties in the basin.

Table 8. Irrigated Acreage and Crop Types for Basin Planning Areas in Utah

Basin											
Acres (1000)	**Uintah**		**Virgin R**		**SE Colorado River**			**WEST Colorado River**			**Basin Counties**
Year	2000	2006	2001	2007	1999	2005	2011	1998	2005	2011	2007[a]
Total Irrigated	207.5	219.9	17.9	18.4	19.0	15.1	14.8	86.1	97.1	94.9	322
Pasture	100.2	108.6	7.3	10.0	6.1	4.0	4.2	37.8	36.2	38.7	159
Alfalfa	60.2	80.7	6.0	4.3	9.1	8.1	6.9	34.8	49.7	41.4	125
Grass hay	32.0	16.9	2.4	2.1	1.9	0.7	0.8	3.7	3.6	7.2	27
Corn	8.0	7.0		0.2		0.2	1.6	3.1	1.6	2.7	5
Grain	7.0	6.2	0.8	0.5	1.0	1.9	1.0	6.3	4.9	2.5	
Orchard (fruit)	0.1		0.6	0.7	0.2			0.1		0.1	
Sorghum		0.2	0.3	0.2	0.1	0.2			0.2	0.5	

Sources: UT DWR and the 2007 agricultural census. All values from UT DWR unless noted otherwise.
(a) Basin Counties, from agricultural census.

[41] Utah's 2007 *Kanab Creek/Virgin River Basin 2007 Inventory* includes the following disclaimer on p.6:

> Due to changes in methodology, improvements in imagery, and upgrades in software and hardware, increasingly more refined inventories have been made in each succeeding year of the Water-Related Land Use Inventory. While this improves the data we report, it also makes comparisons to past years difficult. Making comparisons between datasets is still useful; however**, increases or decreases in acres reported should not be construed to represent definite trends or total amounts of change up or down.** To estimate such trends or change, more analysis is required. [*emphasis in original*]

Figure 16. Water Consumption and Withdrawals for Irrigation in Utah's Colorado River Basin, 2000-2010

Notes: USBR's provisional 2006-2010 *Consumptive Uses and Losses Report* only provides consumptive use volumes for the Upper Basin. USGS values are for the counties within the basin (see fn. 40, above).

Figure 16 clearly shows the impacts of the 2002 drought and resultant 24 percent decrease in USBR's total irrigation consumptive use from 2001 to 2002; it took more than four years for Utah's irrigation use to return to 2001 volumes. Note that this decrease is much greater than the roughly 10 percent decrease in total irrigated acreage from 2001 to 2002 reported by USBR: this suggests that irrigators applied less water to existing acreage, in addition to decreasing total acreage from 2001 to 2002. USGS reports groundwater withdrawals for irrigation at about 16 KAF per year, less than 2 percent of total withdrawals.

Figure 16 shows consumptive use as reported by USBR and total withdrawals as reported by USGS for irrigation in the Upper and Lower basins in Utah.[42] A comparison of these numbers reveals some interesting differences and similarities. USBR and USGS both report an increase in total irrigation water use from 2000 to 2005, though USBR shows a 10 percent increase in consumptive use while USGS reports a 30 percent increase in withdrawals. Interestingly, as shown in Figure 16, USGS reported a roughly 8 percent *decrease* in total irrigated acreage between 2000 and 2005, so USGS's reported increase in total withdrawals is even more striking, as total withdrawals per acre increased by 42 percent.

Figure 17 compares USBR-reported consumptive use volumes for the Upper Basin in Utah with USBR-reported irrigated acreage in the Upper Basin. Note that irrigated acreage declined by about 2 percent from 2004 to 2005, while consumptive use reportedly increased by more than 10 percent.

USBR reports the state's total annual average depletions of Upper Basin water as 888 KAF for the period 2000-2010, for all uses. These uses increased by 27 percent over this period, to a high of 983 KAF in 2010. Utah exports about 117 KAF per year out of the Upper Basin into the area known as the Wasatch Front, which includes the Salt Lake City metropolitan area. Since 1990, about a third (44 KAF/year) of these exports has supplemented Wasatch Front irrigated agriculture.

[42] Utah's State Water Plan (2001) includes a table showing total agricultural water use by basin, but includes a note stating "Water use values were derived from previous water use budgets conducted by the Division of Water Resources," so we have not included those values here. According to the State Water Plan, total water use (presumably withdrawals) for the four Plan Areas within the basin was 1,194 KAF, but this reflects a mix of different years.

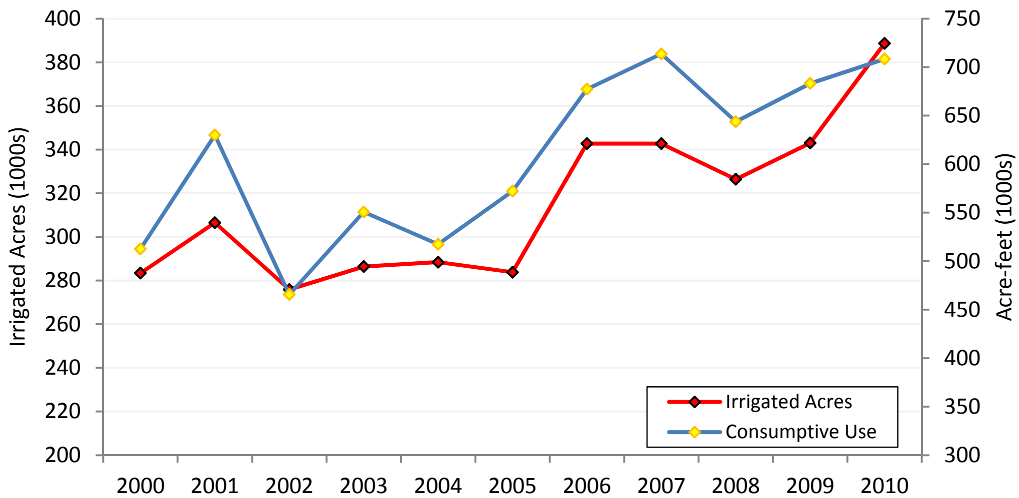

Figure 17. Irrigated Acreage and Consumptive Use in the Upper Basin in Utah, 2000-2010

Source: USBR *Consumptive Uses and Losses Reports*

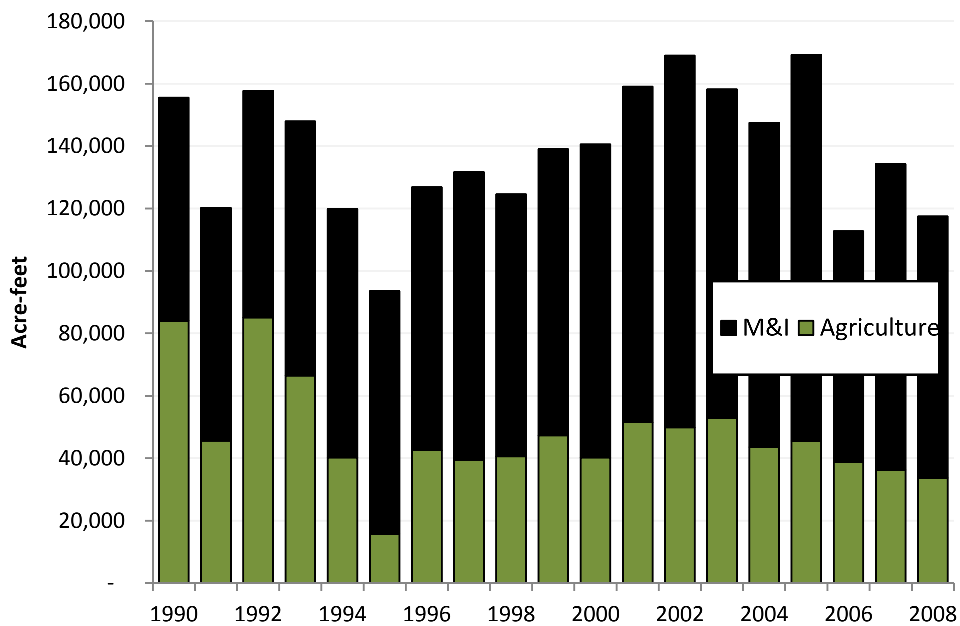

Figure 18. Utah's Exports from the Basin, by Use, 1990-2008

Source: Utah, USBR[a]

Notes:

(a) The sectoral breakdown generated by Utah was provided by USBR staff.

Figure 18 shows total basin exports for agricultural uses, and for municipal and industrial ("M&I") uses, for the period 1990 to 2008. This water is exported from the Uintah basin to the Wasatch Front. The declining trend in exports for irrigation reflects the general urbanization of Wasatch Front agricultural land; total exports for agriculture declined by 60 percent from 1990 to 2008. Median total annual export during the period shown is 139 KAF, slightly higher than the volume exported in 2007.

For the Basin Study, Utah's "Current Projected Demand Scenario" projects that total Colorado River basin irrigated acreage will experience a roughly 2 percent decline from 2015 to 2060. Over the same period, Utah projects that total irrigation water demand within the basin could increase by about 5 percent, reflecting a more than 7 percent increase in applied water use per acre.

For the Basin Study, Utah also projects that its total Wasatch Front irrigated acreage could decrease by about 11 percent from 2015 to 2060.

Summary

The reported extent of irrigated land in the Colorado River basin within Utah ranged from a low of about 266,000 acres in 2002 (agricultural census) to a high of 389,000 acres in 2010 (USBR, *provisional*). Utah reports irrigated acreage on a six-year rotating cycle by planning area, limiting comparisons between the state's and the federal agencies' reported acreages. The federal agencies' reported acreages showed little consistency, with USGS reporting a significant decline in irrigated acreage from 2000 to 2005 while USBR reported no significant change in that period. USBR reported relatively constant irrigated acreage for 2000 through 2005 (with the exception of an 8 percent increase in 2001), but an almost 22 percent increase in the period with provisional data (2006-2010) relative to 2000-2005, and a 37 percent increase from 2000 to 2010. For the period 2000-2010 as a whole, USBR records give an average value of about 315,000 irrigated acres for the state. According to the agricultural census, more than 95 percent of the land is in irrigated pasture and forage, to feed livestock, with the remainder in corn and other crops. Utah's State Water Plan reports total diversions in the Colorado River basin (from a mix of years) at 1,240 KAF, a volume very similar to that reported by USGS for the year 2005 but about a third higher than the volume USGS reported for 2000. USBR reported the lowest consumptive use by irrigation in the Upper Basin in Utah in 2002 at 466 KAF and the highest in 2007 at 714 KAF, with an average volume of 607 KAF over the decade. In the Basin Study, Utah projects that irrigated acreage within the basin could decrease by about 2 percent and irrigated acreage in adjacent areas could decline by 11 percent from 2015 to 2060.

New Mexico

New Mexico, an Upper Division state, includes about 9,700 square miles of the Upper Colorado River Basin and about 13,200 square miles in the Lower Basin. The Upper Basin's San Juan River passes through northwest New Mexico before flowing past the four corners region into southwest Utah. The Lower Basin in New Mexico includes the headwaters of the San Francisco and Gila rivers and a tributary of the Little Colorado River. Although the Lower Colorado River Basin in New Mexico is about 35 percent larger than the state's portion of the Upper Basin, roughly three-fourths of the irrigated agriculture in New Mexico's portion of the basin occurs in the Upper Basin, near the San Juan River and its tributaries in San Juan County, at an elevation of about 5,400 feet. Annual average precipitation in the area is about 8.2 inches. The frost-free growing season in the area averages about five months. According to the USGS and to New Mexico's Office of the State Engineer (NMOSE) (2008), surface water is the only source for irrigation in San Juan County and the Upper Basin in New Mexico generally. Irrigated agriculture in the Lower Basin in New Mexico, however, is much more disperse, spread over parts of five counties (see Figure 19, below). Elevations in the Lower Basin rise to more than 10,000 feet, but most irrigated agriculture occurs along valley floors, with elevations as low as 4,000 feet, where summer temperatures can exceed 100° F.[43] The frost-free growing season exceeds eight months in some low-elevation areas. Average annual precipitation in the Lower Basin ranges from about 11 to 16 inches. Figure 19 shows the Upper and Lower Colorado River basins in the western part of New Mexico. Figure 19 also shows agricultural lands in the Colorado River basin, based on information from UGSS.

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[43] *Southwest New Mexico Regional Water Plan*, http://www.ose.state.nm.us/isc_regional_plans4.html.

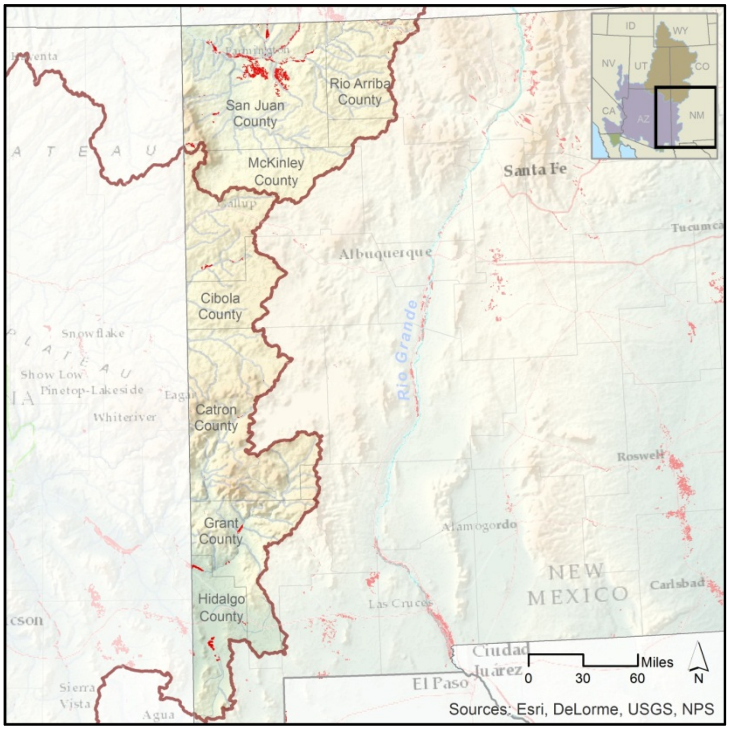

Figure 19. Agricultural Lands (in red) in the Upper and Lower Basins in New Mexico
Source: USGS

Figure 20 shows the extent of irrigated acreage in the Colorado River basins in New Mexico for the years 2000-2010, as reported by various sources. USBR and NMOSE report irrigated acreage by basin while USGS and the agricultural census report these data within New Mexico by county.[44] The agencies' reported acreages for the Upper Basin are almost indistinguishable, suggesting that they share a common source. Reclamation's Lower Basin acreages, available through the year 2005, are about a third of those reported by the other agencies, which are generally very consistent. USBR, USGS, and NMOSE all reported a roughly 15 percent increase in Upper Basin irrigated acreage from 2000 to 2005, though NMOSE reported a much greater increase in Lower Basin acreage in that period. The agricultural census reported a roughly 18 percent increase in irrigated acreage from 2002 to 2007. Overall, the annual values and trends across all four reporting agencies are very consistent.

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[44] Catron, Grant, Hidalgo, and McKinley counties lie solely or predominantly in the Lower Basin, while San Juan County lies in the Upper Basin. We did not include Cibola County, which includes about 3,000 irrigated acres that lie predominantly outside the basin.

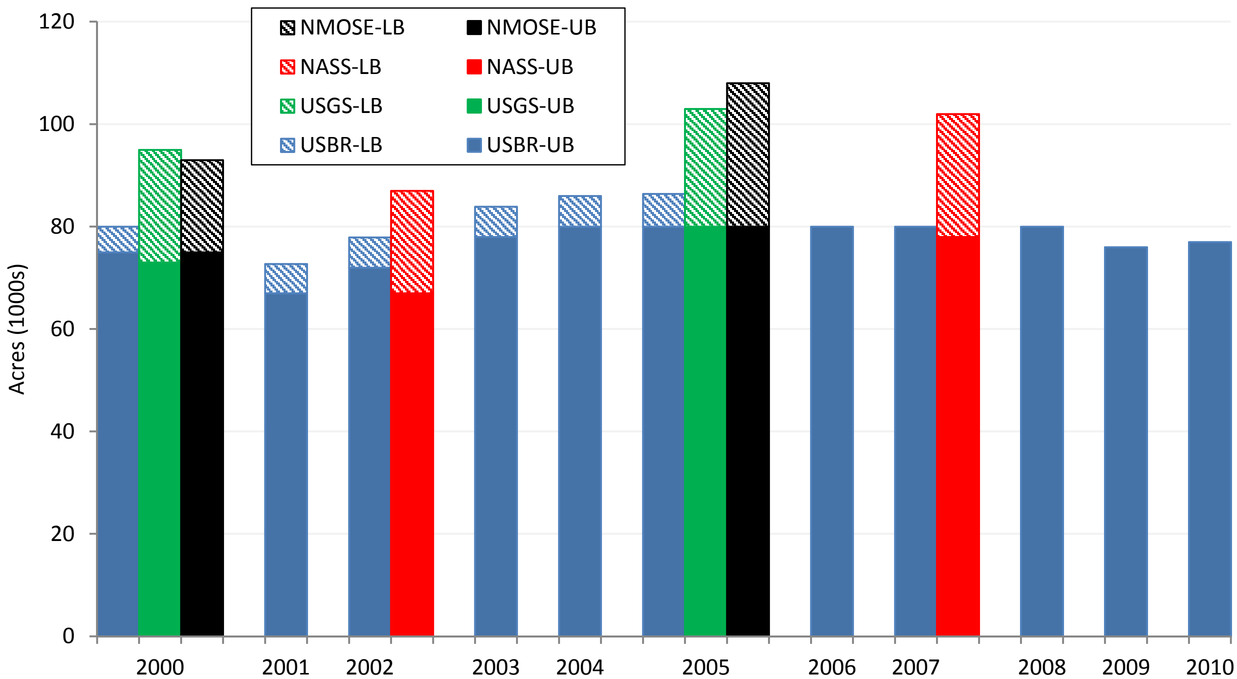

Figure 20. Irrigated Acreages in the Colorado River Basins in New Mexico

Sources as shown in legend[a].

Notes:

(a) "NASS" refers to the agricultural census. The USBR data are from the semi-decadal *Consumptive Uses & Losses* reports. Provisional Upper Basin data are available through 2010; Lower Basin data are only available through 2005, so total irrigated acreage is not available. USGS reports 5,100 irrigated acres in McKinley County in the year 2000, but only 880 acres in the year 2005, even though the agency also reports that total irrigation water withdrawals in the county *increased* by almost 50% between the two years.

Table 9 shows acreages for the major crop types grown in the Colorado River Basin in New Mexico, as reported by the agricultural census. As in the states described previously, forage and pasture accounts for more than half of total irrigated acreage. However, other crops, notably vegetables, comprise a much greater percentage of irrigated land in New Mexico than seen in the other Upper Division states. San Juan County contained about four-fifths of the irrigated acreage in 2007; less than 0.3 percent of total harvested cropland in the county was not irrigated. The census did not report the crop type on more than 35 percent of irrigated land in either 2002 or 2007, to protect the privacy of individual census respondents' data.[45]

The reported acreages show that forage crop acreage increased by 45 percent from the 2002 drought year to 2007, while acreage devoted to irrigated pasture declined by about 20 percent. The marked change in vegetable acreage is partly attributable to data suppression in 2002, meaning that actual acreage in vegetables in 2002 was higher than shown.

[45] The census reports that "Any tabulated item that identifies data reported by a respondent or allows a respondent's data to be accurately estimated or derived, was suppressed and coded with a 'D.'" In San Juan County, more than 40 percent of total crop acreage was not identified.

Table 9. Crop Acreages in the Colorado River Basins in New Mexico

Acres (1000s)	2002	2007	% increase
Total Irrigated	87	102	
Forage	26	37	36%
Pasture	22	18	-18%
Vegetables[a]	2	11	11%
Corn for grain	2	-	-
Orchards	0.5	0.5	0.5%
subtotal	**53**	**67**	**26%**

Source: Agricultural Census
Notes:
(a) The agricultural census reported about 2,000 acres planted in vegetables in the Lower Basin in 2002 and 2007, but did not report any acres in vegetables in the Upper Basin in 2002. The census reported some 9,500 acres in vegetables in 2007.

As shown in Table 9, more than half of New Mexico's irrigated acreage within the Colorado River basin is planted in forage and pasture, to feed livestock. In 2007, the NASS agricultural census reported about 106,000 cattle; 11,000 horses; and 55,000 sheep in the counties within the basin.

Figure 21 on the following page shows the volumes of different types of water use for irrigation, as reported by USBR and NMOSE at the basin level, and by USGS at the county level, by basin of use.[46] Two key points emerge from this figure. The first is the very close agreement between the different agencies in reported values for 2000, for withdrawals generally and for Upper Basin consumptive use/depletions. USGS- and NMOSE-reported withdrawals in 2005 are also very similar, suggesting a common source. The second point is that USBR's reported consumptive use for the Lower Basin is disproportionately low relative to the consumptive use reported by NMOSE and relative to the withdrawals reported by USGS and NMOSE. USGS and NMOSE both report a roughly 40 percent increase in total withdrawals for irrigation between 2000 and 2005, much greater than the roughly 10 percent increase in consumptive use reported by USBR. USBR reports the highest consumptive use for the Upper Basin in 2002,[47] when the total runoff of the San Juan River was estimated to be only 26 percent of average.[48] USBR reports a 22 percent increase in consumptive use from 2001 (when San Juan runoff was about 81 percent of average) to 2002, much greater than the 7 percent increase in irrigated acreage reported by USBR.

[46] For the USGS data, we considered San Juan County to represent the Upper Basin and Catron, Grant, Hidalgo, and McKinley counties to reflect Lower Basin use.

[47] Higher temperatures and lower precipitation likely increased crop evapotranspiration in 2002, increasing irrigation requirements.
[48] USBR (2011)

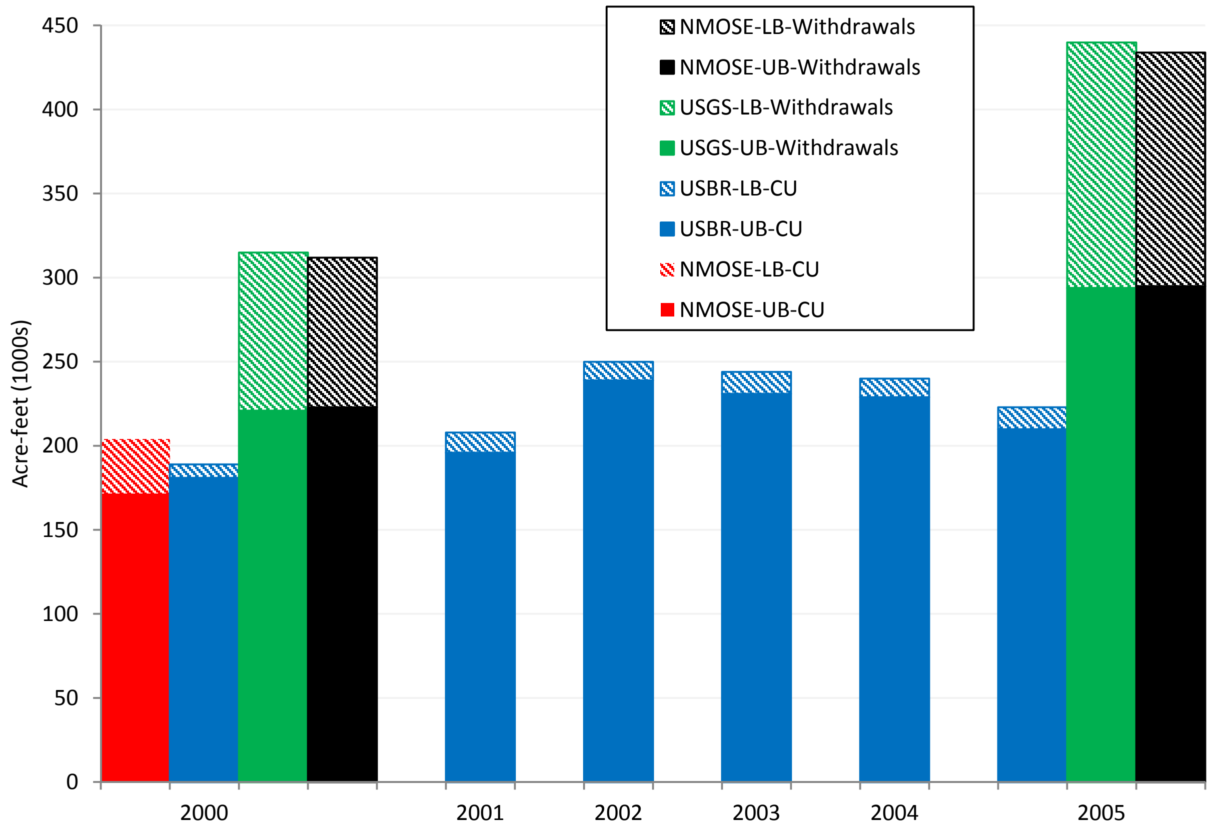

Figure 21. Water Used for Irrigation in the Colorado River Basin in New Mexico, 2000-2005

Sources as shown in legend.

Neither USGS nor NMOSE report any groundwater use for irrigation in the Upper Basin in New Mexico. According to NMOSE, groundwater supplied 39 percent of total Lower Basin irrigation water in 2000, and 64 percent of irrigation water in 2005; USGS data reflect very similar percentages for the two years.

According to USBR, New Mexico exports an average of 89 KAF of water per year from the Upper Colorado River Basin to the Rio Grande basin, via the San Juan-Chama Project, for agricultural and municipal purposes. Of this volume, the Middle Rio Grande Conservancy District (MRGCD) holds contracts for 20.9 KAF annually for supplemental irrigation of 89,711 acres, and the Pojoaque Valley Irrigation District holds contracts for about 1.0 KAF annually for supplemental irrigation of 2,768 acres.

Unfortunately, data on annual diversions and irrigated acreage for the MRGCD are not available, so a detailed accounting of the application of Colorado River basin water in the adjacent areas could not be made.

Given recurrent droughts along the Middle Rio Grande, we project that demands for Colorado River basin water in the MRGCD will not diminish in the future. For USBR's Colorado River Basin Study, New Mexico projected that total irrigated acreage within the basin in the year 2015 would be 51,159 acres, less than half of the total acreage that New Mexico itself reported in 2005 (the most recent year available). New Mexico's projection includes 48,254 irrigated acres in the Upper Basin, about 60 percent of the amount USBR reports in its provisional *Consumptive Uses and Losses Report* and the state itself reports in its 2005 water plan. New Mexico projects a roughly 5 percent decline in total irrigated acreage within the basin from 2015 to 2060, entirely within the Lower Basin, with no change at all projected in the Upper Basin or in adjacent areas.

Summary

The reported extent of irrigated land in the Colorado River basin within New Mexico ranged from a low of about 87,000 acres in 2002 (agricultural census) to a high of 108,000 acres in 2005 (NMOSE), with no clear trend over the past decade. NMOSE and USGS records for 2000 and 2005 are very similar, and their reported Upper Basin acreages are also similar to those reported by USBR. For the period 2000-2010 as a whole, USBR records give an average value of about 77,000 irrigated acres for the Upper Basin; combined with the USGS average of about 22,000 irrigated acres in the Lower Basin, this suggests an average of just less than 100,000 irrigated acres in the basin in New Mexico. The agricultural census did not report the crop type on about a third of the total cropland in the basin. Still, slightly more than half of total irrigated acreage is known to be in forage and pasture and about 11 percent in vegetables. NMOSE reported 311 KAF of withdrawals for irrigation in 2000 and 433 KAF in 2005, while USBR reported that consumptive use rose from 189 KAF to 223 KAF in that period. New Mexico projects a roughly 5 percent decline in total irrigated acreage within the basin from 2015 to 2060, entirely within the Lower Basin, with no change at all projected in the Upper Basin or in adjacent areas.

Arizona

Arizona is a Lower Division state with a small Upper Basin water entitlement. Roughly 45 percent of the land area of the Colorado River basin lies within the state of Arizona. Almost all of Arizona's 114,000 square miles lie within the Lower Basin, with the exception of 5,200 square miles along the border with Mexico that are outside the basin entirely and 7,000 square miles in the northeast corner of the state that lie within the Upper Colorado River and San Juan watersheds, in the Upper Basin. The state's agriculture varies from cooler, higher elevation cattle and sheep ranching operations in the northeast portion of the state to year-round production in the Yuma area, a major producer of the nation's winter vegetables. Elevations range from some 12,000 feet in the San Francisco Range at the edge of the Coconino Plateau to 140 feet in Yuma. Average annual precipitation also varies, from some 36 inches at the highest elevations, to about 3 inches in Yuma, where temperatures rarely drop below freezing. Figure 22 on the following page shows the water planning areas and groundwater basins used in the Arizona Water Atlas.[49] With the exception of the "Western Mexican Drainage," "San Simon Wash," "Douglas," and "San Bernardino Valley" along the border with Mexico, all of the state lies within the Colorado River basin.

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[49] See http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/default.htm.

Figure 22. Arizona Planning Areas and Groundwater Basins
Source: Arizona Water Atlas

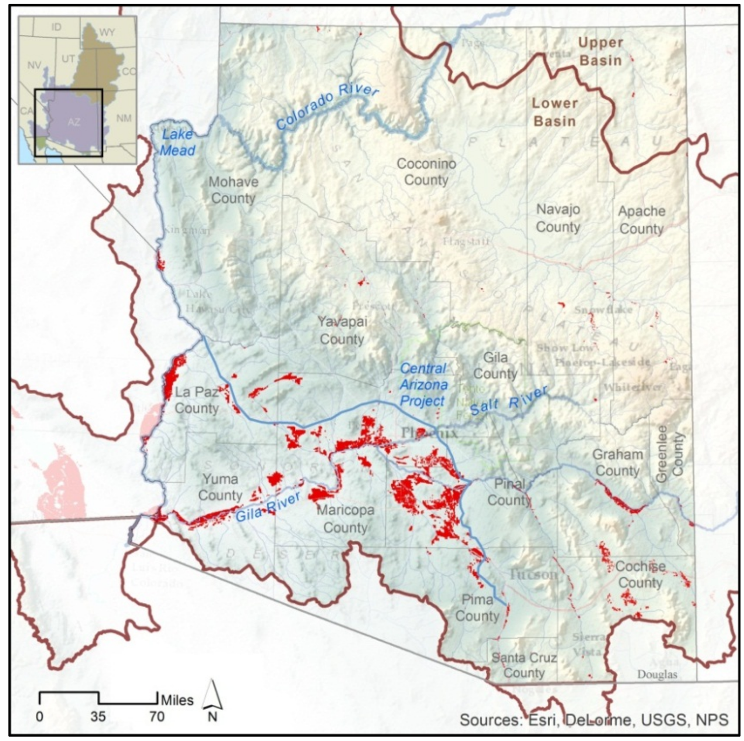

Figure 23. Agricultural Lands (in red) in Arizona.
Source: USGS

Figure 23 shows that most of the state's agricultural lands (including non-irrigated land) lie along the Colorado River and in central Arizona along the Gila, Salt, and Verde rivers. The Central Arizona Project diverts about 1,600 KAF each year from the mainstem, for irrigation and for municipal and industrial uses in Maricopa, Pinal, and Pima counties, supplementing or supplanting existing surface and groundwater sources in the south-central part of the state. The state of Arizona does not track the total amount of irrigated agricultural land within the state. An average of recent surveys by the agricultural census, FRIS, and USGS suggest that about 890,000 acres were irrigated in the state in the last decade, though recent trends suggest that this total is decreasing by about 20,000 acres annually.

Figure 24 shows total irrigated acreage in Arizona over time, as reported by various agencies. There are several important caveats to note about the way the information is reported by the different sources. Data shown for the agricultural census and for FRIS are for irrigated acreage for the state as a whole, including an estimated 10,000 acres in areas outside the basin. USBR's *Consumptive Uses and Losses Report* (CULR) only reports acreage in the state's interior, while USBR's annual *Lower Colorado River Accounting System* (LCRAS) reports list acreage along the river's mainstem.[50]

[50] Prior to 2004, LCRAS reports did not include Wellton-Mohawk Irrigation & Drainage District (WMIDD) irrigated acreage, which averaged 56,118 acres per year for the period 2004-2010. For the sake of consistency, we have added the 2002 irrigated acreage as reported by WMIDD itself, and

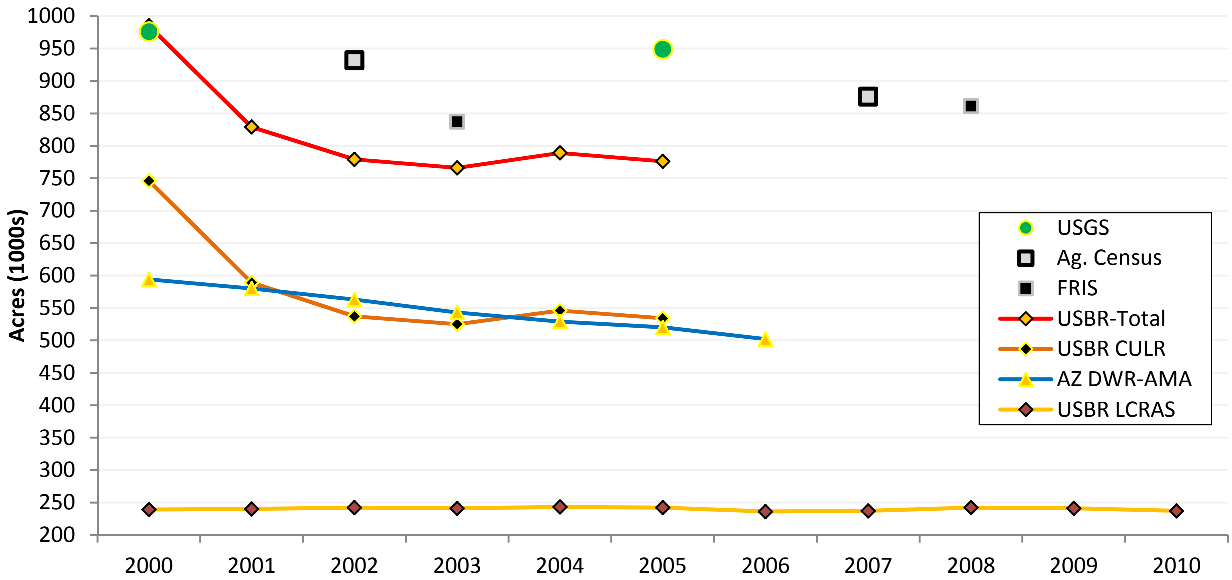

Figure 24. Irrigated Acreage in Arizona's Portion of the Basin, 2000-2010, by Reporting Agency

Figure 24 is a sum of the CULR and LCRAS values. Arizona does not report irrigated acreage for the state as a whole but does report such acreages for the state's five Active Management Areas (AMAs),[51] shown in yellow in **Figure 22.** Arizona Planning Areas and Groundwater Basins
Source: Arizona Water Atlas

Irrigated acreage in Arizona showed a general decline through the early part of the decade, while irrigated acreage along the Colorado River mainstem remained relatively constant throughout the period.[52] The agricultural census shows a decline in irrigated acreage in Arizona as a whole of 199,000 acres from 1997 (not shown) to 2007; this same rate of decline also appears in the numbers reported by USBR's CULR and by AZ DWR, for the period shown in Figure 24. Irrigated acreage in the Phoenix AMA declined by more than 50 percent from 1985-2009; total irrigated acreage in the five AMAs declined by 192,000 acres from 1985-2006. As shown in Figure 25, most of the decline in irrigated acreage in Arizona's interior reflects the sharp decline in the Phoenix area.

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added the 2004-2010 average acreage as an estimate for 2000, 2001, and 2003, to provide a consistent 2000-2010 time series.

[51] The 1980 Arizona Groundwater Code designated five Active Management Areas (AMAs) to manage the state's groundwater resources in regions with unsustainable levels of extraction. For information on the AMAs, please see http://www.azwater.gov/AzDWR/WaterManagement/AMAs/default.htm.

[52] Mainstem acreage from LCRAS reports. The exception to this is the 2003 FRIS survey, which reported a decline of almost 100,000 irrigated acres relative to the 2002 Agricultural Census, and then reported an increase from 2003 to 2008 of about 24,000 acres.

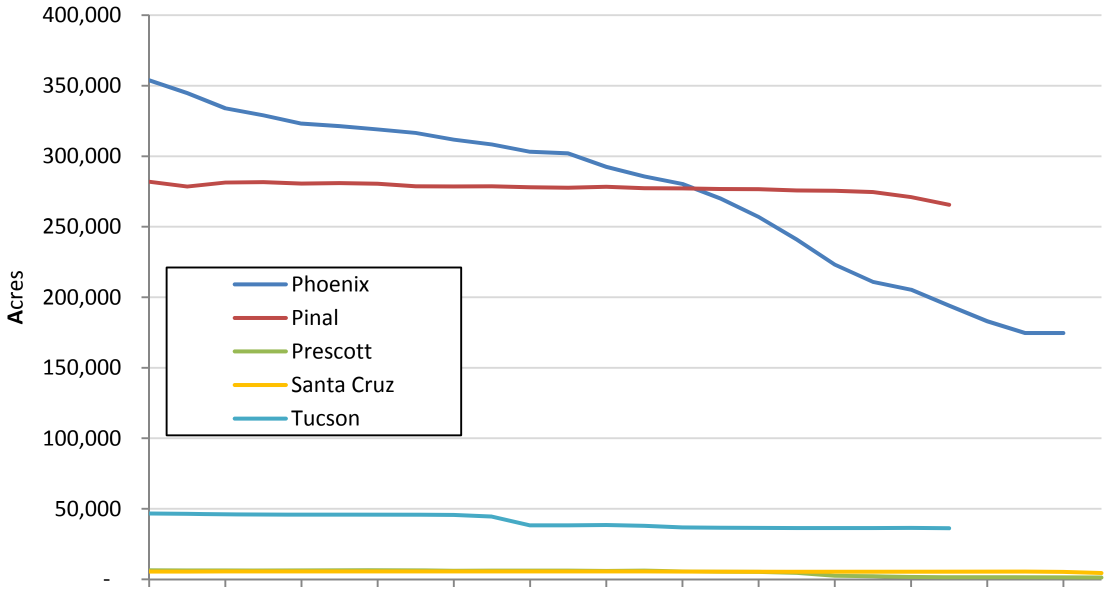

Figure 25. Irrigated Acreage in Arizona's Active Management Areas, 1985-2010
Source: Arizona DWR

Figure 26 shows the major crop types grown in Arizona in the past decade, the amount of land planted in these crops, and changes in acreage over the past decade, as reported by NASS.[53] The figure shows a general increase in field crop acreage but a decline in vegetables and citrus. Lettuce acreage fell by about 10 percent over the decade, but the acreage devoted to all vegetables fell by about 25 percent over this period. Alfalfa (and all hay) acreage increased over the past decade by more than 30 percent, while cotton acreage decreased by more than 30 percent, corn by 20 percent, and citrus by more than 50 percent.

Note that cotton acreage decreased by more than 50 percent from 2001 to 2008, but then increased dramatically in the last two years of the decade.[54] The increase in hay acreage may have been driven by the increase in the number of cattle and calves in the state, which rose from 840,000 in 2000 to peak at 1,020,000 in 2009. The number of sheep and lambs in the state also rose, from 140,000 in 2000 to 160,000 in 2010.

The state estimates total water withdrawals for all uses at about 6,600 KAF for the year 2006, the most recent available.[55] USGS reports total water withdrawals for all uses in Arizona in 2005 at about 7,000 KAF. USBR reports total annual in-state consumptive use (not withdrawals) at about 4,700 KAF in 2005.

There is little consensus on the total volume of irrigation water use in Arizona. Differences in reporting methods, frequency, and terms challenge efforts to determine the total volume of water used for irrigation in the state. Arizona, for example, reports total agricultural "demand," a somewhat nebulous term that here means total

[53] Information from the NASS *Arizona Annual Statistics Bulletin*. Unlike the agricultural census, the annual bulletin does not offer a comprehensive overview of total harvested cropland or total irrigated land in the state.

[54] This increase continued into 2011, when the amount of land planted in cotton reportedly grew to 248,000 acres. Several factors help explain the recent increase in cotton acreage. Prominent among these is that cotton farmers, incentivized by rising cotton prices, leased back land they had sold to developers who were unable to build on the land during the housing slump, to re-plant land previously in cotton.

[55] See "Statewide Water Demand," dated July 2010.

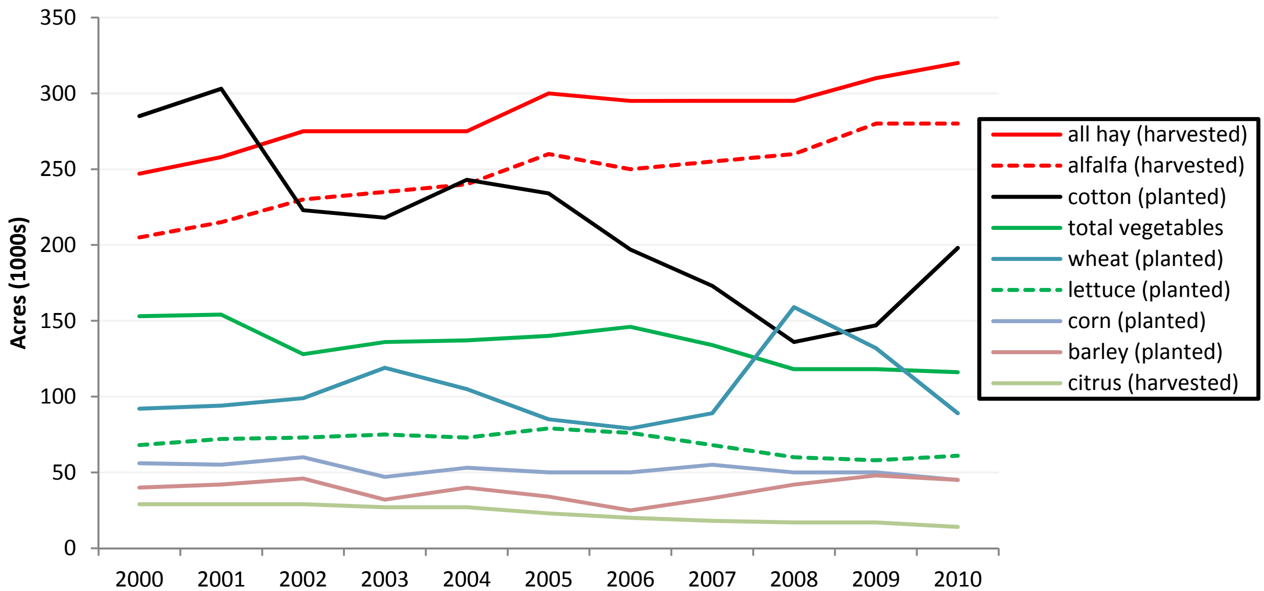

Figure 26. Major Arizona Crops and Acreages, 2000-2010

Source: NASS[a]

Notes:

(a) See http://www.nass.usda.gov/Statistics_by_State/Arizona/Publications/Bulletin/index.asp. Alfalfa is the largest sub-category of "all hay," rather than a separate category. Lettuce is a sub-category of "total vegetables," which also includes melons and potatoes.

withdrawals.

Arizona reports one agricultural demand volume as an average for the years 2001-2005, and a second, slightly lower volume for the year 2006, but has not released a more recent value. USGS reports withdrawals for irrigation for the state as a whole every five years, while USBR reports consumptive use for the state's portion of the basin by year. Every five years, FRIS reports total applied water for irrigation, a volume that does not account for conveyance losses and is not directly comparable to either withdrawals or consumptive use. Figure 27 shows the range of agricultural and irrigation water use volumes reported by the various agencies. The USBR data shown below do not include a broader "total agriculture" category that includes livestock watering and stockpond evaporation, which average about 40 KAF annually. AZ DWR reports total non-Indian agricultural demand but does not report Indian agricultural demand as a distinct category.[56] The volume of groundwater used for irrigation averages about 29 percent of total applied water according to FRIS, 49 percent of total withdrawals according to USGS, and 41 percent of total withdrawals according to AZ DWR.[57]

Although there is little consensus on total irrigation water use in Arizona, Figure 27 shows great agreement between USBR, USGS, and AZ DWR in the rate of change of water use from 2000 to 2005, declining in each case by about 10-13 percent over that period. However, while FRIS shows a 23 percent increase in water use from

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[56] AZ DWR reports that Indian demand, which includes both agricultural and municipal demand, rose from about 355 KAF in 2000 to 451 KAF in 2009. Much of this increase reflects increases in agricultural demand, partly as a result of recent water rights settlements. Total Indian demand is expected to continue to rise in coming years.

[57] These differences in total reported groundwater withdrawals and percentage of total withdrawals could be due to legal distinctions as well as to differences in accounting practices.

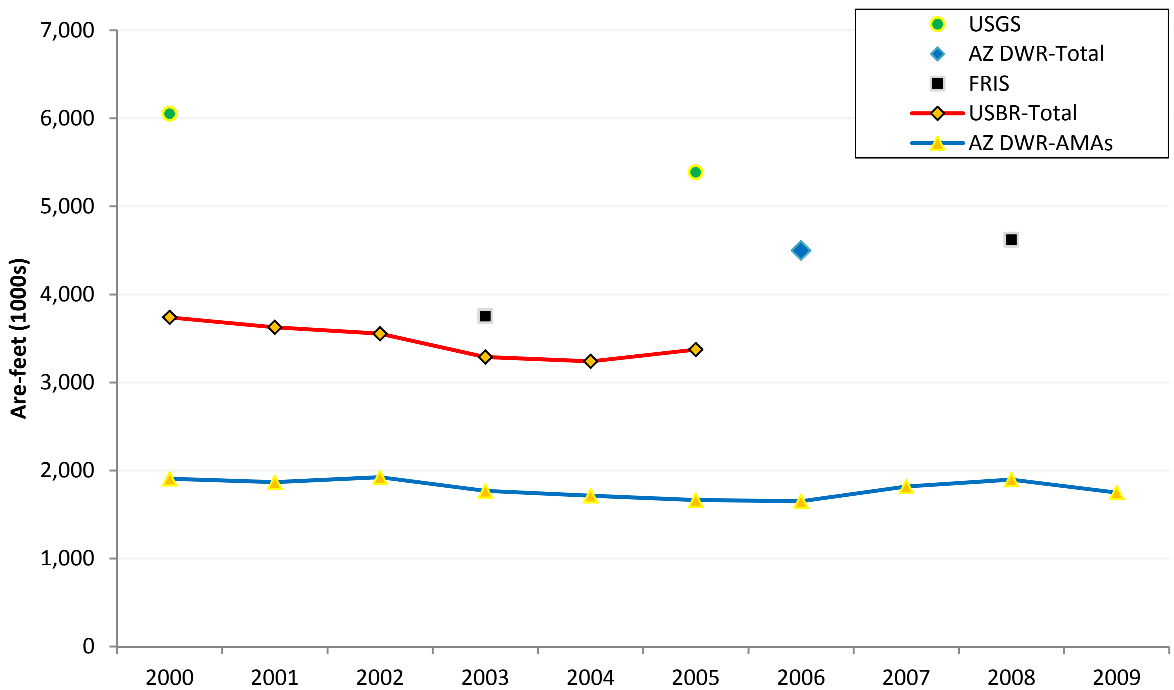

Figure 27. Water Consumption and Withdrawals for Irrigation in Arizona's Colorado River Basin

Notes: The sources for Figure 27 are as listed in the legend. The USBR data are from the *Consumptive Uses and Losses* report, showing irrigation use only. AZ DWR reports total agricultural demand, a combination of irrigation and livestock uses.

2003 to 2008, AZ DWR only shows a 9 percent increase over that period. AZ DWR's reported total agricultural demand for 2006 is 200 KAF lower than the value reported as an average for the period 2001-2005, consistent with the general trend reported by the other agencies.

Another way to look at the information presented by each agency is to compare water use per acre. Such a comparison must recognize the difference in terms and measurements: "withdrawals" is the broadest category and "consumptive use" is the narrowest, as water is first withdrawn from surface and groundwater sources, conveyed to the farm, applied to the land, and the portion not returned calculated as consumptive use. According to USGS, total withdrawals averaged 5.9 AF/acre. According to FRIS data, applied water averaged 4.9 AF/acre. According to the USBR data, consumptive use averaged about 4.2 AF/acre. Conveying water from the point of diversion or extraction to the land to be irrigated generates losses to seepage and evaporation and other losses to the system,[58] which could account for the roughly 17 percent difference between the USGS and FRIS ratios.

For USBR's Colorado River basin study, Arizona projected that irrigated acreage in central Arizona could decline by some 258,000 acres from 2015 to 2060, to about 189,000 acres, primarily due to urbanization,[59] while irrigated acreage

[58] Such losses can also include canceled water orders within an irrigation district and other instances in which water is delivered to a headgate or other diversion structure but not applied to the field, or otherwise lost in transit. Total losses between the point of diversion and deliveries to end users may exceed 15 percent.

[59] The Central Arizona Water Conservation District "Supplemental Policy For Marketing Of Excess Water For Non-Indian Agricultural Use" states that non-Indian agricultural water use will end in 2030. The policy is posted here.

along the mainstem would not change. Future shortages on the Colorado River mainstem may contribute to the central Arizona decline, though urbanization will likely drive this change more than surface water availability. Farmland supplied by the Central Arizona Project suffers from a very junior priority and will be among the first to be shorted when surface water supplies tighten. Central Arizona irrigators currently rely on an excess water pool that will shrink over time and in response to surface water availability.[60] However, these irrigators have rights to groundwater in perpetuity per the 1980 Groundwater Management Act, so future shortages may result in at least a partial return to groundwater. For the basin study, Arizona projects that total agricultural water demand could decrease by 900 KAF from 2015 to 2060, driven almost entirely by anticipated declines in the central part of the state.

Summary

The reported extent of irrigated land in the Colorado River basin within Arizona ranged from a high of about 985,000 acres in 2000 (USBR) to a low of about 766,000 acres in 2003 (USBR) with a clear downward trend, though USBR records are incomplete for the latter half of the decade. USGS records of irrigated acreage in 2000 are very similar to those of USBR but are 22 percent higher than USBR's in 2005. USBR and Arizona records for the AMAs both show a roughly 20,000 acre annual decline in irrigated acreage. According to the agricultural census, forage and pasture accounted for about 40 percent of total irrigated acreage in 2007, with cotton accounting for about 20 percent, vegetables 15 percent, and wheat at about 10 percent. There is little consensus on the total volume of irrigation water use in Arizona. USGS reported 6,053 KAF of withdrawals for irrigation in 2000 and 5,387 KAF in 2005, while the state reported about 4,700 KAF in total agricultural demand in 2005. USBR reported an average of about 3,470 KAF of consumptive use for irrigation from 2000 to 2005, with a general decline from about 3,740 KAF to 3,370 KAF over that period. For the Basin Study, Arizona projected that irrigated acreage in central Arizona could decline by some 258,000 acres from 2015 to 2060, to about 189,000 acres, while irrigated acreage along the mainstem would not change.

[60] See CAWCD excess water policy, in footnote 59.

Nevada

Nevada, a lower division state and home of the headwaters of the Muddy River and portions of the Virgin River, contains some 12,400 square miles of land within the lower Colorado River basin. As shown in Figure 28, the basin extends across Clark, Lincoln, Nye, and White Pine counties in Nevada.[61] Clark County is home to the Las Vegas metropolitan area and contains more than 72 percent of the state's total population. Lincoln County, immediately to the north of Clark County, is home to only 0.2 percent of the state total. Less than two percent of Lincoln County land is privately held; the vast majority is managed by the federal Bureau of Land Management.

Irrigated agriculture in Nevada's Muddy and Virgin river basins occurs predominantly in river valleys, at elevations ranging from about 5500 feet at the headwaters of the Muddy River, near Lund in White Pine County, to a low of about 1200 feet in Clark County's Moapa Valley, near the river's mouth at Lake Mead. Nevada is also home to a small amount of irrigated acreage in the Fort

[61] In this study, we generally follow USBR's categorization of basin lands by county: we assume that 100 percent of irrigated lands in Clark and Lincoln counties are within the basin, and further assume that 25 percent of irrigated lands in White Pine County are also within the basin. We did not include Nye County irrigated acreage in the total reported for the basin, since only a small fraction of the county lies within the basin.

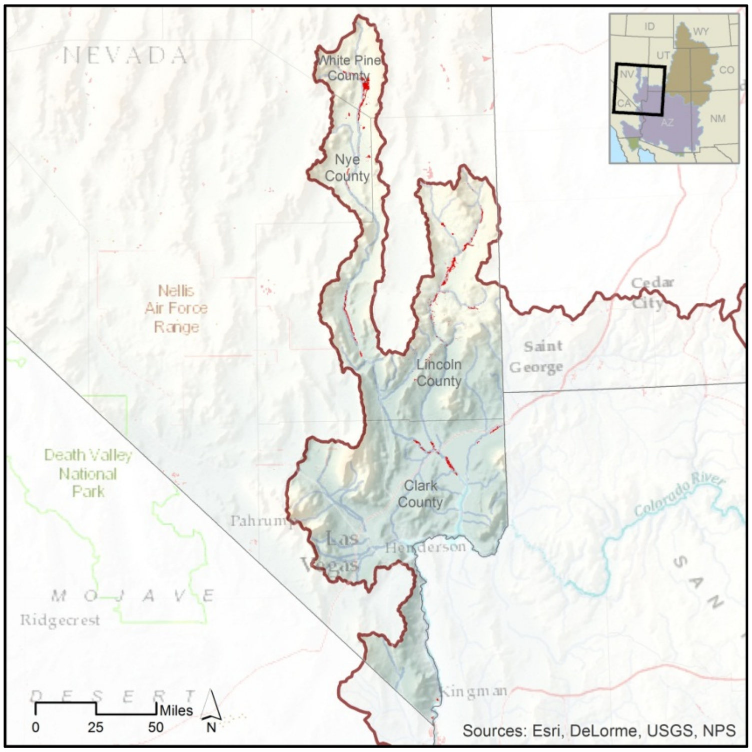

Figure 28. Agricultural Lands (in red) in Nevada's Portion of the Colorado River Basin
Source: USGS

Mohave reservation, along the Colorado River at the very southern end of Clark County. Average annual precipitation in the Moapa Valley is 5.1 inches, and 11.0 inches near Lund. The frost-free growing season in the upper portion of the basin is 150 days long on average, but 250-275 days long in the lower portion of the basin (Glancy and Van Denburgh 1969).

According to data presented in Nevada's State Water Plan (1999), there were about 29,600 total irrigated acres in the Colorado River Basin in Nevada in 1995 (the most recent year reported). Almost all of this land is in irrigated pasture and forage, to feed some 27,000 cattle. Table 10 shows the extent of irrigated acreage in the basin in Nevada for the years 2000-2005 and 2007,[62] as reported by various sources. Both USBR and USGS report a roughly 33 percent decline in irrigated acreage over time, though the agricultural census shows a much smaller decline. Note that the 2002 NASS report withheld total irrigated acreage in Clark County to avoid disclosing data for individual farms; the value reported in the table undercounts the total irrigated acreage in the county, and in the basin, for that year.

According to data presented in Nevada's State Water Plan (1999), total irrigation water withdrawals in the basin in 1995 (the most recent year reported by the state) were about 127 KAF, while total depletions by irrigation were about 93 KAF. Figure 29 shows consumptive use by irrigation in Nevada's portion of the basin as reported by USBR, as well as withdrawals for irrigation as reported by USGS. Over the period shown, USBR reports that total consumptive use

Table 10. Irrigated Acreage in the Colorado River Basin in Nevada

ACRES (1000s)	Category	2000	2001	2002	2003	2004	2005	2007
USBR	Total	32	17	25	24	20	19	
USGS	Total	30					21	
Ag Census	Total			35[a]				33
	Forage			26				21
	Pasture			8[a]				10

Notes: USGS and agricultural census values include total reported irrigated acreage in Clark and Lincoln counties, plus 25 percent of the irrigated acreage in White Pine County.
(a) Incomplete; census suppressed information to protect respondents' privacy.

[62] No information was available for the year 2006.

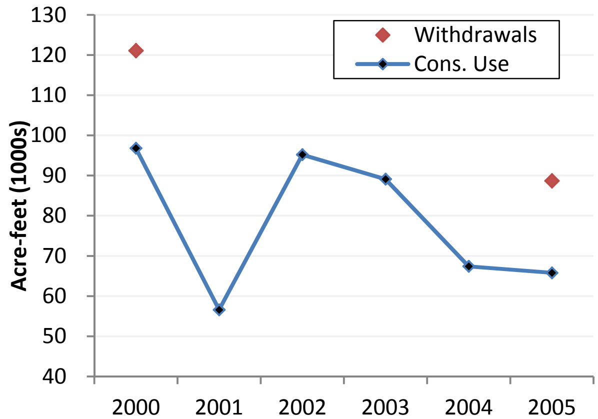

Figure 29. Irrigation Water Use in the Colorado River Basin in Nevada, 2000-2005
Source: withdrawals reported by USGS, consumptive use reported by USBR.

declined by about a third, similar to USBR's reported decline in irrigated acreage in the basin. According to USGS, groundwater extraction accounted for about half of total withdrawals in 2000 but three-quarters of the total in 2005. No water is exported from the basin to irrigate land outside the basin.

Generally, there appears to be a decline in the past 15 years in irrigated acreage in Nevada's portion of the basin. In recent years, the Southern Nevada Water Authority (SNWA) has been purchasing or leasing water rights or shares for irrigated lands in Clark County and redirecting the water previously used for irrigation to municipal uses. In 2010, SNWA acquired a total of 30.1 KAF of water from a variety of sources, temporarily or permanently fallowing slightly less than 2,000 acres.[63] Both the USGS and USBR values show a relative decrease in irrigated acreage in Clark County of about 2,000 acres in the early part of the past decade. Irrigated acreage in Lincoln County also declined by about 25 percent over the same period.

Summary

The reported extent of irrigated land in the Colorado River basin within Nevada ranged from a high of more than 35,000 acres in 2002 (agricultural census) to a low of about 19,400 acres in 2005 (USBR). USBR reports a decline in irrigated acreage from a high of about 31,900 acres in 2000 to the low noted above, a decline similar to that reported by USGS. However, the agricultural census reports 40 percent more irrigated acreage in 2002 than USBR, and still reports more than 32,000 irrigated acres in 2007, inconsistent with the trend shown by USBR records. According to the agricultural census, forage and pasture accounted for almost all irrigated acreage in 2002 and in 2007. USGS reported 121 KAF of withdrawals for irrigation in 2000 and about 89 KAF in 2005. USBR reported an average of about 78 KAF of consumptive use for irrigation from 2000 to 2005, with a general decline from about 97 KAF to 66 KAF over that period. For the Basin Study, Nevada reported no irrigated acreage at all within the basin.

[63] In 2010, SNWA conserved 16,783 AF of water from the Muddy River, which includes water from the Muddy Valley Irrigation Company (8161 AF); a Paiute Lease (3700 AF); LDS church rights lease (2001 AF); NV Energy lease (1770 AF); Hidden Valley Dairy (1040 AF); Cox Right (acquired by SNWA, 85 AF); and Mitchell Right (also acquired by SNWA, 26 AF). SNWA conserved another 13,290 AF from the Virgin River, including about 820 acres in Bunkerville (at an annual duty of 9.06 AF/acre); about 950 acres in Mesquite (at an annual duty of 9.06 AF/acre); and about 92 acres in Riverside (at an annual duty of 6 AF/acre). Source: SNWA *Intentionally Created Surplus* report to USBR for calendar year 2010, on file with author. Intentionally Created Surplus rules dictate that 5 percent of this total reverts to the Colorado River system, so the total available to SNWA was about 28.6 KAF.

California

California, a lower division state, includes about 3,500 square miles of the Lower Basin along the Colorado River mainstem and an additional 7,250 square miles of the Salton Sea watershed. For Colorado River accounting purposes, the Salton Sea watershed, home to the intensively irrigated Imperial and Coachella valleys, is typically characterized as an "adjacent area," outside of the Colorado River basin, because diversions to the area do not generate return flows to the Colorado River mainstem.[64] However, the Salton Sea is part of the Colorado River delta: prior to channelization and impoundment, the river periodically meandered north and west to discharge into the below-sea-level Salton Sea depression. We include the Salton Sea watershed as part of the basin but, for the sake of consistency with other agency data, report California data with and without the Salton Sea watershed portion of the basin.

Most of the region is a subtropical desert, where summer temperatures exceed 110° F and winter temperatures rarely fall below freezing. Extreme summer temperatures limit crop productivity, but mild winters make the region a major producer of the nation's winter vegetables. Annual precipitation ranges from less than three inches in most of the Salton Sea watershed to slightly more than six inches along parts of the Colorado River mainstem. Much of the area is cultivated year-round, with tens of thousands of acres planted in more than one crop each year.

As shown in Figure 30, the Colorado River basin extends across all of Imperial County and parts of three other counties, confounding efforts to use USGS and agricultural census county-level information.[65] USBR does not report Lower Basin mainstem acreage in its consumptive uses and losses reports, though it does report irrigated acreage by individual contractor in its annual LCRAS reports. Several of California's irrigation districts also compile detailed reports on agricultural land and water use. The California Department of Water Resources (CA DWR) compiles and posts detailed land and water use data at a variety of scales. As shown in Figure 30, the Colorado River basin includes four of the six planning areas (everything except areas 1001 and 1003) included in CA DWR's "Colorado River hydrologic region." More than 99.5 percent of all irrigated acreage in the "Colorado River hydrologic region" occurs within the Colorado River basin itself (including the Salton Sea watershed).

As shown in Figure 30, more than 80 percent of the irrigated land within California's portion of the Colorado River basin lies within the Salton Sea watershed, in the Imperial Irrigation District (IID) and the Coachella Valley Water District (CVWD). Most of the acreage along the mainstem lies in the Palo Verde Irrigation District (PVID), with a smaller amount north of Yuma in an area known as the Yuma Project Reservation Division, bounded by the All-American Canal and the river itself.

Figure 31 shows how the amount of irrigated acreage has changed over time, as reported by the various agencies. According to provisional CA DWR information, irrigated acreage in the Colorado River basin declined by 54,000 acres (8.6 percent) from 2000 to 2009. This is roughly equivalent to the decline in irrigated acreage reported by USBR for the mainstem and Salton Sea watershed from 2004-2010; USBR reports an almost 25 percent decline in irrigated acreage along the mainstem alone from 2000-2010. There

[64] With the exception of limited conveyance losses, which do generate small volumes of return flows.

[65] Riverside, San Bernardino, and San Diego all include land within the Salton Sea watershed, but each has extensive amounts of irrigated acreage outside the basin.

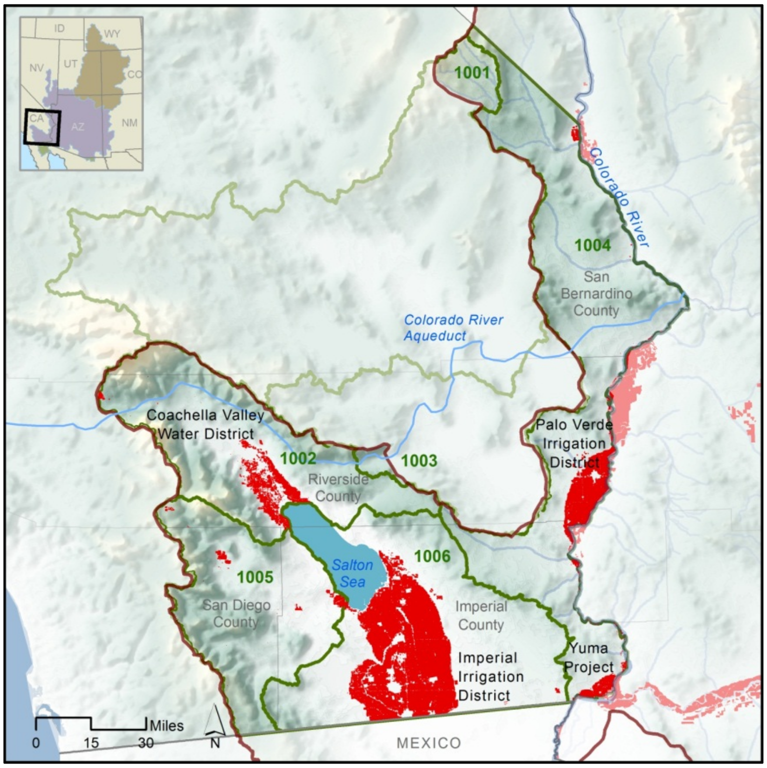

Figure 30. Planning Areas (in green) and Agricultural Lands (in red) in California's Portion of the Colorado River Basin
Sources: CA DWR, USGS
http://www.water.ca.gov/landwateruse/images/maps/California-PA.pdf

are several reasons for the declining trend, most notably the fallowing of irrigated land associated with two major water transfers in the basin. USGS and the agricultural census both report roughly 20 percent declines in irrigated acreage in Imperial County over their respective five-year reporting cycles.

Figure 31 also shows irrigated acreage as reported by USBR and by CA DWR for the mainstem (predominantly PVID and the Yuma Project Reservation Division) and for the Salton Sea watershed.[66] USGS and agricultural census values only reflect reported irrigated acreage for Imperial County, since the other counties in the basin include extensive acreage outside the basin. USGS reports almost 630,000 irrigated acres in Imperial County in 2000, roughly equivalent to the irrigated acreage CA DWR reports for the hydrologic region as a whole and some 50,000 acres greater than Imperial County itself reported that year as the total *harvested* acreage in the county, including extensive multi-cropping. The figure shows that USBR and CA DWR report very similar values for the mainstem, but that CA DWR reports about 4 percent more irrigated acreage than USBR does for IID and CVWD in the Salton Sea watershed.[67]

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[66] USBR's LCRAS reports provide irrigated acreages for the irrigation districts in the region, for the years 2004-2010. CA DWR values reflect Planning Area 1004 (see Figure 30) for the mainstem and the sum of planning areas 1003, 1005, and 1006 for the Salton Sea watershed; values shown for the years 2006-2009 are provisional.

[67] CA DWR also reports 8,000 irrigated acres in the Borrego Planning Area (labeled "1005" in Figure 30); this acreage is shown as part of CA DWR's total for the Salton Sea watershed in Figure 31 but is not mainstem use and is not counted by USBR.

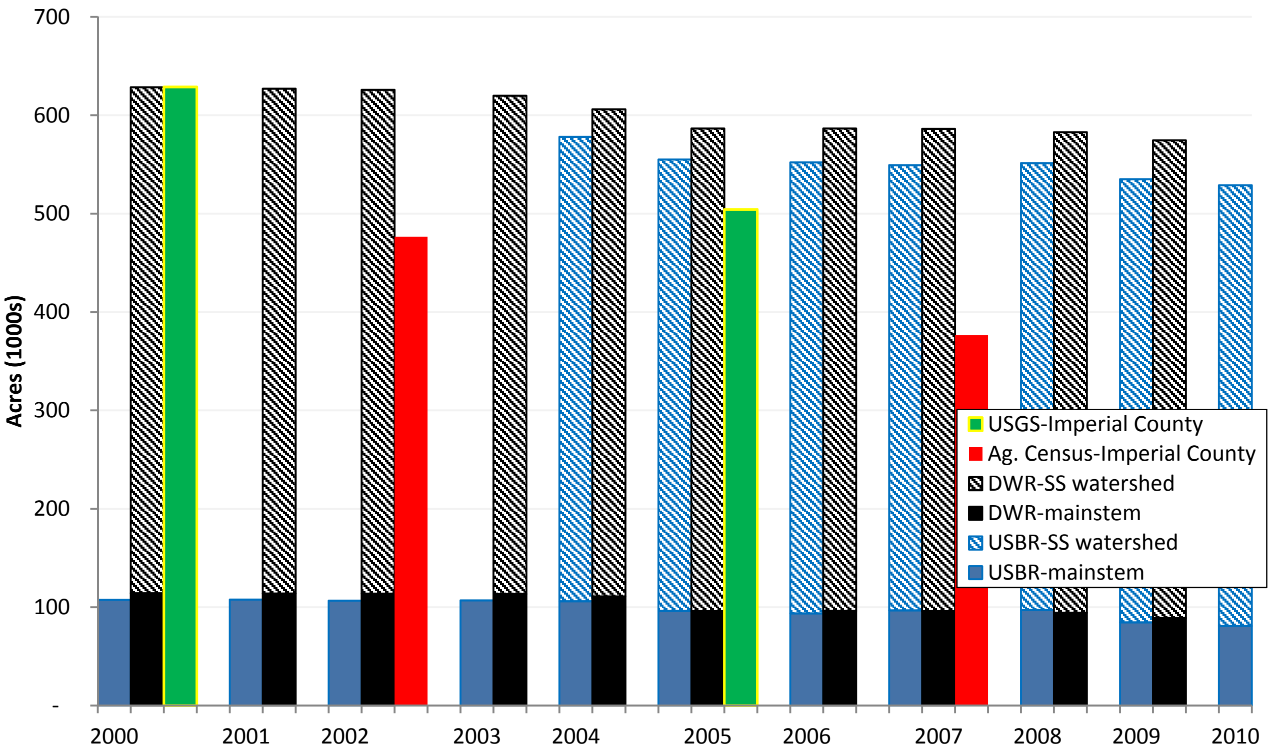

Figure 31. Irrigated Acreage in California's Portion of the Colorado River Basin, 2000-2010, by Reporting Agency

Notes: Values for the USGS and agricultural census only reflect irrigated acreage in Imperial County; other counties in the basin also include significant acreage outside the basin and so were not included.

Table 11 shows irrigated acreage by crop type, as reported by CA DWR for 2002 and by the agricultural census (labeled "NASS" in the table), in combination with self-reported values by CVWD and PVID, for 2002 and 2007.[68] Two key points emerge in Table 11. The first is that the agricultural census and district reports show that alfalfa acreage fell precipitously from 2002 to 2007, while the amount of land planted in other field crops and in vegetables increased by an equivalent amount. The second is that the acreage planted in fruits and vegetables is much greater, both in terms of percentage of total acreage and in absolute terms, than in any of the other states in the basin except Arizona. Even so, alfalfa, field, and pasture still represent almost half of the total crop acreage. Note that CA DWR and the agricultural census use different crop classifications in many instances; the categories listed below reflect an effort to group similar crop types, but these are not wholly consistent. For example, CA DWR's "Pasture" category includes forage crops such as rye grass and klein grass, which are lumped under "Other Field" in the NASS/CVWD/PVID columns. "Grain" is predominantly wheat, plus a smaller amount of oats in 2007. Note that total crop acreage shown in Table 16 is greater than the total amount of land irrigated, shown in Figure 31: this reflects multi-cropping.

[68] The adjusted values are the sum of agricultural census values for Imperial County plus self-reported acreages from CVWD and PVID, to reflect the majority of reported acreage in the basin in California.

Table 11. California Basin Acreages by Crop Type

	CA DWR	NASS[a]+PVID+ CVWD	
Acres (1000s)	2002	2002	2007
Alfalfa	237.3	255.7	169.1
Vegetables	145.0	103.4	96.4
Other Field	83.1	120.3	97.2
Pasture	61.1	2.1	2.2
Grain	55.0	49.1	55.4
Seed crops	-	54.3	61.6
Sugar beets	35.3	28.5	25.7
Citrus & dates	31.0	26.7	23.0
Cotton	24.3	24.3	21.5
Vine	16.1	-	9.1
Onions & garlic	15.4	-	-
Corn	12.7	7.5	9.8
Potato	3.9	-	-
TOTAL	719.7	631.9	692.0

Note:
(a) NASS – USDA/NASS Census of Agriculture

The large alfalfa acreage shown in Table 11, plus other forage crops captured in "Other Field" crops, helps support the livestock industry in the area; forage crops are also exported to other regional and international markets. CA DWR reported about 360,000 head of cattle and 190,000 head of sheep in the region in 2005, while the 2007 agricultural census reported 446,000 cattle and 137,000 sheep in the Salton Sea watershed alone. The California Department of Agriculture reported 415,000 cattle at the start of 2011 in Imperial County alone, plus an additional 100,000 head in Riverside County as a whole, most of which were outside the basin.

Figure 32 on the next page shows irrigation water use in California's portion of the Colorado River basin, as reported by various agencies for the years 2000-2010. CA DWR reports both total withdrawals and depletions[69] (consumptive use) for the individual planning areas for the years 1998-2005, with provisional data for the years 2006-2009. For the sake of comparison, Figure 32 shows CA DWR-reported withdrawals as the sum of depletions and returns. USGS values only reflect Imperial County irrigation withdrawals; like USGS-reported irrigated acreage, their reported volume of irrigation water withdrawals is much higher than that reported by the other agencies in 2000. According to CA DWR, California's total annual withdrawals for agricultural uses within the Colorado River basin[70] averaged 4,004 KAF for the years 2000-2009. With the exception of about 390 KAF per year from local groundwater,[71] all of this water was imported or diverted from the Colorado River mainstem.[72]

[69] Depletions here include agricultural drainage flowing to the Salton Sea.
[70] We define California's portion of the Colorado River basin as the mainstem plus the Salton Sea watershed but not CA DWR's planning areas 1001 or 1003, as shown in Figure 30.
[71] CA DWR reports 390 KAF total groundwater withdrawal for all uses, not solely for irrigation.
[72] The Coachella Valley Water District has an exchange agreement with MWD, allowing MWD to take CVWD's State Water Project (SWP) allocation in exchange for an equivalent volume of Colorado River water, diverted from the Colorado River Aqueduct to recharge groundwater in the Upper Coachella Valley. On paper, this means that CVWD receives SWP water, but on the ground this is Colorado River water.

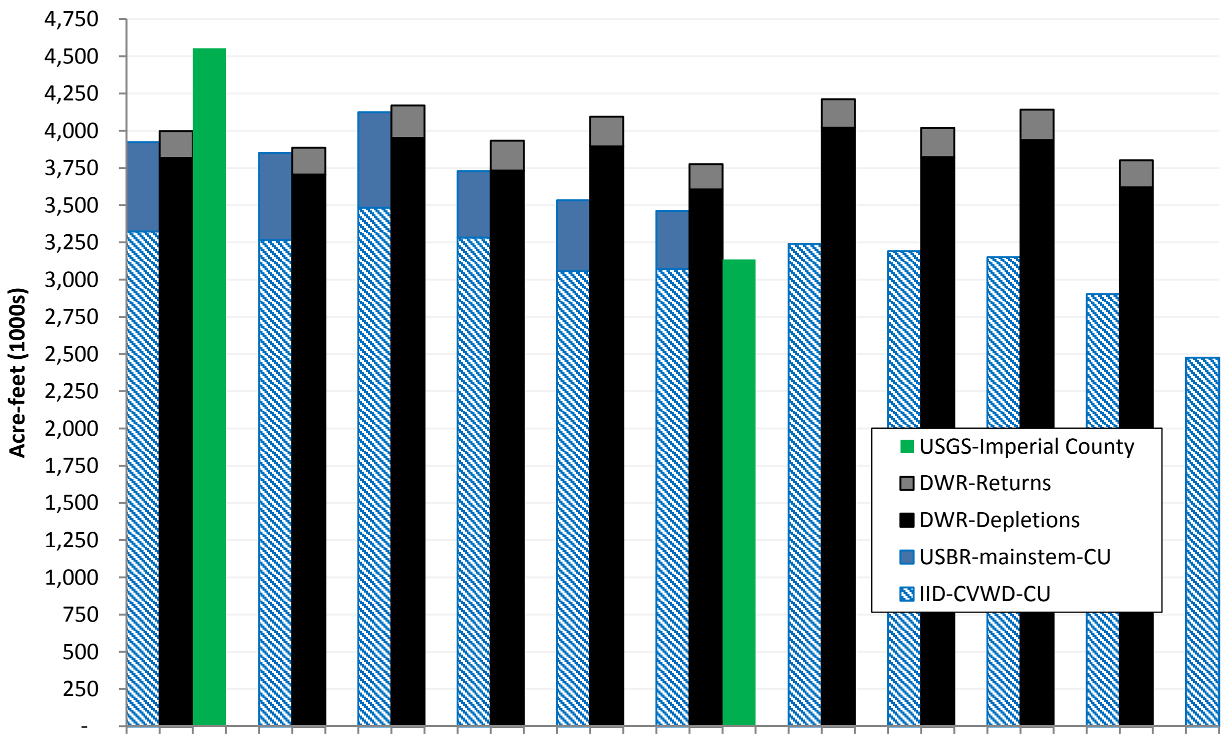

Figure 32. Irrigation Water Use in California's Portion of the Basin

Notes: Sources as shown in legend[a]

(a) CA DWR's 2000-2005 water use data are from *Update 2009 Volume 5 - Technical Guide*: DATA DETAIL: Water Portfolio and Balance, available at http://www.waterplan.water.ca.gov/technical/cwpu2009/; provisional 2006-2009 values generously provided by CA DWR staff. USBR mainstem uses from its *Consumptive Uses and Losses* reports (data only available through 2005). IID and CVWD values are from self-reported *Crop and Water Data* forms submitted to USBR and on file with author.

Figure 32 shows interesting similarities and differences in the values reported by the various agencies. CVWD and IID report a very marked (15 percent) decline in consumptive use from 2009 to 2010, and an overall decline of almost 30 percent from their peak use in 2002 to 2010. CA DWR records show considerable inter-annual variability but no real trend over the period shown. The large increase from 2005 to 2006 in total depletions reported by CA DWR is split primarily between increased use in IID and a similar increase along the mainstem, in PVID. Interestingly, the agencies all report that 2002 – a significant drought year in the Upper Basin – witnessed some of the greatest irrigation water use in the past decade.

According to USBR's annual Decree Accounting reports, 962 KAF per year were exported from the Colorado River basin during the period 2000 to 2010, via the Colorado River Aqueduct to the Metropolitan Water District of Southern California (MWD). Figure 33 shows the annual volumes of imported water sold for agricultural purposes in the MWD[73] and San Diego County Water Authority (SDCWA)[74] service areas; these are total volumes of water sold, reflecting a mix of Colorado River and Northern California sources.[75] Note the dramatic decline in agricultural use, associated with MWD's increases in the water charges for the

[73] MWD's 2003 *Comprehensive Annual Financial Report* stated that MWD "historically has provided water supplies to meet 30 to 50 percent of total agricultural water demand."

[74] SDCWA is a member agency of MWD.

[75] Historically, the Colorado River provided about 90 percent of SDCWA's total supply.

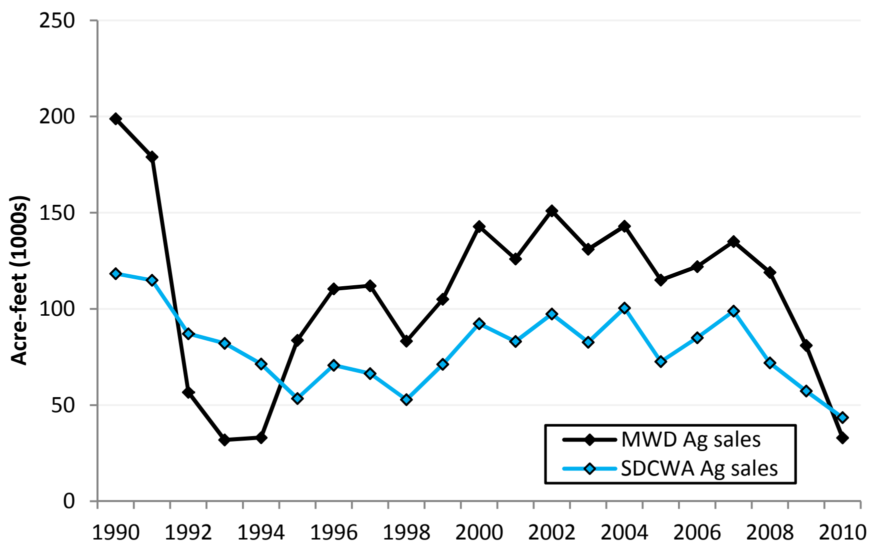

Figure 33. Irrigation Water Sales by MWD and SDCWA by Fiscal Year 1990-2010

Note: Fiscal year ending June 30. MWD data from *Comprehensive Annual Financial Reports* and from 1990 *Annual Report*; SDCWA data from annual reports. Volumes shown in the figure only reflect "amounts certified through the Interim Agricultural Water Program," and do not reflect local supplies or total agricultural water use.

"Interim Agricultural Water Program," where prices rose in a series of rate increases from $236/AF in December 2004 to $537/AF in January 2012. In recent years, SDCWA has diversified its water supply portfolio and reduced its reliance on water purchased from MWD; we could not determine the source of SDCWA water sales in excess of total MWD water sales in 1992-1994.[76]

In the Basin Study, California projects that irrigated acreage within the basin (including the Salton Sea watershed) could decline by about 4,600 acres (0.7%) from 2015 to 2060, and by about 12,000 acres (19%) in the MWD service area. In the Basin Study, California projects that total agricultural consumptive use could decline by about 64 KAF (2%) within the basin (including the Salton Sea watershed), with much greater declines in CVWD partly offset by increases in PVID. In the MWD service area, California projects that agricultural consumptive use could decline by 42 KAF (19%) from 2015 to 2035, and remain constant thereafter.

Summary

The reported extent of irrigated land in the Colorado River basin within California ranged from a high of almost 630,000 acres in 2000 (CA DWR) to a low of about 529,000 acres in 2010 (USBR). USGS reports almost as many acres in Imperial County alone in 2000 as CA DWR does for the entire Colorado River hydrologic region. Generally there appears to have been a roughly 8 percent decline in irrigated acreage over the past decade. Alfalfa was the largest single crop by acreage in the region, accounting for about a quarter of total acreage, but there is much greater diversity in crop types in the region than in other parts of the basin in the U.S., including wheat, a large variety of vegetables, seed crops, sugar beets, citrus, melons, and grapes, among others. CA DWR records for total diversions peaked in 2002 at 4,170 KAF, only slightly greater than the volume of consumptive use reported by USBR for that year. Both agencies reported that water use peaked in 2002 and declined in following years, though records for the latter part of the decade are incomplete. USBR records indicate that average annual consumptive use for the years with complete information (2002-2005) was about 3,716 KAF. For the Basin Study, California projects that total irrigated acreage and water use within the basin would decline by two percent or less.

[76] Some of the SDCWA sales in these years may have come from previous years' storage.

Mexico

Mexico contains most of the Colorado River delta and, some 290 miles to the east-southeast, the headwaters of the Santa Cruz and San Pedro rivers, both tributaries of the Gila River. The headwaters region, southeast of Nogales, Arizona, encompasses 1,200 square miles, while the delta region and its associated watershed includes roughly 5,200 square miles.[77] The relatively featureless topography to the east of the delta region, combined with very limited precipitation and runoff, challenges efforts to determine the actual extent of the watershed. To the west, the delta watershed includes the below-sea-level depression known as Laguna Salada, which occasionally receives Colorado River water during extreme high flows and high tides. Figure 34 shows the delta and headwaters regions of the Colorado River basin in Mexico.

The delta region is hot and dry, with less than three inches of annual precipitation and minimum temperatures rarely below freezing. Elevation in the area is only slightly above sea level. The region enjoys a year-round frost-free growing season; about 30,000 acres are double-cropped. In the headwaters region, the elevation ranges from a low of about 3,900 feet near Nogales, rising to about 4,900, feet near Cananea. Average annual precipitation ranges from about 19 inches near Nogales to about 22 inches near Cananea; minimum temperatures rarely fall below freezing. However, limited surface water availability and limited diversion infrastructure mean little water is available for irrigation, so irrigated acreage in the headwaters region is low.

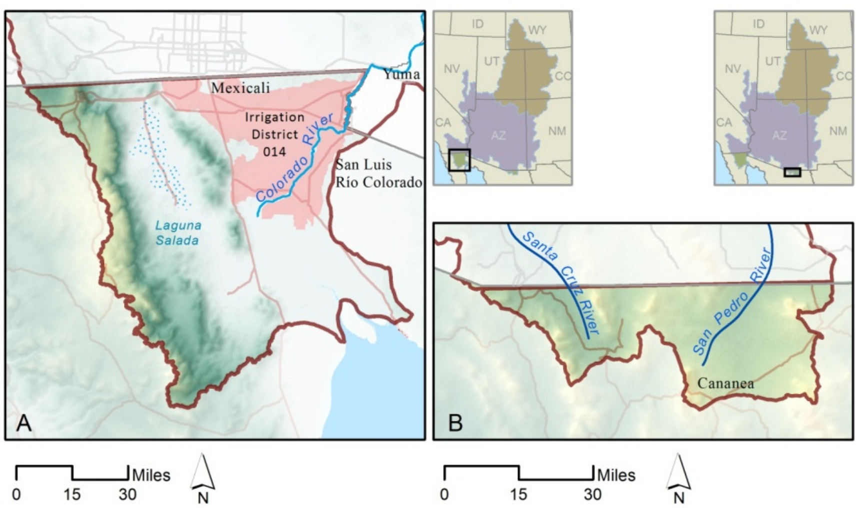

Figure 34. The Colorado River Basin in Mexico

[77] We define the "delta region" here very broadly, to include the full extent of the Colorado River delta within Mexico – including the Laguna Salada lakebed, plus areas draining to the delta. Note that this broad definition results in a larger watershed than is traditionally associated with the delta alone. Much like the river historically discharged to the Salton Sea watershed, it also periodically drained to the Laguna Salada, creating a clear hydrologic link. There is no irrigated agriculture in the Laguna Salada area.

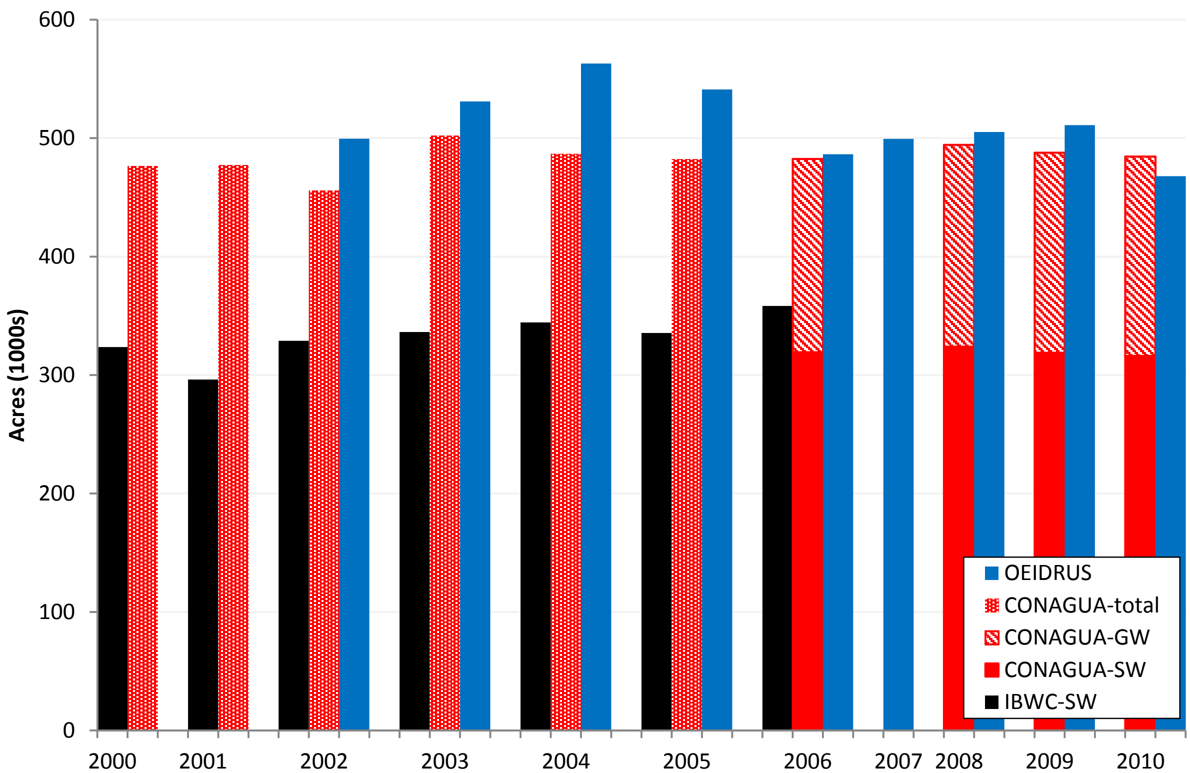

Figure 35. Irrigated Acreage in the Colorado River Delta Portion of the Basin in Mexico, 2000-2010[a]

Notes: Sources as shown in legend.[b] "SW" – surface water; "GW" – groundwater, reflecting the source of water used to irrigate the land.
(a) IBWC values shown by calendar year while *CONAGUA* and *OEIDRUS* values shown by crop year (October through September).
(b) *OEIDRUS* data are available at http://www.oeidrus-bc.gob.mx/oeidrus_bca/a1.php; *CONAGUA* data from periodic *Estadísticas agrícolas de los Distritos de Riego*, available at http://www.conagua.gob.mx/Contenido.aspx?n1=3&n2=60&n3=106; IBWC irrigated acreage from its annual Western Water Bulletins (through 2005 posted at http://www.ibwc.state.gov/Water_Data/water_bulletins.html).

Figure 35 shows the *Comisión Nacional del Agua* (*CONAGUA*) and the *Oficinas Estatal de Información para el Desarrollo Rural Sustentable* (*OEIDRUS*) of Baja California and of Sonora – the main agencies tracking irrigated acreage in the Colorado River basin in Mexico – report similar values in the latter half of the decade, though not for the years 2002-2005. The International Boundary and Water Commission (IBWC) only reports acreage irrigated with surface water in the delta region; for the one year with data from both *CONAGUA* and IBWC, IBWC reports about 12 percent more irrigated acreage.[78] Total irrigated acreage in the headwaters region near Nogales averages about 1,200 acres annually, too low to appear at the scale shown in Figure 35.

Figure 35 does not show the declining irrigated acreage seen in many of the U.S. basin states over the past decade. *OEIDRUS* reports that total irrigated acreage was about 2 percent higher in 2009 than in 2002, while *CONAGUA* reports a

[78] *CONAGUA* only reports data for irrigation districts; the delta region falls entirely within Irrigation District 014, but the headwaters region near Nogales is not part of an irrigation district and is not included in *CONAGUA*'s reports. *OEIDRUS* of Baja California and of Sonora both report irrigated acreage by *municipio* (roughly equivalent to a county in the U.S.); *OEIDRUS* reports these data for the headwaters *municipios*, rather than for the watershed. However, a review of satellite imagery suggests that almost all irrigated acreage within these *municipios* lies within the Colorado River basin. Note that *CONAGUA* and *OEIDRUS* report data by crop year (October through September), while IBWC reports calendar year data.

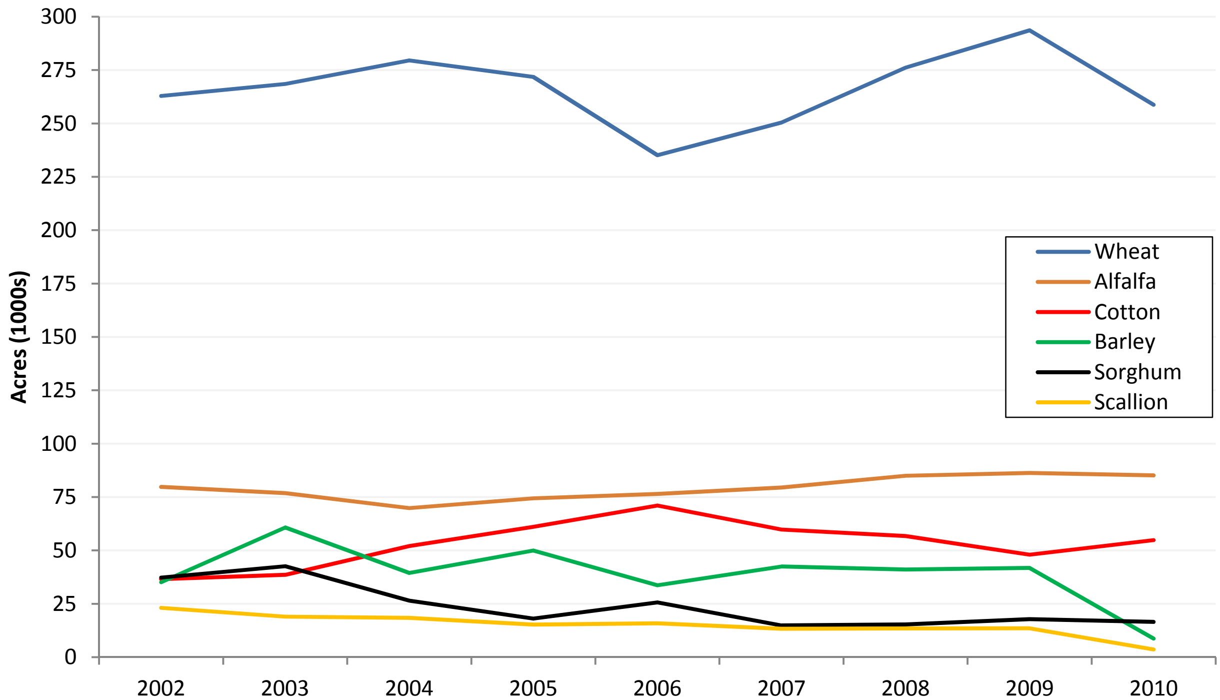

Figure 36. Acreages of Major Crops Grown in Mexico's Portion of the Basin, 2002-2010
Source: OEIDRUS

roughly 2 percent increase from 2000 to 2009.[79] In April 2010, a major earthquake damaged some of the delta region's hydraulic infrastructure and disrupted the growing season for many irrigators, reflected in the form of about 40,000 fewer irrigated acres as reported by *OEIDRUS*. Interestingly, *CONAGUA* reports no significant decline in irrigated acreage from 2009 to 2010. In the headwaters region, irrigated acreage is planted almost entirely in forage crops. *OEIDRUS* also reports about 255,000 head of cattle slaughtered per year in the delta region.

OEIDRUS provides detailed information on acreage by crop type. Figure 36 shows annual variability for the six crops with the greatest acreages;[80] wheat is planted on more than 50 percent of total acreage in the basin in Mexico.[81] Alfalfa acreage increased slightly in the last three years of the decade, but generally remained fairly stable over the period shown. Cotton acreage appears to move in inverse correlation with wheat acreage, peaking at 71,000 acres in 2006, when wheat acreage fell to its lowest extent, at about 235,000 acres. Wheat, barley, and scallions all showed their lowest extent in 2010, but this may reflect the impacts of the 2010 earthquake rather than any long-term trend. More than 25 different kinds of vegetables (not including scallions and onions) are grown in the delta region, plus many varieties of tomatoes. Vegetables are planted on about 30,000 acres annually, while fruit crops – including

[79] In April 2010, a large earthquake destroyed or damaged part of the hydraulic infrastructure in the Mexicali Valley, limiting water availability and distorting year-to-year comparisons.

[80] Values shown for planted rather than harvested acreage.
[81] The delta region in Mexico, organized as Irrigation District 014 ("*Distrito de Riego 014*"), has one of the highest wheat yields of any district in the country.

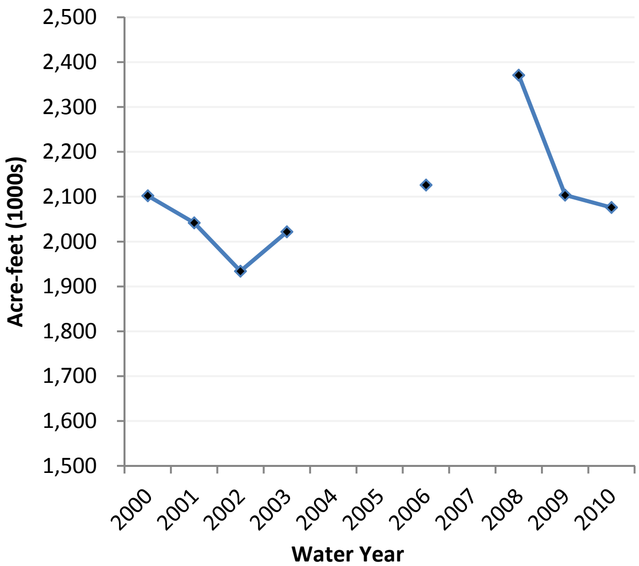

Figure 37. Irrigation Water Deliveries in the Colorado River Delta Region in Mexico
Source: *CONAGUA*Source: *CONAGUA*

strawberries, watermelon, and raspberries – are planted on about 5,000 acres each year. About 30,000 acres per year, mainly in sorghum and corn, were planted on land that grew wheat during the fall-winter crop cycle.

Figure 37 shows total irrigation water deliveries by water year, as reported by *CONAGUA*. Several key points emerge from this figure, most notably the anomalous value reported for 2008. Also notable is that, like the Upper Basin but unlike the Lower Basin, Mexico reports the lowest irrigated acreage and lowest total deliveries in the 2002 drought year. Further, although the volume of deliveries varied over the decade, total reported deliveries in 2009 were almost exactly the same as in 2000; both values approximated the average value of just less than 2,100 KAF. Note that *CONAGUA* reports a 60 KAF decline in surface water distribution from 2009 to 2010, likely reflecting the impacts of the April 2010 earthquake and resultant damage to Mexico's hydraulic infrastructure. We were not able to obtain data for several years, as shown by the gaps in the figure. *CONAGUA* does not report consumptive use or on-farm evapotranspiration or other measures of water depletions. *CONAGUA* reports that groundwater withdrawals for irrigation comprised about 29 percent of total irrigation water deliveries. Dividing the total volume of water distributed by the total reported irrigated acreage yields about 4.3 AF per acre, though this does not account for conveyance losses and operational spills (reportedly 30 percent or greater[82]).

Summary

The reported extent of irrigated land in the Colorado River basin within Mexico ranged from a high of almost 564,000 acres in 2004 (*OEIDRUS*) to a low of about 456,000 acres in 2002 (*CONAGUA*). *OEIDRUS* records show an average of about 513,000 irrigated acres for the years 2002-2010, about 30,000 acres higher than the average *CONAGUA* records give for the years 2000-2010. Incomplete records from both agencies for the years 2000-2010 indicate inter-annual variability but no discernible trend. *OEIDRUS* reports that wheat comprised more than half of total irrigated acreage, with alfalfa acreage increasing to about 18 percent of the total in 2010, cotton at about 12 percent, and a large number of other crops comprising the difference. Records of water use in the district are incomplete. *CONAGUA* reports a maximum water use in 2008 of about 2,300 KAF, reflecting a mix of surface and groundwater sources; average water use over the past decade was about 2,100 KAF.

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[82] *CONAGUA*, 2006, Actualización del Estudio de Factibilidad Para la Rehabilitación y Modernización del Distrito de Riego 014, Río Colorado, B.C. y Sonora.

Discussion

Part I of this report compiles and reviews existing information on irrigated acreage and related water use throughout the Colorado River basin, including Mexico, for the years 2000-2010. This compilation and review highlights several important points about irrigation in the basin:

1. A huge proportion of land and water use in the Colorado River basin is dedicated to feeding cattle and horses;
2. The Upper and Lower basins exhibited very different trends in the extent of irrigated acreage over the last decade;
3. Irrigation water use trends were less clear; and
4. State and federal agencies frequently report inconsistent irrigated land and water use information for areas within the Colorado River basin, hampering understanding of key basin issues and efforts to reconcile the basin's water supply and demand challenges.

Crops to feed cattle and horses: Irrigated pasture and forage crops, used primarily to feed beef and dairy cattle and horses, cover about two million acres (60 percent) of the irrigated land in the Colorado River basin. In Nevada and in Wyoming, pasture and forage account for almost all irrigated acreage; in Colorado and in Utah, more than 85 percent of irrigated acreage in the basin is in pasture or forage. We estimate that irrigated pasture and forage in the basin consumes more than five million acre-feet of water each year.[83] Alfalfa alone covers more than a quarter of the total irrigated acreage in the basin, planted extensively from Wyoming to the delta in Mexico.

Arizona, California, and Mexico all have much more crop diversity than the other states in the basin, with hundreds of thousands of acres in vegetables, wheat, and cotton. About 250,000 acres (more than 50 percent) of Mexico's total acreage in the basin is planted in wheat, providing one of the major supplies for that nation. In 2001, Arizona had more than 300,000 acres in cotton, though that acreage declined in subsequent years. California's portion of the basin grows a wide variety of crops, including some 62,000 acres of seed crops. Even so, more than 750,000 acres in the basin in Arizona, California, and Mexico are in forage crops and pasture, consuming roughly 3 million acre-feet of water each year.

Trends in irrigated acreage: Trends in irrigated acreage and in overall water use for irrigation show clear geographic differences. The amount of irrigated acreage in each of the Upper Basin states fell in the early part of the last decade and then recovered or surpassed previous acreages to varying degrees. In New Mexico, Upper Basin irrigated acreage showed the least change, while Utah's acreage experienced the greatest change, increasing by about 25 percent over the decade. In Mexico's portion of the Colorado River basin, however, the extent of irrigated acreage showed some variability over the decade but no clear trend.

In the Lower Basin, each state saw a decline in irrigated acreage over the decade. According to several sources, total irrigated acreage in central Arizona declined by about 20,000 acres per year over the past decade, though the total acreage in

[83] Based on USBR reported consumptive use for irrigation in 2005, we assume that all such use in Nevada and Wyoming, and 85 percent of such use in Colorado and Utah, were for irrigation of pasture and forage. Additionally, we assume about five feet of consumptive use per acre for such crops (predominantly alfalfa and other water-intensive forage crops) in Arizona, California, and Mexico. We do not have sufficient information on New Mexico crop acreages to include that state in this calculation.

other parts of the state remained fairly constant. Limited information for Nevada's portion of the basin suggests that the amount of irrigated acreage is falling there as well, though the total magnitude of irrigated acreage in Nevada is only a small fraction of that seen in Arizona. California's irrigated acreage slowly declined over the decade by about 50,000 acres overall, roughly 9 percent. These differences between Upper and Lower Basin trends reflect the influence of several factors, including water availability and short- and longer-term impacts of the ongoing drought in the basin, the rising impact of agricultural-to-urban water transfers and land conversion in each of the Lower Basin states, as well as real and perceived differences in the volume of water available to be developed in the Upper and Lower basins.

Irrigation Water Use Trends: Interestingly, total irrigation water use trends in the two basins and in the individual states are generally more consistent, showing limited changes over time. Total irrigation water use increased slightly in Utah, though at a lower rate than shown by increases in irrigated acreage. Irrigation water use remained flat or declined slightly in Colorado and in Wyoming, and declined slightly in California. Incomplete information limits assessment of water use trends in Arizona and Nevada. Irrigation water use in Mexico remained fairly constant over the decade.

Inconsistent irrigated land and water use information: One of the most unexpected revelations of this study was the marked disparity in the different state and federal agencies' reported extents of irrigated acreage and volumes of irrigation water use. In New Mexico, there was considerable agreement and consistency among most – but not all – of the agencies' information. Yet in most states, the agencies' reported acreages and water use varied dramatically. The agencies reported different aspects of irrigation water use, challenging efforts to compare values reported by different agencies. A further challenge is that most of the federal and state agencies only report information periodically, making it difficult to draw robust conclusions about trends or compare information reported in different years. These differences reflect the various objectives and intents of the agencies' efforts. Despite these limitations, the available information offers an important and revealing overview of recent land and water use in the Colorado River basin. This also highlights the need for better coordination and consistency among reporting agencies.

3 Conservation and Efficiency Options

The Colorado River Basin suffers from limited water supplies – which could decline by 9 percent or more by 2060 – and by rising municipal demands for water.[84] Many reaches of the river and its tributaries suffer from insufficient instream flows, threatening aquatic and riparian species and recreation-dependent businesses that rely on healthy flows. In *Municipal Deliveries of Colorado River Basin Water* (Cohen 2011), we noted the efforts made to date to conserve water in the fast-growing municipal sector and described the potential for additional water savings. Irrigated agriculture consumes more than 70 percent of the developed water supply in the Colorado River basin, making it an obvious sector in which to explore the potential for conserving water. In the following we describe several water conservation scenarios for the agricultural sector and the potential volumes of water that could be generated by each of these. This report complements previous Pacific Institute efforts to address the potential for improving agricultural efficiency – calculated as yield divided by applied water – in California (Christian-Smith et al. 2010, Christian-Smith et al. 2011, Gleick et al. 2011) by applying some of those lessons to the Colorado River basin. We start this discussion by defining key water use terms, followed by a brief review of several recent studies on agricultural water conservation potential.

Defining Agricultural Water Use

As described in the Introduction (see "Water Use Terms" on page 6) a variety of terms are used to describe agricultural water use, including water withdrawal, applied water, and consumptive use. Water withdrawals refer to water taken from a source and used for agricultural purposes. These withdrawals include groundwater and surface water taken from local sources or water transported via large infrastructure projects from distant sources. Prior to delivery to a farm, water withdrawn from a source is subject to conveyance losses, such as seepage or evaporation from canals. The "applied water" is the quantity of surface and groundwater delivered to the farm, i.e., water withdrawals minus conveyance losses. Agricultural water use can also be categorized as consumptive or non-consumptive. Consumptive use refers to water that is unavailable for reuse in the basin from which it was extracted, due to soil evaporation, plant transpiration, incorporation into plant biomass, seepage to a saline sink, or contamination. Non-consumptive use refers to water that is available for reuse within the basin from which it was extracted. In the Introduction, Figure 1 shows a schematic of an idealized irrigation system in the context of the larger watershed, depicting the various water uses described above.

[84] See for example the Colorado River Basin Water Supply and Demand Study.

Non-consumptive water savings have been erroneously referred to as "dry" water savings (Seckler 1993) based on the assumption that all water losses are re-captured and re-used elsewhere downstream. The implication for many water-stressed regions is that there is no potential to reduce stress or increase resilience through improved water efficiency. This is inaccurate (Gleick et al. 2011). While unused irrigation water typically returns to downstream rivers or recharges aquifers, this process rarely captures all unused irrigation water; return flows also suffer from dislocations in timing and degraded water quality. Furthermore, reducing both consumptive and non-consumptive water losses can leave more water in-stream to support ecosystem flows, can reduce water quality problems associated with agricultural runoff, and can delay or eliminate the need for new water supply infrastructure. Despite the importance of reducing both consumptive and non-consumptive losses, it is useful to distinguish between the two, which we attempt to do throughout this report.

Previous studies

Several studies have found that farm-scale irrigation efficiency gains may not necessarily reduce overall water use (Huffaker and Whittlesey 2000; Skaggs 2001; Ward and Pulido-Velazquez 2008; Huffaker 2008; Frisvold and Deva 2011(b)). Calzadilla et al. (2011) took a global approach to the effects of improved irrigation efficiency and found that improved irrigation efficiency reduced global water use, but regionally the story became much more complex and depended on a variety of factors, such as socio-economics, current irrigation efficiency, and food markets.

A recent study of the Rio Grande River Basin found that subsidies - defined as financial support for capital costs to upgrade irrigation systems - can encourage farmers to adopt more efficient irrigation technologies, but that these did not necessarily reduce water depletions at the basin scale (Ward and Pulido-Velazquez 2008). The study found that an increase in irrigation efficiency can reduce return flows, which are often a valuable downstream water supply source. A study in the Upper Rio Grande River Basin, however, found that efficiency improvements could have a variety of beneficial impacts, including increases in gross revenue, crop production, and decreases in total water use (Brinegar and Ward 2009).

Colorado Agricultural Water Alliance's (2008) findings were similar to previous research in that it found that simply switching to more efficient irrigation technologies does not necessarily create or save "new" water that can be transferred to other uses. However, the Alliance (2008) lists five ways that *consumptive use* may be reduced: (1) irrigated crop acreage is decreased; (2) crop selection is changed from a summer crop to a cool season crop; (3) crop selection is changed to one with a shorter growing season; (4) deficit irrigation is practiced, applying some amount less than full evapotranspiration (ET) over the growing season; and (5) evaporative losses from the field surface are reduced as a result of conservation tillage, mulching, and/or drip irrigation.

Gleick et al. (2011) contend that the real purpose of water use is to provide social and economic well-being and suggest it is more useful to focus on maximizing the productivity of water use or the social and individual well-being per unit of water used, which can be measured in a variety of ways including dollars of GDP per unit of water ("economic productivity"); crop yield per unit of water ("yield productivity"); or households served per unit of water.

Much of the research into irrigation efficiency finds that due to the high percentage of global water use for irrigation, efficiency gains will become increasingly important as global demand increases and hydro-climatic change impacts intensify (Turral et al. 2010). The question becomes how to improve water efficiency given the potential unintended consequences noted above. Luquet et al. (2005) found that for high value crops (e.g., tomatoes), there were inherent incentives for both farmers and water managers to switch to more efficient irrigation technologies. The problem, however, was that for medium- and low-value crops such as cotton there were fewer incentives given the high capital costs and relatively low return per acre of irrigated land. For low value crops, significantly higher water costs and equipment subsidies would be required for farmers to adopt new technologies. Bishop et al. (2010) modeled the possibility of switching to less water-intensive crops in the arid region of northwest Nevada and found that it is economically feasible to change the type of crop being produced and to lower water consumption. This was dependent on the alternative crop meeting several criteria, including suitability of soil type, proximity of markets, and minimal changes in on-farm equipment. Another study looking at farm size, irrigation efficiency, and outside influence on farmer irrigation practices found that larger farm operations are more likely to engage in programs designed to improve irrigation practices, as opposed to small scale operations (Frisvold and Deva 2012). Further, smaller farms are more reliant on intermediary sources of information (e.g., irrigation districts) while larger farms are more likely to use direct sources of information (e.g., internet reports). Thus, any efforts to increase irrigation efficiency must be tailored to the size of operation and source of information.

As noted in Part I of this report, about 60 percent of the irrigated acreage in the Colorado River basin is devoted to pasture, alfalfa, and other forage crops. Not surprisingly, much of the research into irrigation efficiency potential in the western United States investigates the potential water savings associated with these crops. One such study looked at the water saving potential of alfalfa production in the Great Plains and Intermountain West (Lindenmayer et al. 2011). This study found that because the evapotranspiration (ET) rates differed for alfalfa depending on the season, more water could be saved by fully irrigating in the spring season and not irrigating in the summer, rather than deficit irrigating in both seasons.

Agricultural Water Management Improvement Strategies and Scenarios

As described in Part I, the Colorado River basin is a large area with a heterogeneous agricultural sector. In order to develop realistic scenarios of agricultural water management improvements, it is important to understand the current agricultural water uses and how they differ across the upper and Lower Basins.

Crop mix

Upper Basin cropland is devoted primarily to livestock feed crops. As discussed in Part I, the 2007 crop mix can be characterized by hay crops (55 percent); irrigated pasture (37 percent); grains (5 percent); and other crops (4 percent). The crop mix has been stable over the last ten years with minor substitution between hay crops and irrigated pasture. This stability is likely due to the relatively cold climate and the lack of access to markets, both of which limit cropping options (Pritchett 2011).

The Lower Basin, on the other hand, has more varied agricultural production and generates more revenue per acre. The 2007 crop mix in the Lower Basin includes hay crops (39%); cotton (15%); wheat (14%); vegetables (11%); orchards (4%); irrigated pasture (4%); and other crops (12%). Crop shifting (changing from one type of crop to another) has occurred in the Lower Basin over the last ten years. In particular, declines in cotton and barley have coincided with a notable increase in alfalfa production and a less pronounced increase in sorghum, which is being used for biofuels.

Irrigation technologies

Common to both basins is the prevalence of flood irrigation. According to USGS, 80 percent of the cropland within the Colorado River basin is flood irrigated. Flood irrigation involves applying water by flooding an entire basin, border, or furrow (see Improved Irrigation Technology Scenario below for more detail). Other irrigation technologies include sprinkler and drip irrigation, which typically have higher water use efficiencies.[85]

Irrigation scheduling

Traditionally, irrigation was designed to meet full crop water requirements. However, in practice, irrigators may under- or over-irrigate. In some cases, this may be unintentional, due to insufficient water availability, as often occurs in the Upper Basin. In other cases, it may be planned. Regulated deficit irrigation (RDI) stresses plants by not irrigating to meet full crop water needs during drought-tolerant growth stages. RDI is practiced widely on wine grapes to improve crop quality. RDI is also appropriate for some field crops. In particular, deficit irrigation has been applied successfully to alfalfa and pasture in the Colorado River basin (Carter and Sheaffer 1983, Grimes et al. 1992, Undersander 1987, Peterson 1972, Smith 1962, Robinson and Massengale 1968, and Lindenmeyer et al. 2011).

Scenario Analysis

Based on information about recent agricultural water uses, we model the application of a series of agricultural water management conservation strategies including regulated deficit irrigation, crop shifting, and advanced irrigation technologies. We developed different scenarios based on these strategies to compare potential water savings and their costs. The scenarios rely on data collected by the agricultural census and USGS for estimates of irrigated area and freshwater withdrawals for irrigation, respectively. These data sources provide information at the county scale. We run all of the scenarios at the county scale based on these federal data. Economic analyses rely on a variety of different data sources, including cooperative extension service publications and cost and return studies. Note that the potential water savings related to individual scenarios are not cumulative: they should be considered independently to avoid double-counting. Below, we describe the details of each strategy and scenario. We recognize that these data sources, especially the USGS county-level information, are imperfect, but they offer the best available basin-wide information for county-level crop water withdrawals and irrigation method.

Regulated Deficit Irrigation

Crop water requirements vary throughout the crop life cycle and depend on weather and soil conditions. Irrigation scheduling provides a means to evaluate and apply an amount of water sufficient to meet crop requirements at the right time. While proper scheduling can increase or decrease water use depending on current practices, it will likely increase yield and/or quality, resulting in an improvement in water productivity as more crop can be produced per unit of water (Ortega-Farias et al. 2004, Dokter 1996, Buchleiter et al. 1996, Rijks and Gbeckor-Kove 1990).

The traditional irrigation strategy is to supply crops with sufficient water throughout the season so that they transpire at their maximum potential, meeting the full crop

[85] We calculate agricultural water-use efficiency here as crop yield divided by applied water.

evapotranspiration (ET) requirements. However, water scarcity and interest in maximizing crop quality have catalyzed a number of innovative approaches that have been shown to reduce crop water use, including deficit irrigation, tail water recovery, and soil management practices that increase soil moisture retention (Christian-Smith et al. 2011). "Deficit irrigation," defined as the application of water below full crop ET requirements, can be an effective tool to reduce applied water and increase revenue (Chaves et al. 2007, Fereres and Soriano 2007). While deficit irrigation is uncontrolled, and often unintentional, regulated deficit irrigation (RDI) is an irrigation management practice implemented during stress-tolerant growth stages in order to conserve water while minimizing negative impacts on yield (Goldhamer 2007). Because response to water stress can vary considerably by crop, a clear understanding of crop behavior and ecological conditions is required to maintain yields. Water savings associated with RDI depends on many factors, including the crop type and the sensitivity of growth stages to stress, climatic demand, stored available water, spring-summer rains, and the particular irrigation method.[86] RDI has been shown to be successful on several crops in the Colorado River basin, including alfalfa, as described below.

Regulated Deficit Irrigation on Alfalfa

Alfalfa is prevalent throughout the Colorado River basin. RDI has been used on alfalfa with limited reductions in crop yields. Established alfalfa may be adapted to deficit irrigation with drought avoidance mechanisms such as deep rooting (Peterson 1972) and drought-induced dormancy (Peterson 1972, Smith 1962, Robinson and Massengale 1968). There are two ways that studies have applied RDI on alfalfa. The first, "partial season" RDI, involves stopping irrigation during the late summer months when crop growth is low and water supplies are typically the most limited. The second, known as "full season" RDI, reduces total irrigation throughout the season. Lindenmeyer et al. (2011) found that partial season RDI offers greater water use efficiency for alfalfa than does full season RDI.

Partial season irrigation has been shown to reduce alfalfa water consumption by 22.7 inches per year in the Palo Verde Valley in the Lower Basin (Bali et al. 2010) relative to full season irrigation of about 68 inches per year (LCRAS 2007). We assume water savings of 22.7 inches or 1.9 acre-feet in our scenario projecting total volumes of potential water savings from RDI applied on alfalfa in the Lower Basin. The Upper Basin, on the other hand, has a colder climate and a shorter growing season, so annual consumptive use is much lower (Lindenmeyer et al. 2011). Lindenmayer et al. (2011) compiled nine different studies in the Great Plains and Intermountain West examining a variety of RDI strategies and found that, on average, deficit irrigation reduced the average consumptive use of alfalfa by 4.3 inches. We used this value in our scenario of potential water savings from RDI applied on alfalfa in the Upper Basin.[87]

Scenario 1a: Basin-Wide Regulated Deficit Irrigation

In Scenario 1a we calculated the potential volume of consumptive water use that could be avoided by using regulated deficit irrigation (RDI) on about 800,000 acres of alfalfa in the Upper and Lower basins, assuming savings of 22.7 inches per year in the Lower Basin and 4.3 inches per year in the Upper Basin, per acre of irrigated alfalfa. According to our calculations (see Appendix C for a county-by-county breakdown of projected savings), this could reduce consumptive use by

[86] Water savings are described in comparison to a control that received full irrigation to meet ET requirements (estimated by the Penman-Monteith method).

[87] Unfortunately, we were unable to find any uniform estimates of crop water use in the basin, so we used these generalized values rather than location-specific values.

about 970,000 AF annually. Total applied water savings would be higher still but depend on irrigation method and efficiency and were not calculated as part of this scenario. Both the consumptive use savings and the total reduction in water demand that could be captured by this scenario are quite remarkable, representing more than 10 percent of total irrigation water use in the Colorado River basin. Total costs and returns are discussed below, under "Economic Analysis."

Scenario 1b: Lower Basin Regulated Deficit Irrigation

The majority of water consumed for alfalfa production occurs in the Lower Basin, where the growing season is longer and temperatures are higher. In fact, we estimate that alfalfa consumes on the order of 2,200,000 AF annually in the Lower Basin.[88] Given the magnitude of alfalfa's water use, it is also informative to examine how much water could be saved if RDI were only applied in the Lower Basin. In Scenario 1b, we calculated the potential volume of consumptive water use that could be avoided by using regulated deficit irrigation (RDI) in the Lower Basin only, assuming savings of 22.7 inches per year per acre of irrigated alfalfa. According to our calculations, the results indicate that RDI on Lower Basin alfalfa could save about 834,000 AF of water annually. This disproportionate savings reflects the much longer growing season and much greater volumes of water used to irrigate Lower Basin alfalfa.

Economic Analysis

Regulated deficit irrigation reduces alfalfa yields and crop revenues. The net return to the agricultural producer depends on both the commodity price of alfalfa and the cost of water. If we assume that commodity prices and water prices remain constant, we can estimate the economic impacts of reduced yields related to regulated deficit irrigation based on crop enterprise budgets from Colorado River basin states, as described in Appendix C. We assume that regulated deficit irrigation of alfalfa results in a 25% yield loss, which is within the range of yield losses documented by multiple studies (Lindenmeyer et al. 2011). The base costs associated with Scenario 1a would be approximately $78 million, or $81/AF of water saved. In Scenario 1b, base costs would amount to about $52 million or $62/AF.[89]

That is, applying RDI to alfalfa in the Lower Basin alone could generate about 834,000 AF of consumptive use savings per year, with base costs estimated at $52 million per year, or about $62/AF. Total applied water savings would be higher still but depend on irrigation method and efficiency and were not calculated as part of this scenario. For comparison, the recently approved seawater desalination plant in southern California will generate about 56,000 AF annually, at a projected cost of $1,849 to $2,064/AF.[90] To implement RDI, we assume that other interests – such as municipal water agencies or wildlife agencies interested in augmenting instream flows – would compensate irrigators for reductions in crop yields, so total costs would need to be negotiated and would presumably include some additional incentive payments to irrigators. We discuss water transfers at the end of this section.

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[88] Based on about 440,000 acres of alfalfa in the Lower Basin and an evapotranspiration rate of about 5.0 AF/acre, as reported by LCRAS for 2007 in its "IID & Coachella Area ET Rate Table."

[89] We note that the volatility in net returns per acre over time directly affect the total cost projected for these two variations on the RDI strategy. This volatility is due to both commodity prices and yields. Commodity prices in particular can vary dramatically from year to year. For example, according to the University of California Cooperative Extension *2012 Field Crop Guidelines*, the total production value per acre of alfalfa in Imperial County varied by more than a factor of two between 2003 and 2011; the assumptions used to determine the costs for this scenario reflect some of the highest commodity values for alfalfa in the past decade.

[90] Water production and cost projections reported on the SDCWA webpage, visited March 5, 2013.

Crop Shifting Scenarios

Crop shifting refers to converting from one type of crop to another. A variety of factors limit producers' ability to shift crops, from physical constraints such as soil conditions, climate, and water availability to market considerations and other less tangible factors. In the Upper Basin the crop mix (predominantly pasture and forage) has been stable for many years, at least partly due to these factors. In the Lower Basin, producers have demonstrated much greater ability and willingness to shift between crops. Any specific decision to shift crops will be grounded in a set of factors particular to that location. For these scenarios, we take an abstract view of the potential water savings that could be generated by several different cropping patterns, predicated on the demonstrated need to conserve water in the Colorado River basin and the potential for funding to incentivize such shifts.

The crop shifting scenarios are based on agricultural census data from 1997, 2002, and 2007. To estimate the potential water savings associated with changes in cropping patterns, we apply mean crop water use based on field studies conducted primarily by the USDA Agricultural Research Service (Erie et al. 1982). Since these calculations rely on differences in crop water use, all projected savings can be characterized as consumptive use savings; total applied water savings would be even greater, but were not estimated for these scenarios. Since there has been very little crop shifting in the Upper Basin over the 1997-2007 time period, we limit the crop shifting scenarios to the Lower Basin.

We developed three crop shifting scenarios for the Lower Basin: (a) shifting from cotton to wheat; (b) shifting from alfalfa to sorghum; and (c) shifting from alfalfa to wheat and cotton. The scenarios focus on field crops because they dominate the basin, because they have relatively high water use, and because variable costs associated with field crop production are relatively low compared to other crops types, such as row crops or vegetables (Colby and Frisvold 2011). The crop shifting scenarios do not project any changes in crop acreage. They focus only on the water savings associated with different cropping patterns. These scenarios cannot be combined with the RDI or irrigation technology scenarios; these are independent, stand-alone scenarios.

Scenario 2a: Decreased Cotton, Increased Wheat

Scenario 2a estimates the potential consumptive water use savings that could be generated by shifting some 70,000 acres of cotton to wheat.[91] Based on field studies conducted primarily by the USDA Agricultural Research Service (Erie et al. 1982), we assume that converting one acre of irrigated cotton to wheat would save almost 1.3 AF of water.[92] Given these assumptions, this scenario estimates consumptive use savings of about 101,000 acre-feet per year from shifting 80,000 acres from cotton to wheat.

Scenario 2b: Decreased Alfalfa, Increased Sorghum

Scenario 2b shifts about 74,000 acres of alfalfa[93] to sorghum, a relatively efficient, drought-tolerant biofuel (de Vries 2010), in Arizona, where there is an existing biofuel plant. Based on field studies conducted primarily by the USDA Agricultural Research Service (Erie et al. 1982), we assume that converting one acre of irrigated alfalfa to sorghum would save 1.9 AF of water.[94]

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[91] Cotton acreage has fluctuated dramatically in the Colorado River basin, falling from about 332,000 acres in Arizona in 1997 to a low of 136,000 acres in 2008, but then rose again to 248,000 acres in 2011. The 70,000 acre shift selected for this scenario represents a value within this range.

[92] Erie et al. (1982) state that irrigated cotton consumes 41.2 inches of water per year, while irrigated wheat consumes 25.8 inches of water per year, on average.

[93] This represents about 30 percent of total alfalfa acreage in Arizona in 2007.

[94] Erie et al. (1982) state that irrigated alfalfa consumes 74.3 inches of water per year, while irrigated sorghum consumes

Given these assumptions, this scenario estimates consumptive use savings of just over 140,000 acre-feet of water per year.

Scenario 2c: Decreased Alfalfa, Increased Wheat and Cotton

In this scenario, about 74,000 acres of alfalfa within all counties along the lower mainstem of the Colorado River are replaced by cotton and wheat, in equal proportions. Based on field studies conducted primarily by the USDA Agricultural Research Service (Erie et al. 1982), we assume that converting one acre of irrigated alfalfa to wheat would save 4.0 AF and converting one acre of irrigated alfalfa to cotton would save about 2.8 AF.[95] Given these assumptions, this scenario estimates consumptive use savings of about 250,000 acre-feet per year from shifting 74,000 acres from alfalfa to cotton and wheat.

Economic Analysis

The economic analysis reflects changes in the net returns above operating costs associated with the three crop shifting scenarios described above.[96] Net returns above operating costs are calculated by subtracting total annual operating costs from the total annual revenue (or gross receipts) per acre. The economic analysis of Scenario 2a reflects the change in net returns associated with substituting a portion of cotton acreage with wheat. Crop return studies from the Lower Basin states document higher net economic returns for cotton (around $276 per acre) as compared to wheat (around $133 per acre).[97] We estimate that the base costs for Scenario 2a are approximately $11.3 million, equivalent to $112/AF of water savings. The base costs for Scenario 2b reflect substituting a higher-value field crop (alfalfa) with a lower-value field crop (sorghum).[98] The change in net returns shows base costs of $13.5 million, or about $96/AF of water savings. Finally, the change in net returns for Scenario 2c reflects the slightly lower values of cotton and wheat relative to alfalfa with base costs totaling $8.6 million, or $36/AF. Commodity prices are extremely volatile, so these base costs will vary. The economic analyses of these scenarios do not consider the third party impacts associated with changes in cropping patterns. To incentivize the shift from one crop to another, we assume that other interests – such as municipal water agencies or wildlife agencies interested in augmenting instream flows – would compensate irrigators for making the conversion, so total costs would need to be negotiated and would presumably include some additional incentive payments to irrigators. We discuss water transfers at the end of this section.

Improved Irrigation Technology

Flood irrigation is the oldest form of irrigation – it is simply the application of water by gravity flow to the surface of the field. Either the entire field is flooded (by uncontrolled flood or basin irrigation) or the water is fed into small channels (furrows) or strips of land (borders). It is most

51.5 inches of water per year, on average, a difference of 22.8 inches. Although these rates are considerably higher than those reported by LCRAS (61.6" and 33.9", respectively), the difference in water consumption between alfalfa and sorghum is comparable.

[95] Erie et al. (1982) state that irrigated alfalfa consumes 74.3 inches of water per year, while irrigated cotton consumes 41.2 inches and irrigated wheat consumes 25.8 inches of water per year, on average.

[96] We conservatively calculate "net returns above operating costs" to capture the loss of income associated with a single year's harvest rather than "net returns above total costs," which are much lower. In many instances, the net returns above total costs for alfalfa and some of the other field crops are negative: depending on market prices, growers in many years lose money with some crops.

[97] Cost and return studies from the University of Arizona and the University of California, Davis.

[98] These estimates are derived from cost and return studies from 2008. In subsequent years, the market price for alfalfa fell, so the total cost for shifting from alfalfa to other crops would be less.

often used on field crops, such as rice and alfalfa. Flooding often requires less infrastructure and labor than other forms of irrigation and is therefore typically the least expensive, but it may not be suitable where there is sloping terrain or for crops that do not tolerate ponding or develop moisture-related diseases.

Sprinkler irrigation was introduced in the 1930s. With a sprinkler irrigation system, water is delivered to the field through a pressurized pipe system and is distributed by rotating sprinkler heads or spray nozzles or a single gun-type sprinkler. The sprinklers can be either permanently mounted (solid set) or mounted on a moving platform that is connected to a water source (traveling). Low-energy precision application (LEPA) sprinklers are an adaptation of center pivot systems that use drop tubes that extend down from the pipeline. LEPA systems can conserve both water and energy by applying the water at a low-pressure close to the ground, which reduces water loss from evaporation and wind, increases application uniformity, and decreases energy requirements. Many row crops and orchard crops are currently irrigated with sprinklers.

Drip irrigation refers to the slow application of low-pressure water from plastic tubing placed near the plant's root zone. Drip systems commonly consist of buried PVC pipe mains and sub-mains attached to surface polyethylene lateral lines. A less expensive but also less durable option is drip tape. Water is applied through drip emitters placed above- or below-ground, referred to as surface and subsurface drip, respectively. Microirrigation systems are similar to drip systems with the exception that water is applied at a higher rate (5-to-50 gallons per hour) by a small plastic sprinkler attached to a stake (Evans et al. 1998).

Despite the success with precision irrigation systems on a wide variety of crops, there are barriers to transitioning to new irrigation technologies. Chief among these barriers are cost, as sprinkler and drip systems often cost over $1,000 per acre to install; there can also be additional costs associated with maintaining the systems. In addition, sprinkler and drip systems can impede farm equipment in fields that are cropped multiple times a year. Furthermore, irrigators are limited by their water supply. In most cases, agricultural water suppliers do not provide pressurized water, which is necessary for precision irrigation technologies, so individual irrigators have to buy pumps to pressurize their water. In addition, some agricultural water suppliers are on rotational delivery systems where each irrigator must periodically take a large amount of water on a schedule designed for flood irrigation rather than sprinkler irrigation.

Flood irrigation is the least efficient because of the larger volumes of unproductive evaporative losses that occur, the application of water to non-targeted surface areas, and the propensity for deep percolation, all of which mean that much of the water that is applied does not contribute to crop growth.[99] With proper management and design, drip and micro-irrigation are the most efficient at maximizing crop yield-per-unit water use. The potential irrigation efficiencies (defined here as the volume of irrigation water consumed by the plant divided by the volume of irrigation water applied to the field minus change in surface and soil storage) for flood irrigation systems range from 60-85 percent, whereas for sprinklers, the potential irrigation efficiencies range from 70-90 percent. Potential irrigation efficiencies for drip and micro-irrigation systems are even higher, ranging from 88-90 percent (Table 12).

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[99] Some portion of this unproductive water is lost to the system and can be characterized as a consumptive use; some of the unproductive water returns to the system and may be applied to other downstream uses. The proportion of consumptive and non-consumptive uses of this unproductive water varies with location and other factors.

Table 12. Irrigation Systems and Associated Efficiencies

Type of Irrigation System	Efficiency
Flood	
Basin	85%
Border	77.5%
Furrow	67.5%
Wild Flooding	60%
Gravity	75%
Average	73%
Sprinkler	
Hand Move or Portable	70%
Center Pivot and Linear Move	82.5%
Solid Set or Permanent	75%
Side Roll Sprinkler	70%
LEPA (Low Energy Precision Application)	90%
Average	78%
Drip /Micro-irrigation	
Surface Drip	87.5%
Buried Drip	90%
Sub-irrigation	90%
Micro Sprinkler	87.5%
Average	89%

Source: Salas et al. 2006
Note: Efficiency is calculated here as the volume of irrigation water consumed (equal to ET) divided by the volume of irrigation water applied minus change in storage of irrigation water.

The average increase in water use efficiency between flood and sprinkler irrigation described in Table 12 above is approximately 5 percent. This is a conservative estimate of potential increases in water use efficiency. For example, Johnson (2002) found a 20 percent increase in water use efficiency associated with shifting from flood to sprinkler irrigation, along with significant improvements in river flow and crop yield.[100]

In the scenarios below, we conservatively estimate a 5 percent reduction in applied water associated with the conversion from flood to sprinkler irrigation, although we note that actual savings could be much higher.

Scenario 3a: Basin-wide Improved Irrigation Technology

Scenario 3a models the water savings associated with shifting a portion of crop acreage from flood to sprinkler irrigation. We assume that about 633,000 acres of flood irrigated acreage (25 percent of the total) are converted to sprinkler irrigation basin-wide. The agricultural census and USGS report slightly different percentages of flood irrigated acreage (75 percent and 80 percent, respectively). We use the USGS percentage because USGS also provides an estimate of irrigation withdrawals by county, allowing for a consistent data source for both acreage and withdrawals.[101] We limit this scenario to evaluating the potential savings generated by conversion from flood to sprinkler (rather than from flood to drip) because many field crops have already been converted successfully and because sprinkler irrigation has a higher return on investment for field crops than drip irrigation, making it more economically attractive (Al-Jamal et al. 2001, Sanden et al. 2011).

Assuming that sprinkler irrigation is 5 percent more efficient than flood irrigation, the scenario projects that converting 25 percent of flood-irrigated acreage to sprinkler irrigation would generate approximately 175,000 acre-feet of potential applied water savings per year. These savings represent a reduction in total water

[100] Johnson (2002) states, "After the conversion from flood irrigation to sprinklers, average crop yields increased from 1.6 ton/acre to 2.1 ton/acre. Crop yields increased because farmers can now more evenly distribute irrigation water to their fields and irrigate higher reaches of their fields."

[101] We recognize that the USGS-reported withdrawals are not equivalent to actual volumes applied directly to the field; in the absence of a better basin-wide data source, we use these volumes as a proxy for applied water.

demand as defined by USBR's Basin Study but are generally non-consumptive savings. Appendix D shows the potential water savings at the county level for each county in the U.S. portion of the Colorado River basin.

Scenario 3b: Lower Basin Improved Irrigation Technology

Shifting to more efficient irrigation technologies reduces return flows in areas where such water normally returns to the system for subsequent reuse, but in several key areas in the Colorado River basin such as the Salton Sea watershed and parts of central Arizona, unconsumed irrigation water does not return to the system. Improving irrigation efficiency in these areas that do not generate return flows can be produce true consumptive use savings. For Scenario 3b we only include those counties that do not generate return flows, using the same methods described in Scenario 3a. Please see Appendix D for a list of these counties and the volumes of water conserved in each. By converting from flood to sprinkler irrigation in areas that do not generate return flows (a total of 36,600 acres in the Lower Basin), Scenario 3b generates potential savings of approximately 60,000 acre-feet per year of consumptive use.

Economic Analysis

Converting to sprinkler irrigation involves pressurizing water, setting up pipe and/or hose networks, and can require additional labor and maintenance. This requires both large capital costs and increased annual expenses. The increase in annual costs to grow alfalfa in California with sprinkler irrigation rather than border irrigation ranges from $123/acre for a center pivot sprinkler system to $264/acre for a side-roll sprinkler system to $415/acre for a solid set sprinkler system. These estimates include the annualized capital cost as well as energy, water, labor, and maintenance costs (Sanden et al. 2011).

The conversion of 633,000 acres in the U.S. portion of the Colorado River basin, as described in Scenario 3a, would increase annual costs by $78-$260 million, equivalent to about $450-$1,500/AF of water savings. Scenario 3b, which converts about 36,600 acres in areas that are not hydrologically connected to the Colorado River mainstem, would increase annual costs by $28-$96 million, or about $470-$1,600/AF of water savings. Despite increased annual costs, multiple studies conclude that over time, sprinkler systems provide a high return on investment through increased crop yields and improved crop quality, offering clear benefits to the agricultural producer (Al-Jamal et al. 2001, Sanden et al. 2011). Nonetheless, these annual costs are much higher than the net returns generated by most crops and by field crops generally. To convert from flood to sprinkler irrigation, we assume that other interests – such as municipal water agencies or wildlife agencies interested in augmenting instream flows – would compensate irrigators for making the conversion, so total costs would need to be negotiated and would presumably include some additional incentive payments to irrigators. We discuss water transfers at the end of this section.

Discussion

The RDI, crop shifting, and improved irrigation technology scenarios described above estimate annual water savings and costs. The scenarios vary in the amount and type of water savings produced and the cost of those savings. These strategies are not cumulative and in many cases are mutually exclusive. For example, shifting from alfalfa to other crops means that the total acreage available to apply RDI to alfalfa would be decreased, so the estimated volumes of water savings from the difference scenarios should not be combined. Still, it is useful to compare across the strategies and scenarios, as shown in Table 13.

Table 13 shows the potential water savings, in both total applied water and in consumptive use, for the three scenarios explored here. With the exception of the conversions from flood to sprinkler, the general strategies described above could generate large volumes of transferable conserved water at low cost. This is very encouraging. Indeed, according to our estimates, one of the least expensive options – RDI applied to Lower Basin alfalfa (Scenario 1b) – could conserve more than 800,000 AF of consumptive use. While the improved irrigation technology strategies (Scenario 3) specifically estimate potential reductions in applied water, the other strategies focus on consumptive water use savings: total applied water savings in Scenarios 1 and 2 could be a third or more greater than the values listed. Typically, only the consumptive use savings can be transferred to other uses, but total reductions in applied water and in total withdrawals more broadly offer significant benefits for water quality and stream health generally, as well as for the sustainability of local aquifers in the case of groundwater extraction.

Table 13. Summary of Scenarios

Scenario	Description	Applied Water Savings (AF)[a]	Consumptive Use Savings (AF)	Estimated Base Costs
Scenario 1a: Basin-wide RDI	Applied to alfalfa in the entire basin	>970,000	970,000	$81/AF
Scenario 1b: Lower Basin RDI	Applied to alfalfa in the Lower Basin only	>834,000	834,000	$62/AF
Scenario 2a: Decreased cotton, increased wheat	70,000 acres of cotton substituted by wheat	>90,000	90,000	$112/AF
Scenario 2b: Decreased alfalfa, increased sorghum	74,000 acres of alfalfa substituted by sorghum	>140,000	140,000	$96/AF
Scenario 2c: Decreased alfalfa, increased cotton and wheat	74,000 acres of alfalfa substituted by 37,000 acres of cotton and 37,000 acres of wheat	>250,000	250,000	$36/AF
Scenario 3a: Basin-wide improved irrigation technology	Basin wide: 25% shift from flood to sprinkler	175,000	60,000	$450-$1,500/AF[a]
Scenario 3b: Lower Basin improved irrigation technology	Counties with no return flows: 25% shift from flood to sprinkler	60,000	60,000	$470 - $1,600/AF[a]

Notes:
(a) These are estimated costs per AF reduction in total applied water savings, not base costs per AF consumptive use savings.

As discussed previously, the intent of these scenarios is to explore the potential magnitude of irrigation water conservation available in the Colorado River basin. The volumes and values estimated above should be seen as order of magnitude level estimates and are not definitive. Commodity prices – a key factor determining total costs of RDI and of crop shifting – are especially volatile, so the cost estimates could well vary by a factor of two or more. The volumes of water estimated by these scenarios are based on several general studies, rather than location-specific investigations for each county or water district, so actual volumes that could be conserved will also vary. While the USGS provides the only available basin-wide source for irrigated acreage, water use, and irrigation method for the study area, USGS reports total water withdrawals per county rather than applied water use, so total volumes that could be conserved via the irrigation technology strategies (Scenario 3) are likely overstated.

These strategies all impose direct costs on producers. To cover these costs, we assume that other interests – such as municipal water agencies or wildlife agencies interested in augmenting instream flows – would compensate irrigators for implementing the changes involved. Total costs would need to be negotiated and would presumably include some additional incentive payments to irrigators. In the following section we briefly discuss water transfers as a mechanism for moving conserved water savings to other users.

We note that not all consumptive water use savings may be available for transfer, due to state legal restrictions, water rights limitations, and other challenges. We acknowledge that water rights holders are under no obligation to transfer their water to urban or instream uses: we assume that all such transfers would be voluntary and would be compensated. Furthermore, when considering crop switching or deficit irrigation, there are implications related to demands for specific crops that will affect individual producer's decisions.

Transferring Conserved Water

The National Research Council (1992) defined water transfers as changes in the point of diversion, type of use, or location of use. Transfers are often linked to agricultural water conservation efforts as a mechanism to distribute water conserved by increased efficiencies in irrigation distribution networks and by on-farm savings such as those described in the scenarios above. Typically, legal agreements need to be negotiated to document the volume of water conserved, to ensure that junior water rights holders are compensated and do not divert the water to be transferred, and to otherwise ensure that the conserved water is available for its intended use. Our intent here is simply to note that such mechanisms do exist, but require careful consideration and can involve significant transactions costs (Getches 1985, National Research Council 1992). It is well beyond the scope of this report to review or assess potential mechanisms for transferring the water that the scenarios suggest could be conserved, so we briefly highlight a few key ideas below.

In response to increasing demands with limited new supplies, many have suggested transferring water from existing uses as a way to meet increasing, particularly urban, demands (Jones and Colby 2012). These "ag-to-urban" transfers are often described as a solution, but there has not been significant development of these transfers and they often encounter significant legal, social, and economic barriers. For example, Hamburger (2011) argues that incentive structures in Utah discourage water transfers and that legal barriers reduce the feasibility and efficiency of such transfers while increasing transaction costs. Water transfers in Arizona have encountered similar legal and incentive barriers, in addition to another level of complexity brought by the large federal presence in the Lower Basin

(Price 2011).Some have argued that these barriers are inherent to the American West and are a result of the complex system of water appropriation and development in the region (Libecap 2010, Bretsen and Hill 2009, Lieberman 2011). However, studies indicate that there have been some water transfer successes in the Colorado River basin, at a state and local level. For example, an economic analysis of transfers within the Northern Colorado Water Conservancy District (Northern) found that not only were transfers readily available (mostly from agriculture to urban uses), but there had not been significant impacts on the local economy (Howe and Goemans 2003). The authors suggest the success of water transfers depends on the size of the transfer, the economic vitality of the region, and whether or not the transfer is within the same economic region.

Many studies have described the potential economic impacts associated with fallowing agricultural land and transferring the water that would have been used for irrigation out of the area to other users. The scenarios we describe above purposefully avoid these “buy-and-dry” transfers in an effort to minimize third-party economic impacts. We recognize that, by eliminating one or more alfalfa cuttings, RDI would have some economic impacts on labor and suppliers, though to a much lesser extent than would be the case if the crop were eliminated entirely. Such economic impacts would need to be recognized and mitigated as part of the transfer negotiations.

4 Conclusions and Recommendations

Irrigation and agriculture are closely linked in the Colorado River basin. More than ninety percent of pasture and cropland in the basin receives supplemental water to make the land viable for agriculture. The total volume of water diverted from surface sources and pumped from the ground for irrigation in the Colorado River basin as a whole (including Mexico) reportedly exceeded 18,500 KAF in 2005 (USGS, *CONAGUA*), while the total consumptive use by irrigation in the U.S. portion of the basin that year was about half as much (USBR). Yet even this massive volume of water, equivalent to more than half of the river's annual flow, was insufficient to meet the total demand for irrigation in the basin. In 2005, when Colorado River flows were 13 percent above the long-term average, USBR estimates that Upper Basin irrigators would have consumed an additional 117 KAF of water had it been available. In the 2002 drought year, USBR estimates that Upper Basin irrigators would have consumed an additional 337 KAF.[102] As John Wesley Powell stated more than a century ago, there is not sufficient water to supply the land.

The total amount of irrigated land within the Colorado River basin as a whole was about 3,260,000 acres in 2007, an increase of less than one percent from 2002 (agricultural census, *CONAGUA*).[103] This basin-level overview masks the changes that occurred at the state and local levels over the past decade, when total irrigated acreage increased at varying rates in the Upper Basin, remained relatively flat in Mexico's portion of the basin, and fell in the Lower Basin, especially in Arizona. These changes reflect the Lower Basin's water use in excess of normal year apportionment in the early part of the decade (especially in California) and subsequent reduction to the normal year apportionment.[104] The conversion and transfer of irrigation water to urban uses in all three Lower Basin states led to this reduction of total Lower Basin water use generally and reductions of irrigated land and water use for irrigation more specifically. These reductions occurred as a result of fallowing and transfer programs in California, leases and outright purchases of water in Nevada, and urbanization of irrigated land in Arizona, among other factors.

This report clearly shows that a majority of irrigated land and water in the Colorado River basin is devoted to growing pasture and crops

[102] Data from USBR's Table UC-9, "Upper Colorado River Basin Agricultural Water Shortage Estimates, 2001-2005,"Consumptive Uses and Losses Report 2001-2005 and **CURRENT natural flow data 1906-2008**.

[103] These figures do not include the roughly 2.5 million acre-feet of land outside of the basin that use water imported from the Colorado River basin for some at least a portion of their irrigation needs, according to information submitted by the basin states to the *Colorado River Basin Water Supply & Demand Study*.

[104] The normal year apportionment for the Lower Basin is 7.5 million acre-feet (MAF) of consumptive use. In 2002, total reported consumptive use for the Lower Basin was 8.407 MAF (USBR). In 2007, it was 7.454 MAF (USBR).

used to feed livestock. This study's compilation of existing information also shows the increasing diversity of crop types from north to south in the basin, shifting from exclusive use for pasture and forage in Wyoming to wheat, cotton, alfalfa, and scores of vegetable and fruit varieties on both sides of the U.S.-Mexico border. A host of factors affect cropping decisions by individual producers, including soil type, length of growing season, climate, timing and quantity of water availability, labor supply, markets for products, and cultural factors, among others. While some high-elevation irrigators in the Upper Basin are limited by a four-month growing season, many irrigators along the international border are able to produce two or even three different crops in their year-round growing season. Simply put, producers in Wyoming do not have the same cropping options available to them as are available to producers in other parts of the basin.

Shorter growing seasons and cooler climates, as well as limited upstream water storage and water availability, also mean that irrigated lands in the Upper Basin consume less water per acre than do irrigated lands in the Lower Basin. In fact, according to FRIS and CONAGUA, about four times more water is delivered to Lower Basin and Mexican fields than is delivered to Upper Basin fields. Excluding Mexico, Lower Basin irrigated agriculture (including the Salton Sea watershed) consumed three times more water from the Colorado River basin in 2005 than did the Upper Basin (USBR). These disparities demonstrate that the amount of irrigated acreage does not correspond to basin water use and underscores differences between Upper and Lower basin irrigation.

The recent *Colorado River Basin Water Supply & Demand Study* also highlights several key differences between the basins. Primary among these are the challenges posed by rising demand - especially in the Lower Basin - at a time when total water supply in the Colorado River basin is projected to decline by nine percent or more in coming years due to climate change. Since total water use by the basin states and Mexico already exceeds average annual water supply, this is a significant concern. The water use trends described in this report indicate that the Lower Basin states have already begun to adjust to these new water supply constraints by decreasing irrigated acreage and reducing irrigation water use.[105] The Upper Basin states, on the other hand, have generally not reached their apportionment limits[106] and have not similarly reduced irrigated acreage or water use for irrigation.

This report reveals the surprising level of disagreement between and among the state and federal agency estimates of irrigated acreages and agricultural water use in the basin states. For example, USGS-reported acreages for many of the states differed by 30 percent or more from the acreages reported by other agencies. Two states - Arizona and Nevada - simply do not track irrigated acreage at a statewide level, resulting in a large gap in coverage of irrigated acreage and water use in the basin. Other factors also affect data collection and reporting. For example, the agricultural census occasionally under-reports total acreage (such as for Nevada) or crop type acreages in an effort to protect the privacy of individual producers. Reported water use varied greatly by agency, partly because USGS, USBR, and FRIS report on different aspects of irrigation water use. These differences complicate efforts to understand water use in the Colorado River basin. Part of the problem can be attributed to the fact that the agencies measure

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[105] As noted in *Municipal Deliveries of Colorado River Basin Water* (Cohen 2011), many of the municipal water agencies in the Lower Basin have also adjusted to limited supplies by dramatically reducing per capita water use, in many cases using less total water despite significant population growth.

[106] Unlike the Lower Basin's volumetric apportionment, the Upper Basin states have legal rights to a percentage, rather than a strict annual quantity, of Upper Basin annual runoff. The actual amount of water that may still be available for development and use in the individual Upper Basin states is the subject of disagreement.

and report land and water use for different reasons and for different audiences, limiting the comparability of the data. Despite these limitations, the available information enables an important and revealing assessment of recent land and water use in the Colorado River basin.

Irrigated agriculture consumes more than 70 percent of the developed water supply within the Colorado River basin.[107] In the context of rising demand for water and projections of climate-change driven reductions in supply, irrigation water use is an obvious sector to explore for potential reductions in demand. The second part of this report describes a set of scenarios that explore the potential for reducing irrigation water use in the Colorado River basin, without reducing the amount of irrigated land. We excluded scenarios that would reduce irrigated acreage in an effort to minimize the socio-economic impacts caused by taking land out of production.

The projected savings estimated under the various scenarios evaluated in Part II of this report are very encouraging. The application of regulated deficit irrigation to alfalfa throughout the US part of the basin could achieve almost a million acre-feet of consumptive water use savings, with estimated lost economic returns of about $81 per acre-foot. Other scenarios, such as shifting from water-intensive to less water-intensive crops, also yield impressive water savings with relatively low lost economic returns, without reducing the total amount of irrigated acreage in the basin. For example, replacing about ten percent of the basin's irrigated alfalfa acreage with cotton and wheat would save about 250 KAF of consumptive water use each year, with estimated lost economic returns of less than $40 per acre-foot. Total reductions in water withdrawals and applied water would be even greater. We assume that other interested parties – such as municipal water providers or wildlife agencies wishing to augment instream flows – would compensate irrigators for implementing the changes envisioned under the scenarios, so total costs would need to be negotiated and would presumably include additional incentive payments to irrigators. Nonetheless, the magnitude of the potential water savings and the range of costs associated with these changes suggest considerable potential for reducing irrigation water use while keeping agricultural land in production.

We note that these scenarios differ in their projected yields and costs from those described in USBR's Basin Study. These differences arise from several factors. For example, the Basin Study applies regulated deficit irrigation to orchards, vineyards, small grains, corn, and sunflower acreage while we applied it to alfalfa acreage. This generates very different savings per crop and in the aggregate, since alfalfa acreage is more than four times greater than the acreage included in the Basin Study scenario and since alfalfa typically consumes more water per acre than the crops included in the Basin Study option.[108] Furthermore, the Basin Study did not explore the water-savings potential of shifting from one type of crop to another (our Scenario 2), but does evaluate the potential water savings that could be generated by shifting from flood irrigation to sprinkler and drip irrigation, using less conservative savings rates than we use in our version of this option (Scenario 3). The Basin Study also applies this irrigation technology change to irrigated lands outside of the basin that import Colorado River basin water, while we limited our scope to lands within the basin. The Basin Study found that their version of irrigation technology improvements could realize up to 490

[107] Exclusive of exports and reservoir evaporation.

[108] See "Appendix F10—Option Characterization - Agricultural Water Conservation" for additional information on the agricultural water conservation options reviewed by the Basin Study.

KAF per year of consumptive water use – several times the volume that we project from changes within the basin only.

The Basin Study also evaluated the potential consumptive use savings generated by system efficiency and operational improvements (such as lining canals, constructing regulatory reservoirs, and installing tailwater pump-back systems), finding that such improvements could save about 820 KAF per year in areas adjacent to the Colorado River basin, based on savings projected by IID's Definite Plan. We did not include a system efficiency scenario in this study because of the complexity of water conveyance infrastructure in, and adjacent to, the Colorado River basin and the challenges associated with determining water savings in each system. We do, however, recognize the magnitude of consumptive and applied water savings that could be achieved by implementing such changes and recommend that they be implemented.

Recommendations

The magnitude of the potential consumptive water use savings generated under this report's scenarios – especially by applying regulated deficit irrigation to alfalfa acreage in the Lower Basin and by shifting a small portion of alfalfa acreage to other, less water-intensive field crops – compels further analysis and implementation. So long as the already high demand for water in the basin and in adjacent areas continues to grow, relatively low-cost, high-yield programs such as regulated deficit irrigation and shifts to less water-intensive crops should be explored and pursued.

Yet, as we described in our companion *Municipal Deliveries* report (Cohen 2011), growing municipal demand should first be addressed by improving municipal water conservation. It makes little sense to deficit irrigate alfalfa unless municipal water agencies and their ratepayers have adopted best available technologies and programs and made real progress toward increasing their own water use efficiency. As cities improve their water conservation rates, regulated deficit irrigation may be implemented most appropriately as a drought response measure, keeping land in production while transferring some portion of the irrigation water requirement to cities struggling with significant shortages and to streams facing greatly diminished flows and threatened aquatic species. Crop shifting could also be implemented in the context of projected water shortages, incentivizing willing producers to plant less water-intensive crops and transfer a portion of the resultant water savings to improve supply predictability for cities or other irrigators.

Such water conservation agreements will need to be negotiated directly, though state water agencies and USBR could facilitate such discussions by developing and promoting guidelines and best practices. Water conservation agreements will need to respect existing water rights and ensure that water conservation and transfers do not result in forfeiture or condemnation of existing water rights. The development of new water conservation and transfer agreements is complicated by differences in water rights structures and existing water law between the states. Although any analysis of these different rights regimes is well beyond the scope of this report, we note that such analysis will be necessary prior to the development of new irrigation water conservation agreements.

We recommend that the relevant state and federal agencies develop and implement better methods for tracking and quantifying annual irrigation data to address the discrepancies and inconsistencies described in this report. USBR's land and water use information for the basin has been cited as the best and most comprehensive (Kuhn 2007), because USBR specifically measures basin use. We encourage USBR to confer with USGS and NASS to coordinate measurement and reporting of irrigation and cropping patterns and to clearly explain any differences that may arise in their respective reports. There are currently several efforts underway to assess various aspects of irrigation and crop evapotranspiration rates, including the suitability of remote sensing to determine the extent of irrigated land in the Upper Basin. Again, we encourage coordination among these efforts, to improve consistency in reporting and to avoid duplication. As noted in the recent USBR Colorado River Basin Study, rising demand and diminishing supply frame the future of the basin. In this context, the luxury of not measuring or compiling information on water use and irrigated land can no longer be afforded. Much greater effort needs to be made to resolve these data challenges.

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Appendix A – USBR Terminology and Methodology

Source: *Consumptive Uses and Losses Report, 2001-2005*

We reprint relevant portions of USBR's Terminology and Methodology sections in the semi-decadal *Consumptive Uses and Losses Report* to show the source of much of the information cited in this report.

> The Colorado River System is defined in the Colorado River Compact of 1922 as "...that portion of the Colorado River and its tributaries within the United States,", whereas the Colorado River Basin is defined as "...all of the drainage area of the Colorado River System and all other territory within the United States of America to which waters of the Colorado River System shall be beneficially applied.". The compact divided the Colorado River Basin into two sub-basins—the "Upper Basin" and the "Lower Basin," with Lee Ferry as the division point on the river. Lee Ferry, located in Arizona, is a point in the main stem one mile below the mouth of the Paria River. For the purpose of this report, the Great Divide Basin, a closed basin in Wyoming, and the White River, also a closed basin, in Nevada have not been considered as part of the Colorado River System since flows from these basins never reach the Colorado River. Diversions from the system to areas outside its drainage area are considered herein as exports and have not been classified by types of use.
>
> Beneficial consumptive use is normally construed to mean the consumption of water brought about by human endeavors and in this report includes use of water for municipal, industrial, agricultural, power generation, export, recreation, fish and wildlife, and other purposes, along with the associated losses incidental to these uses.
>
> Qualitatively, what constitutes beneficial consumptive use is fairly well understood; however, an inability to exactly quantify these uses has led to various differences of opinion. The practical necessity of administering the various water rights, apportionments, etc., of the Colorado River has led to definitions of consumptive use or depletions generally in terms of "how it shall be measured." The Upper Colorado River Basin Compact provides that the Upper Colorado River Commission is to determine the apportionment made to each State by "...the inflow- outflow method in terms of manmade depletions of the virgin flow at Lee Ferry...".
>
> There is further provision that the measurement method can be changed by unanimous action of the Commission. In contrast, article I(A) of the decree of the Supreme Court of the United States in Arizona vs. California defines, for the purpose of the decree, "Consumptive use means diversions from the stream less such return flows thereto as are available for consumptive use in the United States or in satisfaction of the Mexican Treaty obligation.". Nearly all the water exported from the Upper Colorado River System is measured; however, the remaining beneficial consumptive use, for the most part, must be estimated using theoretical methods and techniques. In the Lower Colorado River System tributaries to the main stem, similar methods must be employed to

determine the amount of water consumptively used.

Agriculture

The percentages of irrigation consumptive use ranged between 54 and 90 percent for the Upper Basin tributaries and between 21 and 81 percent for the Lower Basin tributaries. Both percent ranges exclude main stem evaporation. The annual irrigated acreage of most crops grown within each reporting area was estimated from information published in the yearly State Agriculture Statistics, 2002 National Census of Agriculture (since the State statistics do not include pasture land), and from Geographic Information System (GIS) irrigated acreage data available for Colorado, Utah, and Wyoming. The total irrigated acreage values for the Upper and Lower Basins are shown in tables UC-7 and LC-9, respectively. The Lower Basin table excludes Decree Accounting irrigated acreage. Since most of these data were presented on a county basis, it was necessary to separate them into smaller reporting areas for computational purposes. This was accomplished using land inventory maps and relationships developed for the comprehensive framework study.

These sub-basins generally follow tributary stream basin and State boundaries. A representative climatic station was selected for each sub-basin. Using historical records of temperature, precipitation, and frost dates, a consumptive use rate was computed for each major crop in each of the reporting years. For the purpose of this report, the consumptive use rates were computed using the modified Blaney-Criddle evapotranspiration formula in the version described in the Soil Conservation Service Technical Release No. 21, "Irrigation Water Requirements," revised September 1970. Irrigation consumptive use rates were determined by subtracting the effective precipitation from the consumptive use rates. Effective precipitation for the Upper Basin was computed using the Soil Conservation Service method. This method is referenced in "SCS Technical Release No. 21." (It should be noted that this method estimates less effective precipitation than the Reclamation method. Previous reports used the Reclamation method of computing effective precipitation. The values of irrigation consumptive use rates were applied to the estimates of irrigated acreage to yield the final values of irrigation consumptive use.

An exception to this procedure was employed in the Lower Basin in the "low desert" regions of Arizona where a regionally calibrated Blaney-Criddle formula was used to estimate the crop consumptive use. This departure was based on the research results of Leonard Erie, et al. Seasonal crop consumptive use factors ("K") for the lower elevation desert areas were selected from Conservation Research Report Number 29, “Consumptive Use of Water by Major Crops in the Southwestern United States”, issued May 1982 by the United States Department of Agriculture. Effective precipitation was derived from criteria developed for the area by former Utah State Engineer, Wayne D. Criddle.

These theoretical consumptive use calculations were based on the assumption of full water supply during the crop growing season. However, it is estimated that in an average year, about 37 percent of the irrigated lands in the Upper Basin receive less than a full supply of water, either due to lack of distribution facilities or junior water rights. The degree to which these lands suffer shortages varies widely from year to year, depending in large part on the magnitude of runoff. For this study, an estimate of the short supply service lands was made for each sub-basin, primarily on the basis of reports and investigations collected for the comprehensive framework study. A streamflow gauging station was selected within each sub-basin and the magnitude of the recessional portion of the annual hydrograph was used as an index to select the date at which consumptive use calculations should be terminated for the short supply lands. Estimates of total shortage water volumes (the volume of water that would have been consumed by crops if the shortage criteria were not in place) are displayed in table UC-9.

Comprehensive framework studies of the incidental consumptive use of water associated with irrigation indicated that this use varied between 5 and 29 percent of the irrigation consumptive use, depending upon the location of the study area within the Colorado Basin. These percentages were used in the Upper Basin and an average value of 20 percent was used in the Lower Basin to adjust the calculated consumptive use.

The agricultural data is generally adequate for use in this report. Each state prepared annual county irrigated acreage estimates of the harvested crops during the reporting period. These statistics are assumed to be reliable. The irrigated pasture values were based largely on the 1997 and 2002 National Census of Agriculture in the Lower Basin states since the State statistics do not include pasture land. Because of the length of time between reporting dates, this item needs to be considerably strengthened. In the Upper Basin states, GIS irrigated acreage data were used to estimate irrigated pasture lands. Other areas of agricultural data collection that need to be updated and verified are: (1) the consumptive water use of lands that receive less than a full seasonal supply of irrigation water and the areal extent of these lands, and (2) the amount of incidental seepage and phreatophytic losses associated with irrigation.

Ground Water

Currently, all ground-water pumpage is counted as consumptive use charged against the Colorado River Basin. Obviously, this is not necessarily true. Depending on the location and depth of the well and what types of soils are present in the area, it is possible that little or none of the water pumped would have contributed to the Colorado River System for hundreds or even thousands of years. If changes to this ground-water accounting structure are desired, a team consisting of personnel from various State Engineers Offices, the Bureau of Reclamation, and any other pertinent agencies should be established. This team would establish guidelines for computing what amounts of ground water pumped should be charged against the Colorado River Basin on an area-by-area basis. The recommendations of this team could then be incorporated in future Consumptive Uses and Losses calculations. Until these guidelines are established, the Consumptive Uses and Losses Reports will continue to report all ground-water pumping as depletion from the system.

Currently, the Arizona portion of the Upper Basin is the only part of the basin that reports ground-water pumpage as consumptive use. Although significant ground-water usage occurs in Arizona, Nevada, and New Mexico, for purposes of this report ground-water overdraft has not been taken into account in the computation of tributary consumptive use. It should be noted that present ground-water overdraft in Arizona has been estimated to be approximately 2.2 million acre-feet per year.

Trans-basin Diversions

Nearly all the trans-basin diversions both out of and into the Colorado River System were measured and reported by the Geological Survey, or local water commissioners and users. The remainder was estimated on the basis of past records and capacity of facilities. Due to the high degree of measurement, this area of basin consumptive use is considered to be quite accurately determined.

Upper Basin consumptive use varied between 3.6 million and 4.2 million and averaged 3.8 million acre-feet per year for the reporting period, 2001 through 2005. Agricultural uses accounted for about 59 percent of the total Upper Basin consumptive uses and losses. Irrigated acreage fluctuated very little during this period, ranging between 1.36 million acres and 1.51 million acres, and averaged 1.43 million acres per year. Variation in consumptive use during the reporting period was largely due to year-to-year changes in climatic conditions.

Consumptive use for the irrigation of crops represents about 65 percent of the total water use in the Lower Colorado tributary areas. Estimated annual consumptive use for the Lower Basin during the 5-year period averaged about 3.7 acre-feet per acre, varying from approximately 1.4 acre-feet per acre in parts of Arizona to more than six acre-feet per acre in the western portion of the basin. Irrigated lands for the reporting period averaged 592,000 acres.

Appendix B – Dairy Operations in the Colorado River Basin States

Alfalfa provides an important food source for the dairy industry. While the dairy industry is not the only consumer of alfalfa grown in the Colorado River basin, a brief examination of the recent trends in the industry in the seven basin states points to some common trends in the numbers of dairy cattle and in alfalfa acreage. We offer the following summary of dairy industry trends to provide context for the extent of alfalfa acreage in the basin.

Figure B shows the total size of the milk cow herd and the total acreage in alfalfa in each of the seven Colorado River basin states, as reported by the agricultural census for the years 1992, 1997, 2002, and 2007. It is important to note that this is statewide data and includes farms that do not receive Colorado River water. It does, however, illuminate the overall trend of dairy operations for the seven basin states.

The agricultural census shows a steady decline since 1992 in the total number of dairy operations, with some states showing a fairly substantial reduction in the number of farms with milk cows. For example, in 1992 Colorado reported 1,162 farms with milk cows, but by 2007 this number was down to 449. Accompanying this declining trend, however, was a general increase in the total number of milk cows per state, and a large increase in the total number of milk cows per dairy operation. Each state at least doubled

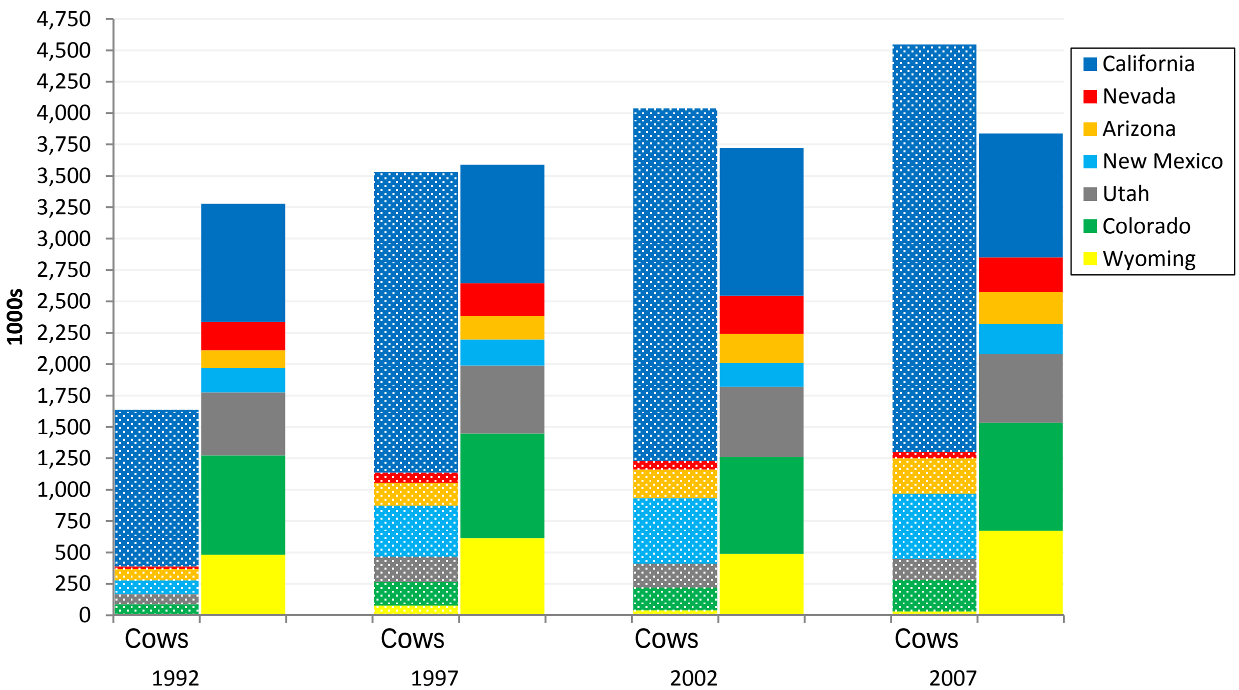

Figure B. Total Numbers of Dairy Cows and Alfalfa Acreages for Colorado River Basin States, 1992, 1997, 2002, and 200

Source*:* Agricultural Census.

Note: Values shown are statewide and include areas outside of the Colorado River basin.

the number of milk cows from 1992 to 2007. It is important to note that for several of the states, this was not a steady increase throughout the time period. In Nevada, Utah, New Mexico, and Wyoming, there seems to be a dramatic increase in the 90's, followed by a leveling off or decline in total numbers somewhere between the 1997 Census and the 2002 Census. Arizona, California, and Colorado show a similar jump in the 1990's, but with sustained growth through the following decade. The total size of the milk cow herd in the basin states as a whole nearly tripled from 1992 to 2007, though most of this increase occurred from 1992 to 1997. From 1997 to 2007, the size of the herd increased by about 30 percent.

There are no general trends in alfalfa acreage among the individual basin states. Arizona was the only basin state to have increased acreage in each census from 1992 to 2007; the other six states had increases and decreases in total alfalfa acreage throughout the time period. However, the overall trend for the seven basin states has been an increase in total alfalfa acreage of about 17 percent from 1992 to 2007. The great discrepancy between each state's alfalfa acreage and the number of milk cows in the state reflects the difference in productivity across the basin. For example, according to the values reported by the agricultural census, the average yield per acre of alfalfa is about 7.2 tons in California and 2.5 tons in Wyoming.

There are many factors that contribute to the growth or decline of these dairy operations in the Southwest. These factors include commodity prices, feed quality and price, water availability, demand (both domestic and international), and climatic conditions. For example, recent increases in US exports of dairy products to Asian markets were not only driven by an increase in demand, particularly from China (Fuller et al., 2006), but also from recent poor growing seasons due to bad weather in New Zealand and Australia (USDA 2012). It is interesting to note that while there has been a relatively steady increase in the number of milk cows in the Colorado River basin states, the total acreage in alfalfa has not kept pace in all states. There are probably a variety of factors contributing to this decoupling, including greater production and higher quality of feed produced per acre of alfalfa, but research at UC Davis looking at California dairy operations suggests that it could also be due to an increase in corn and small grain silage, and the increased use of by-products such as from fermentation and meals (Putnam 2009). In Arizona, however, the increase in the number of milk cows is accompanied by an 83 percent increase in alfalfa acreage from 1992 to 2007.

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Appendix C – Calculations for RDI for Alfalfa in Colorado River Basin Counties

Table C-1. Water Savings and Costs Associated with Regulated Deficit Irrigation Applied to Alfalfa Grown in Counties in the Colorado River Basin

County, State	Alfalfa Acres (1000s)	Water Savings (KAF)	Returns Over Operating Costs ($/acre)	Total Returns ($1000s)
Cochise, AZ	20	37	219	4,297
Graham, AZ	2	4	446	880
Greenlee, AZ	1	2	654	736
La Paz, AZ	60	114	513	30,929
Maricopa, AZ	75	142	403	30,384
Mohave, AZ	10	20	396	4,108
Navajo, AZ	3	5	446	1,202
Pima, AZ	2	4	563	1,063
Pinal, AZ	54	103	297	16,185
Yuma, AZ	26	49	691	17,820
Imperial, CA	127	241	522	67,780
Riverside, CA	47	89	522	25,144
Archuleta, CO	1	0	430	426
Delta, CO	21	7	430	9,109
Eagle, CO	4	1	430	1,772
Garfield, CO	23	8	430	9,803
Mesa, CO	23	8	430	10,093
Moffat, CO	7	3	430	3,141
Montezuma, CO	28	10	430	11,845
Montrose, CO	21	7	430	8,973
Pitkin, CO	3	1	430	1,104
Rio Blanco, CO	5	2	430	2,300
Routt, CO	4	2	430	1,889

County, State (cont.)	Alfalfa Acres (1000s)	Water Savings (KAF) (cont.)	Returns Over Operating Costs ($/acre) (cont.)	Total Returns ($1000s) (cont.)
Saguache, CO	23	8	430	9,781
San Miguel, CO	2	1	430	1,023
Clark, NV	2	3	430	749
Lincoln, NV	11	21	430	4,747
Grant, NM	0	0	433	121
McKinley, NM	1	0	149	200
San Juan, NM	28	10	149	4,172
Carbon, UT	6	2	143	805
Daggett, UT	4	1	183	680
Duchesne, UT	32	11	203	6,506
Emery, UT	17	6	339	5,596
Garfield, UT	9	3	145	1,314
Grand, UT	3	1	162	477
Kane, UT	1	0	121	172
San Juan, UT	2	1	194	462
Uintah, UT	35	12	203	7,187
Washington, UT	5	2	194	972
Wayne, UT	11	4	240	2,642
Carbon, WY	14	5	68	923
Lincoln, WY	30	10	68	2,030
Sublette, WY	4	1	68	285
Sweetwater, WY	15	5	68	1,014
Uinta, WY	6	2	68	407
TOTAL (rounded)	830	970		313,000
Lower Basin Total	440	830		206,000
			base costs from 25% reduction in yield (=**313,000***25%):	78,000
			Lower Basin (rounded):	52,000

Sources: Consumptive savings calculated from Bali et al. 2010, Erie et al. 1982, and Lindenmeyer et al. 2011 and applied to USGS-reported county-level irrigated alfalfa acreage in 2005.
Notes: Crop returns for Southwestern NM are from Dona Ana/Sierra Counties, which are adjacent to counties in the Lower Basin. Crop returns for Northwestern NM are from Bernalillo/Valencia Counties, which are adjacent to counties in the Upper Basin.

Net economic returns were not available for alfalfa in Nevada.
Sources: Colorado State University; University of Arizona; University of California, Davis; Utah State University; New Mexico State University.
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Appendix D – Improved Irrigation Technology Calculations

Table D-1. Potential Water Savings Associated with Shifting 25% of Acreage that was Flood Irrigated in 2005 to Sprinkler Irrigation.

County, State	Irrigation Withdrawals (KAF)	Flood irrigated	25% of flood irrigation (KAF)	Flood to sprinkler savings (KAF)
Apache, AZ	10	91%	2	0
Cochise, AZ	257	13%	8	0
Coconino, AZ	1	100%	0	0
Gila, AZ	3	50%	0	0
Graham, AZ	187	71%	33	2
Greenlee, AZ	15	91%	3	0
La Paz, AZ	698	92%	161	8
Maricopa, AZ	1,271	71%	226	11
Mohave, AZ	105	99%	26	1
Navajo, AZ	18	93%	4	0
Pima, AZ	120	95%	29	1
Pinal, AZ	1,381	90%	311	16
Santa Cruz, AZ	12	90%	3	0
Yavapai, AZ	50	96%	12	1
Yuma, AZ	1,259	70%	220	11
Imperial, CA	2,349	97%	570	28
Riverside, CA	786	83%	162	8
Archuleta, CO	78	99%	19	1
Delta, CO	505	100%	126	6
Dolores, CO	38	19%	2	0
Eagle, CO	165	92%	38	2
Garfield, CO	374	99%	92	5
Grand, CO	254	99%	63	3
Gunnison, CO	617	100%	154	8
Hinsdale, CO	78	100%	20	1
La Plata, CO	414	87%	89	4
Mesa, CO	970	99%	240	12
Mineral, CO	24	100%	6	0
Moffat, CO	167	89%	37	2
Montezuma, CO	276	73%	51	3

County, State (cont.)	Irrigation Withdrawals (KAF) (cont.)	Flood Irrigated (cont.)	25% of flood irrigation (KAF) (cont.)	Flood to sprinkler savings (KAF) (cont.)
Montrose, CO	762	100%	190	9
Ouray, CO	115	99%	29	1
Pitkin, CO	142	98%	35	2
Rio Blanco, CO	255	100%	63	3
Routt, CO	213	99%	53	3
San Miguel, CO	31	99%	8	0
Summit, CO	67	94%	16	1
Clark, NV	17	66%	3	0
Lincoln, NV	55	12%	2	0
Grant, NM	30	97%	7	0
Hidalgo, NM	94	18%	4	0
McKinley, NM	4	100%	1	0
San Juan, NM	294	20%	15	1
Carbon, UT	49	65%	8	0
Daggett, UT	38	82%	8	0
Duchesne, UT	366	43%	40	2
Emery, UT	220	60%	33	2
Garfield, UT	94	38%	9	0
Grand, UT	21	39%	2	0
Kane, UT	32	59%	5	0
San Juan, UT	23	31%	2	0
Uintah, UT	272	43%	29	1
Washington, UT	67	53%	9	0
Wayne, UT	54	13%	2	0
Carbon, WY	401	99%	99	5
Lincoln, WY	207	52%	27	1
Sublette, WY	186	100%	46	2
Sweetwater, WY	97	56%	14	1
Uinta, WY	120	99%	30	1
Total	16,808		3,494	175

Source: U.S. Geological Survey, all data for year 2005.

Table D-2. Consumptive Use Savings Associated with Shifting 25% of Acreage that was Flood Irrigated in 2005 to Sprinkler Irrigation.

County, State	Irrigation Withdrawals (KAF)	Flood irrigated	25% of flood irrigation (KAF)	Flood to sprinkler savings (KAF)
Apache, AZ	10	91%	2	0
Cochise, AZ	257	13%	8	0
Coconino, AZ	1	100%	0	0
Gila, AZ	3	50%	0	0
Graham, AZ	187	71%	33	2
Greenlee, AZ	15	91%	3	0
Maricopa, AZ	1,271	71%	226	11
Mohave, AZ	105	99%	26	1
Navajo, AZ	18	93%	4	0
Pima, AZ	120	95%	29	1
Pinal, AZ	1,381	90%	311	16
Santa Cruz, AZ	12	90%	3	0
Yavapai, AZ	50	96%	12	1
Imperial, CA	2,349	97%	570	28
Total	5,780		1,230	60

Source: U.S. Geological Survey, all data for year 2005