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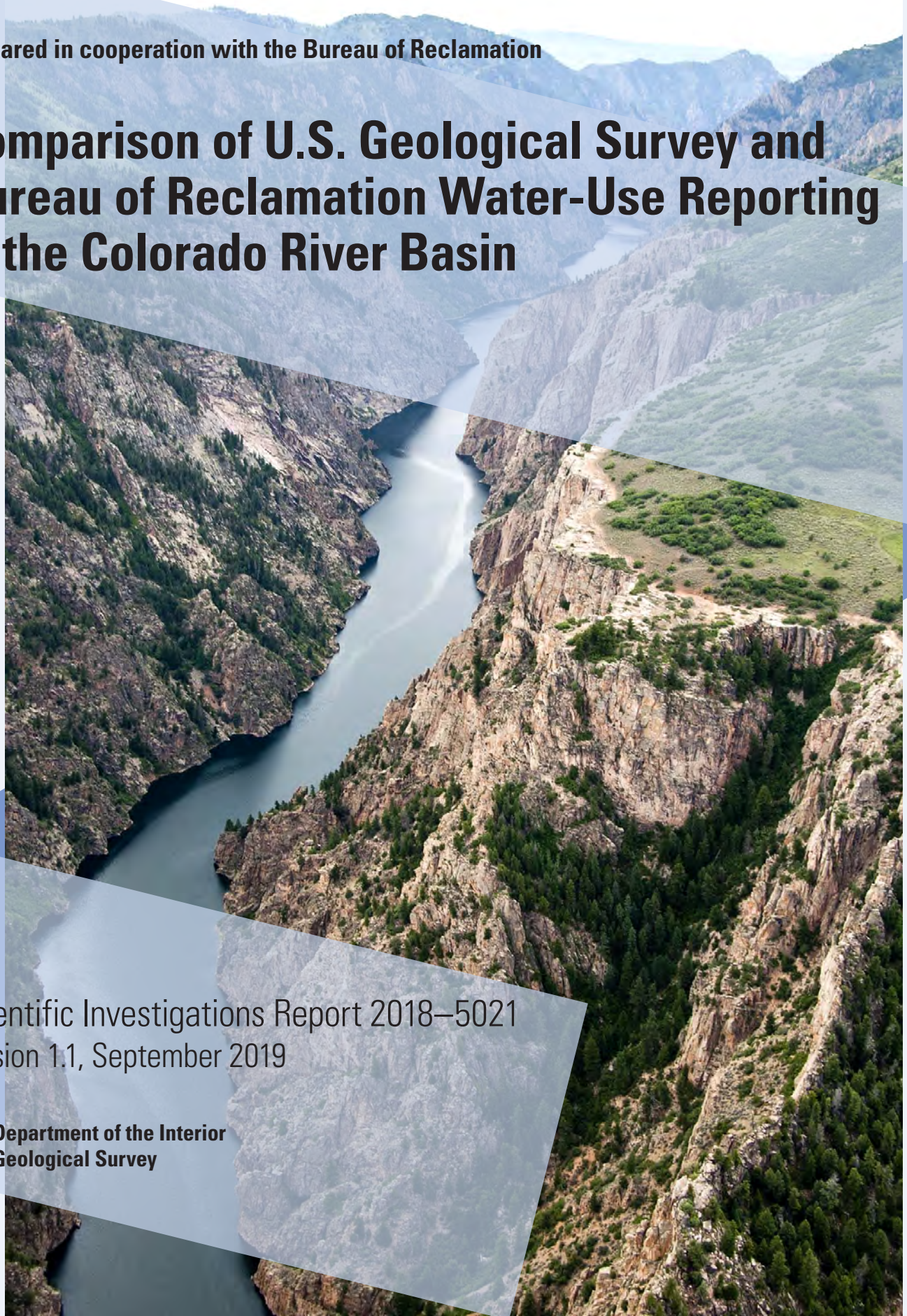
Comparison of U.S. Geological Survey and Bureau of Reclamation Water-Use Reporting in the Colorado River Basin



Scientific Investigations Report 2018–5021
Version 1.1, September 2019

U.S. Department of the Interior
U.S. Geological Survey

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By Breton W. Bruce, James R. Prairie, Molly A. Maupin, Jeremy R. Dodds, David W. Eckhardt, Tamara I. Ivahnenko, Paul J. Matuska, Eric J. Evenson, and Alan D. Harrison

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U.S. Department of the Interior
DAVID BERNHARDT, Secretary

U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia
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Contents

Figure

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
	Flow rate	
millimeter per year (mm/yr)	0.03937	inch per year (in/yr)

Datum

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Elevation, as used in this report, refers to distance above the vertical datum.

Abbreviations

Basin Study	"Colorado River Basin Water Supply and Demand Study"
CUL Report	"Consumptive Uses and Losses Report"
ET	evapotranspiration
ETa	actual evapotranspiration
FWS	free water surface
HFE	high-flow experiments
HUC	hydrologic unit code
Interior	U.S. Department of Interior
IWR	irrigation water requirement
NASS	National Agricultural Statistics Service
NIR	net irrigation requirement
NWUIP	National Water-Use Information Program
Reclamation	Bureau of Reclamation
SCS	Soil Conservation Service
Secretary	Secretary of the Interior
SECURE Water Act	Science and Engineering to Comprehensively Understand and Responsibly Enhance Water Act
SSEBop	Operational Simplified Surface-Energy Balance
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
Water Accounting Report	"Colorado River Accounting and Water Use Report: Arizona, California, and Nevada"
Water Census	USGS National Water Census Program
WBD	Watershed Boundary Dataset

Comparison of U.S. Geological Survey and Bureau of Reclamation Water-Use Reporting in the Colorado River Basin

By Breton W. Bruce,[1] James R. Prairie,[2] Molly A. Maupin,[1] Jeremy R. Dodds,[2] David W. Eckhardt,[2] Tamara I. Ivahnenko,[1] Paul J. Matuska,[2] Eric J. Evenson,[1] and Alan D. Harrison[2]

Abstract

The use of water in the United States is arguably one of the most important factors determining water availability at any specific place and time. Numerous local, State, and Federal entities develop, compile, and report water-use data, which can lead to confusing or conflicting information. This report was authored jointly by the U.S. Geological Survey (USGS) and Bureau of Reclamation (Reclamation) to compare and contrast the two agencies' water-use information programs in the Colorado River Basin. The report also describes the legal drivers for each program, clarifies confusing terminology, compares the methods used, and contrasts the information reported by each agency. This detailed comparison demonstrates that these two Federal agencies have different missions, different programmatic drivers, and different user communities, all of which lead to different approaches to water-use data collection, analysis, and reporting. This report highlights those differences and explains why the USGS and Reclamation programs exist and how the data serve different user communities. Even though the two water-use programs are different by design and purpose, the program comparison presented in this report has identified opportunities for closer coordination and sharing of information between the USGS and Reclamation, as well as program components where agency collaboration can improve water-use estimate methodologies. This comparison effort emphasizes that it is incumbent upon each agency to clearly define the meaning of the terms used and the appropriate application of the reported information to avoid confusion or the accidental misuse of the information. An additional benefit of this comparison effort is the formation of a joint USGS/Reclamation water-use team that will continue to investigate opportunities to expand and coordinate future water-use data compilation and reporting.

[1]U.S. Geological Survey.

[2]Bureau of Reclamation.

Introduction

Water use—the capture, movement, application, and consumptive use of water to meet specific human and ecological needs—has a major influence on the availability of water at any specific time and place. Arguably, the use of water within a hydrologic drainage basin is as important to downstream water availability as the amount of daily precipitation or natural streamflow. Consequently, there are multiple ongoing efforts across the United States to quantify and report on the use of water. These efforts by various local, State, and Federal entities often are done for very different reasons and with different long-term objectives. Understanding water use is of such nationally recognized importance that, in 2009, Congress passed the Science and Engineering to Comprehensively Understand and Responsibly Enhance Water Act (SECURE Water Act) (subtitle F of Public Law 111–11, the Omnibus Public Land Management Act of 2009). In section 9501(7), the SECURE Water Act specifically states that

> "… (7) the study of water use is vital—
>
> (A) to the understanding of the impacts of human activity on water and ecological resources; and
>
> (B) to the assessment of whether available surface and groundwater supplies will be available to meet the future needs of the United States."

The SECURE Water Act further requires that the Secretary of the Interior (Secretary) and the Administrator of the U.S. Environmental Protection Agency establish a Climate Change and Water Intragovernmental Panel composed of relevant Federal bureau heads (or their appointees) that will work together with appropriate governmental and nongovernmental entities "to establish data management and communication protocols and standards to increase the quality and efficiency by which each Federal agency acquires and reports relevant data" (sec. 9506 [c][3]).

To this end, the U.S. Geological Survey (USGS) and the Bureau of Reclamation (Reclamation) have been working to coordinate the compilation, analysis, and reporting of water-use information in the western United States, and have chosen the Colorado River Basin as a pilot region for a program designed to improve efficiency, reduce duplication of effort, and provide a coordinated and authoritative Federal resource for the best available water-use information.

The use of water in the Colorado River Basin is a complex and constantly changing activity governed by a substantial body of interstate and international laws, policies, and agreements, the administration of which depends on accurate accounting of the use of water. The large geographic extent of the basin (approximately 246,000 square miles in parts of seven States [Arizona, California, Colorado, New Mexico, Nevada, Utah, and Wyoming]), and the delivery of water outside the Colorado River Basin (to about an additional 17,500 square miles) (fig. 1) through large basin transfers, makes coordination of data collection and reporting challenging. In addition, the unique and separate missions of the USGS and Reclamation have resulted in both obvious and subtle differences in the way water-use data are collected, compiled, analyzed, and reported. Important examples of these differences include reporting of consumptive water use (Reclamation) versus water withdrawals (USGS), and how each agency reports water use associated with water transfers out of the hydrologic drainage basin. The mission statements of the U.S. Department of the Interior (Interior), Reclamation, and the USGS are presented in the box.

Mission Statements

U.S. Department of the Interior

Protecting America's Great Outdoors and Powering Our Future—The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and Tribal communities, and supplies the energy to power our future (https://www.doi.gov/whoweare/interior).

Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public (https://www.usbr.gov/main/about/mission.html).

U.S. Geological Survey

The U.S. Geological Survey serves the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life (https://www.usgs.gov/about/about-us/who-we-are).

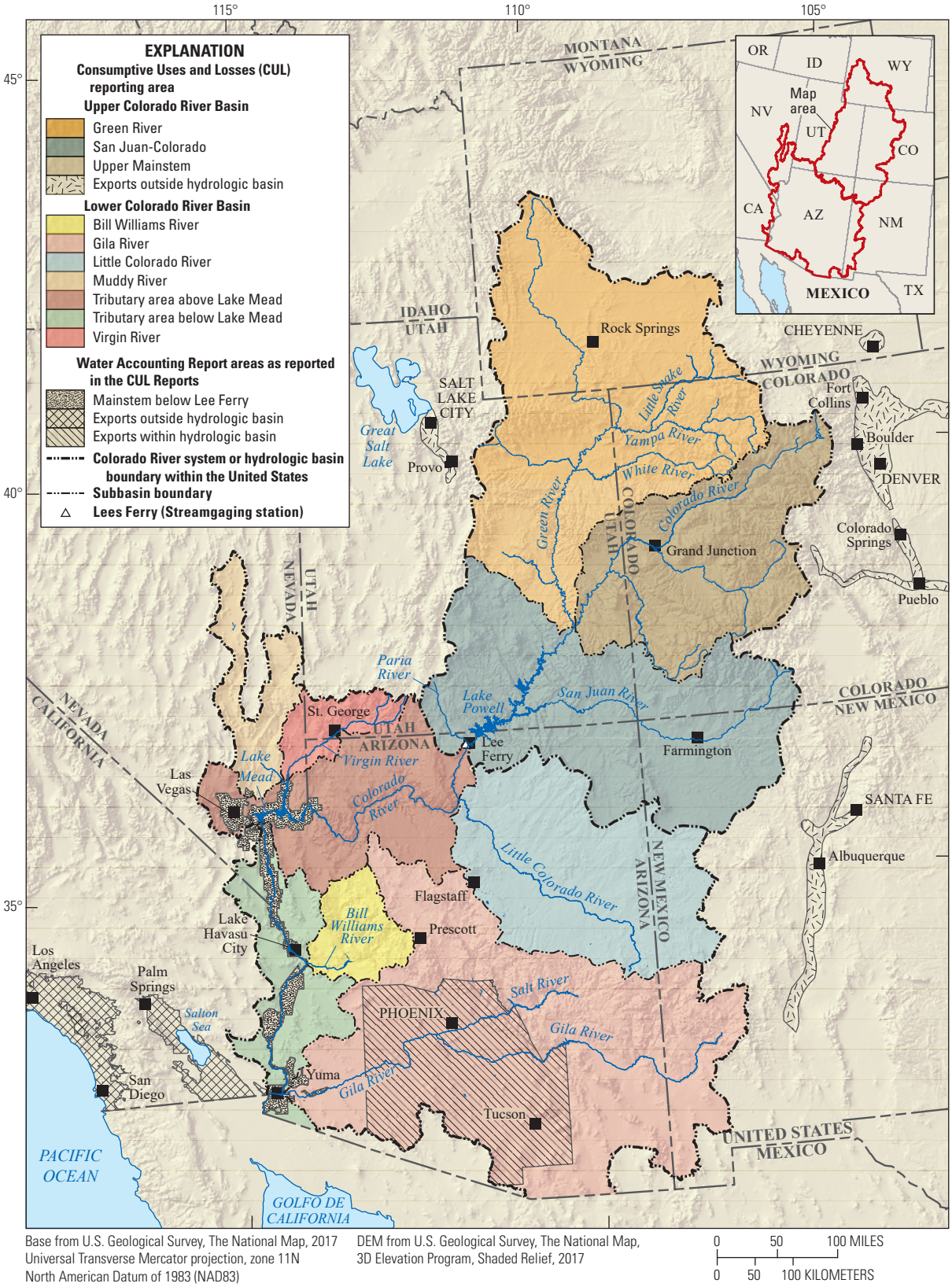


Figure 1. Map of the Colorado River Basin within the United States showing the Bureau of Reclamation's reporting areas for the "Consumptive Uses and Losses Report" (CUL Report; https://www.usbr.gov/uc/library/envdocs/reports/crs/crsul.html) and the "Colorado River Accounting and Water Use Report: Arizona, California, and Nevada" (Water Accounting Report; https://www.usbr.gov/lc/region/g4000/wtracct.html).

This report was developed through a collaborative effort between the USGS and Reclamation to critically look at each agency's water-use reporting program in the Colorado River Basin and identify possible redundancies, better define confusing or contradictory terminology and methods, and work toward improving collaboration between these two Interior bureaus to provide the best available water-use information for the region. It is anticipated that this effort will improve the interagency coordination and water-use reporting in the Colorado River Basin and help to enhance this activity across the western United States where both bureaus are active.

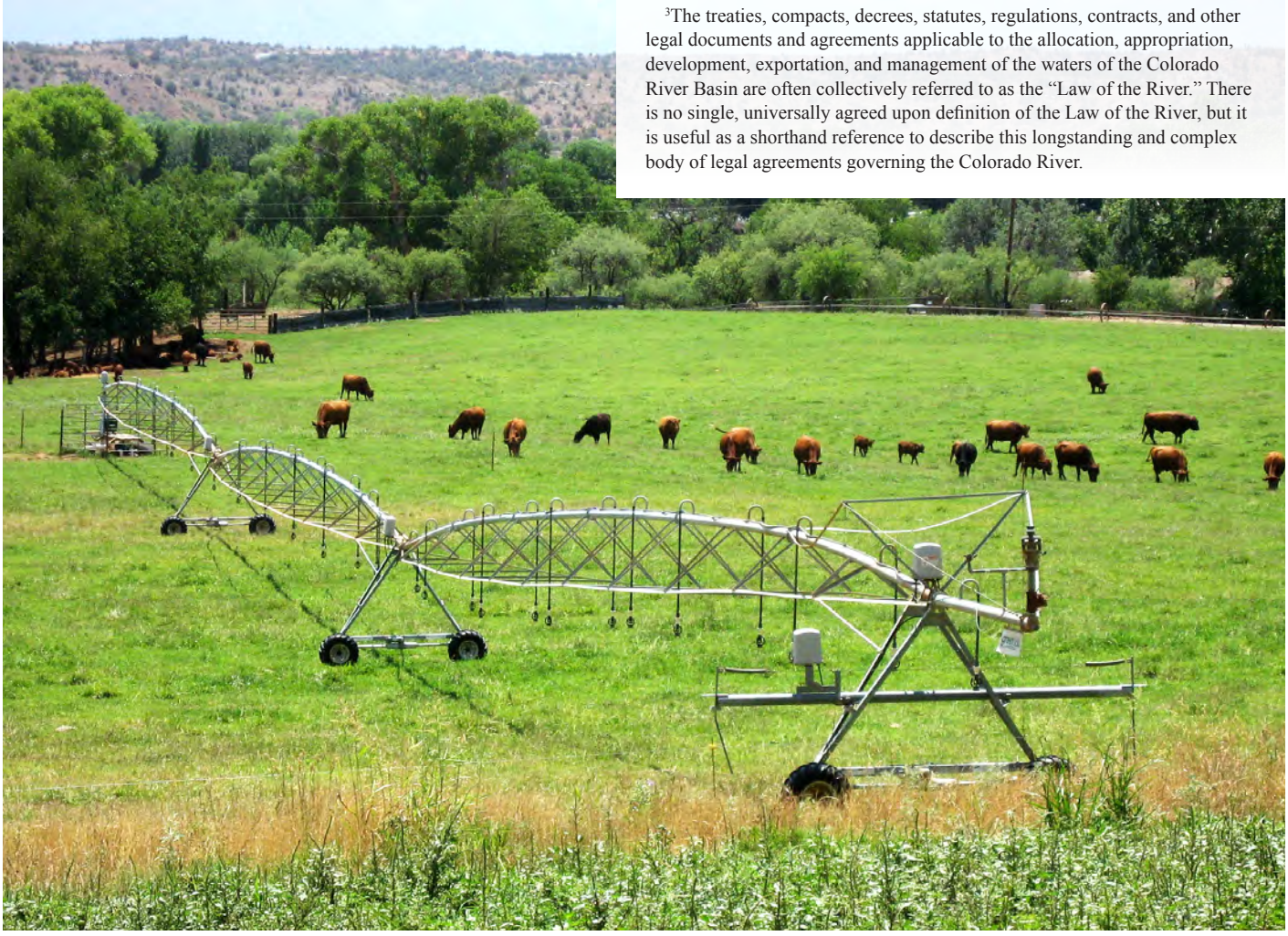
This report will first outline each agency's separate mission regarding water-use data reporting and how the agencies' various water-use programs in the Colorado River Basin meet mission requirements. The programs will then be compared and contrasted to identify redundancies, gaps, and efficiencies. The comparison also will include a review of the terminology and methods used by each agency, as well as a review of data sources. Finally, this report will tie these separate efforts together by identifying future activities to enhance coordination between Federal agencies and State, local, and Tribal partners as they move forward toward an uncertain water-supply future.

Colorado River Basin Water-Use Reporting by the Department of the Interior

Bureau of Reclamation

Reclamation collects and reports information on water use in the Upper and Lower Basins of the Colorado River to satisfy the Secretary's obligations under a body of documents referred to as the "Law of the River"[3] and to effectively manage the water resources of the Colorado River Basin. To accomplish this objective, Reclamation develops two water-use reports. The first, the "Consumptive Uses and Losses Report" (CUL Report), is developed pursuant to section 601(b)(1) of the Colorado River Basin Project Act of 1968 (Public Law 90-537). The second, the Colorado River Accounting and Water Use Report: Arizona, California, and Nevada (Water Accounting Report), is developed pursuant to Article V of the Consolidated Decree of the United States Supreme Court in *Arizona v. California*, 547 U.S. 150 (2006).

[3]The treaties, compacts, decrees, statutes, regulations, contracts, and other legal documents and agreements applicable to the allocation, appropriation, development, exportation, and management of the waters of the Colorado River Basin are often collectively referred to as the "Law of the River." There is no single, universally agreed upon definition of the Law of the River, but it is useful as a shorthand reference to describe this longstanding and complex body of legal agreements governing the Colorado River.



Within Reclamation the term "water use" is often used interchangeably with "consumptive use;" however, the former term includes elements such as diversions or withdrawals, transfers, deliveries, and return flows that are not included in the latter term. The term "consumptive use" is defined differently within the two reporting authorities under which Reclamation publishes the CUL and Water Accounting Reports. The plan of study and methods manual for the CUL Report defines "consumptive use" as a use or depletion of water due to human activity (Bureau of Reclamation, 1992). The U.S. Supreme Court (in prescribing the Water Accounting Report) defines "consumptive use" as "diversions from the stream less such return flow thereto as is available for consumptive use in the United States or in satisfaction of the Mexican Treaty obligation" (547 U.S. 150 [2006]). Both reports include basin transfers as a consumptive use of Colorado River water.

"Consumptive Uses and Losses Report"

Title VI, Section 601(b)(1) of the Colorado River Basin Project Act directs Reclamation, acting on behalf of the Secretary, to prepare the CUL Report as follows:

> "(b) The Secretary is directed to—
>
> (1) make reports as to the annual consumptive uses and losses of water from the Colorado River system after each successive five-year period, beginning with the five-year period starting October 1, 1970. Such reports shall include a detailed breakdown of the beneficial consumptive use of water on a State-by-State basis. Specific figures on quantities consumptively used from the major tributary streams flowing into the Colorado River shall also be included on a State-by-State basis. Such reports shall be prepared in consultation with the States of the lower basin individually and with the Upper Colorado River Commission, and shall be transmitted to the President, the Congress, and to the Governors of each State signatory to the Colorado River Compact…."

Critical to the implementation of this legislation is the meaning of the term "beneficial consumptive use" of water. This definition drives the water-use data compilation, analysis, and reporting effort for Reclamation relevant to this legislatively mandated accounting effort. The term "beneficial consumptive use" is explained in the CUL Report for 2001–2005 as "normally construed to mean the consumption of water brought about by human endeavors and …includes use of water for municipal, industrial, agricultural, power generation, export [basin transfers], recreation, fish and wildlife, and other purposes, along with the associated losses incidental to these uses" (Bureau of Reclamation, 2012a, p. 9).

The term "consumption," as used in this report, means that the water is removed from the system and is no longer available for other uses within the hydrologic Colorado River basin. A further discussion of terms and definitions used by both Reclamation and the USGS including "consumptive use" and "Colorado River Basin," which may differ by agency, is presented later in this report and in the "Glossary" section of the report.

Categories of consumptive use within the CUL Report have remained consistent since 1976 and include agriculture, municipal and industrial, evaporation, and basin transfers (exports). These four categories of use are further divided into ten subcategories for reporting purposes. A Fish and Wildlife category was reported from 1971 to 1975 but the category was later merged into the Agriculture and Evaporation categories and eliminated as a separate category. Nearly all of the water exported from the Colorado River Basin (interbasin transfers) is measured; however, beneficial consumptive use within the remaining categories of use must be estimated using theoretical methods and techniques. Some of the Colorado River Basin States estimate their consumptive uses and losses using different methods from those used by Reclamation. Reclamation and the States continue to work collaboratively to resolve differences in these estimates. For consistency purposes, however, the CUL Reports use Reclamation's methodologies to estimate consumptive uses and losses for all Basin States, with the exception of New Mexico. The New Mexico Interstate Stream Commission provides historical consumptive use and loss estimates to Reclamation for subsequent review and publication in the CUL Reports.

In the CUL Reports, provisional consumptive use and loss data are compiled annually by Reclamation for each State and are further divided by three tributary areas in the Upper Basin and by seven tributary areas and a mainstem area below Lee Ferry (not the same as Lees Ferry; see Glossary of Terms Used in this Report) in the Lower Basin (fig. 1). Consumptive uses and losses reporting is performed by different Reclamation offices for the Upper and Lower Colorado River Basins. The Upper Colorado and Lower Colorado Regional Offices coordinate closely to ensure that, to the degree possible, the reports for each basin are published using consistent methodologies.

Within the Lower Basin section of the CUL Report, methodological and data inconsistencies between published reports were identified in "Technical Report C—Water Demand Assessment" of the "Colorado River Basin Water Supply and Demand Study" (Basin Study) (Bureau of Reclamation, 2012b). Reclamation has committed to, and is currently working on, addressing the concerns raised in the Basin Study analysis. Once these inconsistencies have been corrected, Reclamation plans to publish the revised data.

Final annual consumptive use and loss values are reported every 5 years beginning with the 1971–1975 report (https://www.usbr.gov/uc/library/envdocs/reports/crs/crsul.html). In addition to the annual data reported in the 5-year CUL Reports, Reclamation maintains consumptive use and loss data on a monthly time step at the hydrologic unit code (HUC) 8-digit scale (HUC-8) within the Upper Colorado River Basin to support monthly historical natural flow estimation. (For information on HUCs, see Subcommittee on

Spatial Water Data—Watershed Boundary Data/Hydrologic Unit Codes at https://acwi.gov/spatial/wbd-huc/index.html.) Both spatial and temporal data disaggregation methods are used to estimate consumptive use and loss at this monthly HUC-8 scale because much use and loss data are not available at this resolution.

"Colorado River Accounting and Water-Use Report" (Lower Colorado River Basin)

Reclamation prepares the Water Accounting Report for the Lower Colorado River Basin in accordance with Article V of the Consolidated Decree of the United States Supreme Court in *Arizona v. California*, 547 U.S. 150 (2006). Among other requirements, the Decree mandates that Reclamation, acting on behalf of the Secretary, prepare annual records of:

> "(B) Diversions of water from the mainstream, return flow of such water to the stream as is available for consumptive use in the United States or in satisfaction of the Mexican Treaty obligation, and consumptive use of such water. These quantities shall be stated separately as to each diverter from the mainstream, each point of diversion, and each of the States of Arizona, California and Nevada…"

Data are tabulated in the Water Accounting Report at a monthly time step and summarized by calendar year annually from 1964 to the present (https://www.usbr.gov/lc/region/g4000/wtracct.html). By informal agreement with Lower Basin stakeholders, Reclamation publishes the report by May 15 of each year.

To meet the requirement of Article V(B), the Water Accounting Report tabulates records of diversions, return flows, and consumptive uses from the mainstem[4] of the Colorado River below Lee Ferry (fig. 1) for each Lower Basin State (Arizona, California, and Nevada) by individual water user. Consumptive use is calculated as the sum of diversions minus the sum of measured and unmeasured return flows (diversion minus return flow methodology) using data provided to

[4]Within the Lower Basin the term "mainstream," as defined by the U.S. Supreme Court in *Arizona v. California*, 547 U.S. 150 (2006), is often used interchangeably with the more commonly used term "mainstem." Within this report the term "mainstem" will be used to describe the main channel, and geographic areas in close proximity to the main channel, of the Colorado River in the Upper and Lower Colorado River Basins.

Reclamation by individual water users, Tribes, States, and Federal agencies. Return flows are the volumes of Colorado River water which are "unconsumed" after diversion.

Measured return flows include unconsumed water that is channeled through surface conveyance systems and drains and is measured before returning to the mainstem of the River. Measured return flows also include diverted water that was not applied to its intended use, municipal wastewater returns, and agricultural tail water. The measured return flows are subtracted from the individual diversion volumes to calculate consumptive use for each water user.

Unmeasured return flows represent water diverted from the Colorado River that infiltrates the soil and returns to the river through the groundwater system. Unmeasured return flows are estimated by applying a predetermined coefficient to the total diversion volume for each water user. The coefficients were developed in the early 2000s primarily by analysis of evapotranspiration (ET) losses. These fixed coefficients are multiplied by the total diversion volumes for each water user, and the resulting return flow volumes are also subtracted, along with measured return flows, from the diversion volumes to calculate consumptive use. Reporting of unmeasured return flows by individual water users began with the 2003 Water Accounting Report.

Use of Data

In the Lower Colorado River Basin, the Water Accounting Report is used to administer the Law of the River as it pertains to water users within the Lower Basin. Data from the Water Accounting Report are included in the CUL Report as the record of mainstem consumptive use in the Lower Basin. Consumptive use from the Water Accounting Report is categorized into one of three consumptive use and loss categories: irrigation, municipal and industrial, or exports, based on the predominate water use of each water user, then summarized in the reporting area "Mainstem Below Lee Ferry."

The data provided in the CUL and Water Accounting Reports are used by Reclamation for many mission critical activities in the Colorado River Basin. One such activity is long-term planning studies that rely on monthly water supply and demand projections to analyze operations and (or) basin management alternatives over the next 50 years. Reclamation maintains a natural flow dataset for selected sites throughout the Colorado River Basin; natural flow is calculated from gaged flow corrected for the effects of upstream reservoirs and depletions. This dataset assists Reclamation in estimating long-term variability in the water supply. Collectively, the CUL and Water Accounting Reports provide the depletion (consumptive use) data required to estimate historical natural flow. As described above, the Basin Study identified methodological and data inconsistencies in the CUL Report that Reclamation is in the process of correcting. Once corrected CUL Report data are available, Reclamation can develop natural flow data for the Virgin River Basin, the Little Colorado River Basin, and the Bill Williams River Basin.

U.S. Geological Survey

The USGS has a long-standing program for estimating water-use rates across the entire United States. Specific statutory authority for the USGS National Water-Use Information Program (NWUIP) has its origins in the legislation that created the USGS (Organic Act of March 3, 1879). Prior to 1950, water-use data were collected on an ad hoc basis by various Federal agencies and other organizations for their own purposes, so water-use information for the United States for years before 1950 is limited. The first USGS water-use report, "Estimated Use of Water in the United States—1950" (MacKichan, 1951), began a series of calendar-year summaries of national water-use estimates that were published every 5 years from 1950 through 1975, prior to the implementation of the NWUIP. In 1978, NWUIP was formally created when language appeared in the House of Representatives version of the 1978 appropriations bill which included "an increase…in the federal-state cooperative program…to establish a national water-use data activity" (National Research Council, 2002, p. 18). The Senate concurred and the conference committee made no further mention of the program (National Research Council, 2002). A comprehensive review of the NWUIP was conducted in 2002 by the National Research Council (National Research Council, 2002) and its description of the program remains an excellent resource for those wanting to learn more about the NWUIP.

From a broad perspective, the USGS considers "water use" as the interaction and influence that humans have on the hydrologic cycle, including elements such as diversion or withdrawals, transfers, deliveries, consumption, and return flows throughout the processes of use. Whenever water is withdrawn from, or detained in, the natural environment, there is an influence on the hydrologic cycle and the water use must be accounted for. From this standpoint, water use also includes such influences as basin transfers; detention and evaporation in reservoirs; and instream hydroelectric power, environmental, and recreational uses.

Because the USGS NWUIP generally reports nationally "aggregated" water use (although some site-specific information also is available), scale plays an important role in how and where water use is reported. Depending on whether water use is reported at the county, State, HUC-8, or HUC-12 scale, aggregating water use for different scales can change where the water use is assigned. One example of this is "interbasin transfers," which present a unique accounting situation for the USGS. Water applied to a beneficial use within the same aggregation watershed from which it is sourced (for example, 4-digit HUC scale [HUC-4]) is accounted for at the point of diversion and aggregated at the identified scale. Conversely, water exported out of its source-area watershed (interbasin transfer) is accounted for at the point of use, and is therefore, not aggregated in the data summary within its source-area watershed. This approach yields accurate information on where and how much water is being used (indicating water demand), but the data can be confusing for those

attempting to calculate source depletion or water balance. It is incumbent upon the USGS to make this data artifact clear to users of its data—particularly in areas like the Colorado River Basin with large interbasin transfers—and to carefully articulate this as part of any basin-specific water-use reporting effort. Because the USGS Aggregated Water-Use Database System (AWUDS) (USGS, 2016) does not accommodate storage of basin transfer data as a water use within the source-area basin, these types of data and information should be added to basin-specific water-use reports as a separate topic to clarify this locally important aspect of water use. The USGS recognizes that basin transfers are an important component of water use, and necessary to understand the water availability and use aspects in the Colorado River Basin. The USGS is discussing new collection and reporting mechanisms for nationally consistent information on basin transfers as part of future programmatic initiatives.

Since 1950, the USGS has compiled data and reported on water that is withdrawn from the hydrologic cycle for a specific purpose and returned via a public wastewater system. However, the list of specific water-use categories has varied slightly over time. In 1995 and prior years, the USGS presented information nationally on both water withdrawals and consumptive use. After 1995, national reports discontinued reporting on consumptive use.

U.S. Geological Survey Water-Use Reports

The USGS produces products on national and local water use under a variety of programs and authorities. For the purpose of this report, the discussion will focus on two specific USGS publications relevant to the Colorado River Basin: (1) "Estimated Use of Water in the United States," and (2) "Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010."

Report—"Estimated Use of Water in the United States"

"Estimated Use of Water in the United States" is a series of published USGS Circulars which are produced once every 5 years for calendar years ending in 0 and 5; the most recent published dataset is for 2010 (Maupin and others, 2014). These circulars, referred to as the "National Compilations," summarize and report on water-use data for the entire nation for the single year identified in the title. The USGS compilations of water use have been produced every 5 years since 1950 (https://water.usgs.gov/watuse/50years.html). These circulars represent one of the most highly utilized and highly referenced products of the USGS and are intended primarily for a national audience that is interested in a broad understanding of water withdrawals by major categories, the spatial distribution of those withdrawals at State and county levels, and the long-term trends in those withdrawal categories. The major users of these data are other Federal agencies, academic institutions, nongovernmental organizations, and State water management agencies.

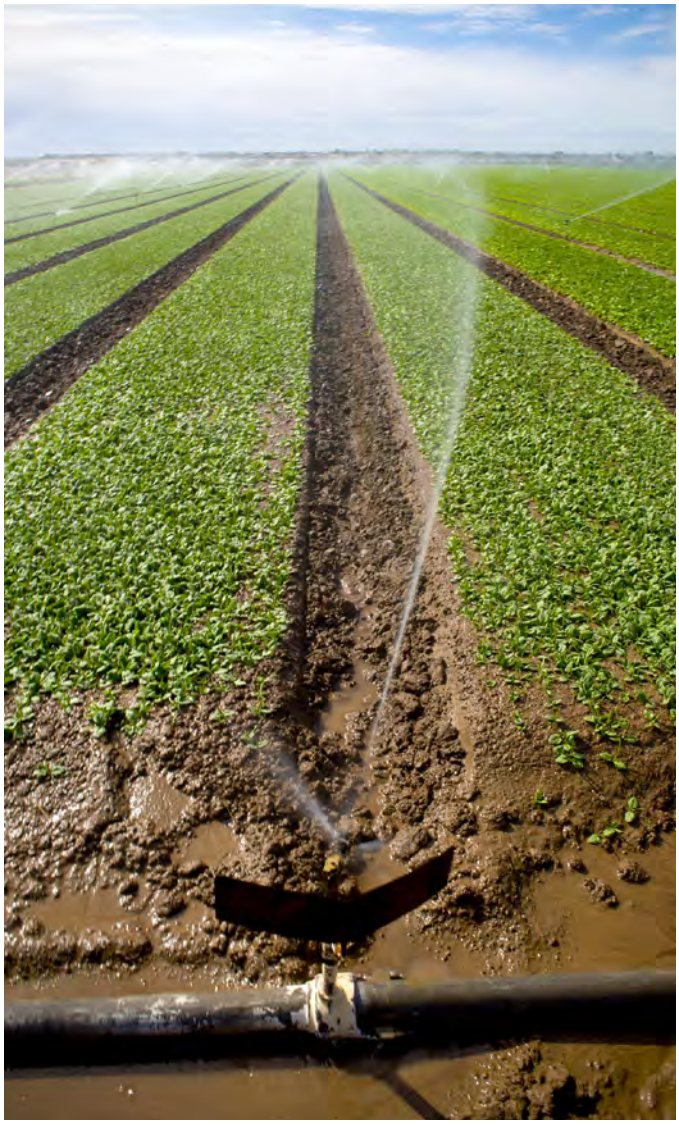
These circulars are produced pursuant to the USGS NWUIP and present aggregated water-use information at the State, county, and (historically) HUC-8 level. The term "aggregated" in the preceding sentence refers to the USGS practice of reporting a total annual usage rate (withdrawal volume/time) of water, for a given sector of use, over a defined geographic area (State, county, and [historically] HUC-8). The annual usage rate may be composed of site-specific data aggregated over time and space or be estimated using spatial datasets and acceptable methods and coefficients (see the "Methods Description" section of this report). The water usage rates are expressed in million gallons per day (MGD), or thousand acre-feet per year for irrigation. The rate of water use represents the total annual withdrawal distributed equally over the year. This is a consideration in areas of the Colorado River Basin where the growing season does not span the entire year as opposed to other areas, such as Arizona, where the growing season does span the entire year.

The water-use categories reported in the USGS circulars have varied significantly over the 60 years that they have been produced and a chart of these changes can be seen on the USGS Changes in Water-Use Categories web page at https://water.usgs.gov/watuse/WU-Category-Changes.html. From 2000 to 2015, the USGS water-use circulars provide aggregated annual estimates of water withdrawals at the county and State levels for eight sectors of water use: public supply, domestic, irrigation, livestock, aquaculture, self-supplied industrial, mining, and thermoelectric power generation. In 1995 and prior years, the circulars included additional sectors for commercial withdrawals, hydroelectric power generation, and public wastewater treatment releases (return flows). The 1995 and earlier summaries also provided information on consumptive use for each sector and presented withdrawal and consumptive-use estimates aggregated on a HUC basis.

The 5-year National Compilations report water withdrawals (with the previously noted exception that begin in 1995) by category and area (county, HUC, aquifer). The withdrawals are aggregated irrespective of the amount of water that is returned to the basin after it is used to satisfy a requirement. For example, if a river has a series of towns along its length and each town has a public-supply surface-water intake located upstream from the town and a municipal (publicly owned) wastewater treatment plant discharge located downstream from the town, the USGS would account for all of the public-supply withdrawals along the stream reach. However, it is recognized that some amount of wastewater that returns to the river is available for future use downstream. Each subsequent downstream withdrawal would be counted as a separate withdrawal, and all of the public-supply withdrawals along a river within a county would be aggregated to the county level. In reality, the town farthest upstream would likely return some amount of water back to the stream through wastewater discharge and the next downstream town would use some of this water for its supply, and so on. In this manner, water would be used over and over again and the accumulative total withdrawals would be reported by the USGS for all of the public-supply

withdrawals in the defined geographic area. Some would correctly say that this is "counting the same water multiple times," however, as explained below, the USGS water-use mission dictates that it characterize all of the water withdrawals for a defined geographic area.

Under the USGS NWUIP guidelines, it is important to understand where withdrawals occur and the quantity of water that is needed to satisfy each requirement. If the USGS were to characterize only consumptive uses, it might be difficult to understand that, for example, a thermoelectric powerplant might actually need 100 million gallons per day of water from the river at a specific location in order to operate because the consumptive use for the plant could be less than 5 percent of the withdrawal. It is also important to understand that the withdrawal of water is related to the water-quantity "requirement" of a particular category of use, regardless of how much is returned after the requirement is satisfied. For these reasons, the USGS 5-year compilations on "Estimated Use of Water in the United States" show the total annual withdrawals by sector of use and State.



Report—"Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010"

The "Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010" report will be a one-time, basin-specific report describing water uses by category and HUC-8 (including analysis of trends) at 5-year increments from 1985 to 2010 (Maupin and others, 2018). Under current plans, this report will not be repeated in the near future. The planned report is a direct product of the USGS National Water Census Program (Water Census), which is developing the report pursuant to the SECURE Water Act. Section 9508(b)(1)(A–B) of the SECURE Water Act directs the USGS to provide

> "…(A) the maintenance of a comprehensive national water use inventory to enhance the level of understanding with respect to the effects of spatial and temporal patterns of water use on the availability and sustainable use of water resources;
>
> (B) the incorporation of water use science principles, with an emphasis on applied research and statistical estimation techniques in the assessment of water use;…."

Section 9508(d)(3–6) of the SECURE Water Act requires the USGS to report on

> "… (3) the withdrawal and use of surface water and ground-water by various sectors, including—
>
> (A) the agricultural sector;
>
> (B) municipalities;
>
> (C) the industrial sector;
>
> (D) thermoelectric power generators; and
>
> (E) hydroelectric power generators;
>
> (4) significant trends relating to each water use sector, including significant changes in water use due to the development of new energy supplies;
>
> (5) significant water use conflicts or shortages that have occurred or are occurring; and
>
> (6) each factor that has caused, or is causing, a conflict or shortage described in paragraph (5)."

To carry out the requirements of the SECURE Water Act, the USGS started the Water Census (https://water.usgs.gov/watercensus/) in 2011. The Water Census is a USGS research program that develops new water accounting tools and assesses water availability and use at regional and national scales. The Water Census produced a detailed report for the U.S. Congress in 2013, as required by the SECURE Water Act, reporting on its plans and progress toward these legislated goals. The report, "Progress Toward Establishing a National Assessment of Water Availability and Use," is available at https://pubs.usgs.gov/circ/1384/.

To achieve the last two SECURE Water Act mandates stated in sections 9508(d)(5–6), the Water Census developed the concept of "geographic focus-area studies" to study water use and other factors affecting the hydrologic cycle in geographic areas with known significant water conflicts and shortages. The first three river basins selected for geographic focus area studies were identified at the Interior level and included the Apalachicola-Chattahoochee-Flint (ACF) River Basin in Alabama, Florida, and Georgia; the Delaware River Basin in Delaware, New York, New Jersey, and Pennsylvania; and the entire Colorado River Basin. In each of these study areas, the USGS met with numerous stakeholders to identify the water availability issues to be studied. Aside from being mandated under the SECURE Water Act, the need for improved water-use information was identified as a key issue in each of the three river basins.

Geographic focus area studies under the USGS Water Census are 3-year, high intensity studies, funded at $500,000 per year. The final reports for the Colorado River Basin focus area study are scheduled for publication in early 2018. The report "Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010" (Maupin and others, 2018) presents water-withdrawal information aggregated at the HUC-8 level for the following water-use sectors: public supply, domestic, commercial, industrial, livestock, mining, aquaculture, irrigation, thermoelectric water, hydroelectric water, and wastewater return flows. Consumptive-use estimates also will be included in the report for irrigated agriculture and thermoelectric power generation, which are the only two categories of use with updated USGS methods for estimating consumptive use. These two water-use categories represent some of the largest water uses nationally and in the Colorado River Basin. Updated methods for estimating consumptive use for other water-use categories are currently being developed by the USGS (for example, Public Supply). The reader is referred to the "Methods" section of this report for a discussion on how these estimates of water use are determined.

Use of Data

The report "Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010" is intended primarily for an audience interested in understanding the major sectors of water use and the spatial distribution of those uses within the Colorado River Basin. It is also anticipated that parties outside the basin might use this information for national or regional water-use summaries. Water use for this Colorado River Basin-specific report includes groundwater and surface-water withdrawal, delivery, consumptive uses for irrigation and thermoelectric power, as well as categories of use not reported since 1995, including hydroelectric power and wastewater return flows. The water-use reports for the Colorado River Basin, Apalachicola-Chattahoochee-Flint River Basin, and Delaware River Basin make a significant contribution to the NWUIP 5-year National Compilation and the water budget aspects of the Water Census by providing a direct means to reinstate reporting of water withdrawals by site-specific uses or aggregated by watershed (HUC-8). National water-withdrawal information aggregated by watershed was last presented by the USGS in 1995 (Solley and others, 1998).

Comparison of Bureau of Reclamation and U.S. Geological Survey Water-Use Reporting

The preceding sections describe the legislative drivers behind water-use data collection and reporting efforts by the USGS and Reclamation in the Colorado River Basin, both at a national scale (USGS) and specifically within the Colorado River Basin (USGS and Reclamation). The sections also introduce the two major report products from each agency that provide information on Colorado River Basin water use. Table 1 lists key differences in these four water-use products, particularly the spatial and temporal scales, the water-use sectors, and the primary purposes of each report.

There are important differences to note between the programmatic focus of, and information reported by, these two agencies. Reclamation is directed by specific Colorado River Basin laws and decrees to estimate the consumptive use of water within the basin to determine how consumption affects the water supply for other downstream uses. To this end, Reclamation documents the monthly and annual amount of water removed (consumed) from the system in the CUL Report for the entire basin and the Water Accounting Report in the Lower Colorado River mainstem. The legal drivers for these data compilations force slightly different approaches in the upper and lower parts of the Colorado River Basin. The compiled information is reported on a State-by-State basis for the entire basin, but also is aggregated for some of the major tributary streams flowing into the Colorado River. In the Lower Basin, other than for the selected major tributaries, the information is reported only for the water diverted from the mainstem of the Colorado River for each diverter of water and for each point of diversion from the mainstem source. Reclamation is not obligated to report instream or non-consumptive uses as part of their water accounting effort. Although Reclamation is legally obligated to collect the prescribed data to meet the water-rights obligations spelled out in the Colorado River Basin compacts and decrees, the agency also uses this information to assist in modeling and managing basin water planning and operations to meet competing demands such as irrigation, municipal supply, and power generation.

In contrast, the primary mission of the USGS NWUIP is to estimate aggregated water withdrawals for most of the primary water uses across the entire United States in order to understand where water is required and how much water is actually withdrawn to meet these requirements. These withdrawals include the major consumptive water-use sectors (for example, irrigation, public supply, thermoelectric power, commercial/industrial, and so on) but also include information on non-consumptive uses such as instream uses (hydroelectric power

Table 1. Water-use data and information publications compared by this report.

[HUC, hydrologic unit code; USGS, U.S. Geological Survey; SECURE Water Act, Science and Engineering to Comprehensively Understand and Responsibly Enhance Water Act; HUC-8, 8-digit HUC]

Report component	U.S. Geological Survey water-use reports		Bureau of Reclamation water-use reports	
	"Estimated Use of Water in the United States"[1]	"Estimate of Water Use and Trends in the Colorado River Basin"[2]	"Colorado River Basin Consumptive Uses and Losses Report"[3]	"Colorado River Accounting and Water Use Report—Arizona, California, and Nevada"[4]
Spatial scope	National scale, reported for county and State areas	Colorado River Basin scale, reported for HUC areas	Colorado River Basin scale, reported for major tributary and State areas	Lower Colorado River Basin mainstem, reported by mainstem diverter and State areas
Agency program or legislative driver	USGS National Water-Use Information Program	USGS National Water Census—SECURE Water Act	Colorado River Basin Project Act of 1968	Consolidated Decree of the United States Supreme Court in Arizona v. California
Purpose or target information	Characterize the water withdrawals of the nation by sector, State, and county	Characterize the water withdrawals, use, and returns of the Colorado River Basin by sector and HUC-8	Accounting for consumptive use and loss throughout the Colorado River System	Accounting for diversions as well as return flows and consumptive use of mainstem Colorado River water, and releases to Mexico
Timing of data compilation and publication	Data compiled at 5-year intervals for years ending in 0 and 5. Published since 1950	Data compiled at 5-year intervals, 1985–2010, in one-time publication. New data for 2010 including consumptive use for selected water-use sectors	Data compiled annually since 1971. Published every 5 years, with provisional estimates published annually	Data compiled monthly and published annually since 1964
Water-use sectors reported	Aquaculture, Domestic, Industrial, Irrigation, Livestock, Mining, Public Supply, Thermoelectric Cooling	Aquaculture, Commercial, Domestic, Hydroelectric, Industrial, Irrigation, Livestock, Mining, Public Supply, Thermoelectric, Wastewater Returns	Irrigation, Livestock, Stockponds, Municipal/Industrial, Mining, Thermal Electric Power, Reservoir Evaporation, Basin Transfers	Surface-water and groundwater consumptive use reported by mainstem diverter and State

[1]Maupin and others (2014).

[2]Maupin and others (2018).

[3]Bureau of Reclamation (2012a).

[4]Bureau of Reclamation (2011).

generation) and some return flows (publicly owned treated wastewater). As explained in the "Report: Estimated Use of Water in the United States" section of this report, the effort to quantify all water withdrawals in a defined area results in a "multiple counting" of water as it is diverted, used, returned, and then diverted and accounted for again downstream. However, this approach to water-use accounting is valuable to those decision makers who need to understand where water requirements are being satisfied and how much water must be present at these locations to meet those requirements, including how much water must be present to satisfy non-consumptive uses (for example, hydroelectric power generation, environmental uses). The USGS works to document these types of water withdrawals nationwide, and applying this all-inclusive assessment of water use in the Colorado River Basin geographic focus area study under the USGS Water Census is consistent with the SECURE Water Act. The data generated during the Water Census focus area study in the Colorado River Basin will be integrated into the broader USGS nationwide datasets that constitute the body of data used in national assessments (such as the 5-year compilations). Additionally, datasets from the focus studies will be integrated into the National Water Census Data Portal for inclusion in water budget analyses.

The different agency missions, and in particular, the legislative actions and legal directives, are the impetuses that drive the different types of water-use information produced by the USGS and Reclamation. These drivers result in different types of data being collected, different sets of water-use sectors being reported, and ultimately, somewhat different constituencies being served by these data. Although the USGS water-use information is not specifically collected for the purpose of legally managing or regulating water use in the Colorado River Basin, certain components of the USGS efforts are comparable or complementary to Reclamation's compiled data. This presents opportunities, discussed in the "Opportunities for Future Collaboration" section of this report, to investigate collaboration opportunities for the agencies to develop more accurate and concise water-use data reporting methods in the Basin.

Contrasting Terminology

In an effort to clarify the similarities and differences between the USGS and Reclamation water-use programs, it is first important to understand any significant differences in the terminology used by the two agencies. Four possible scenarios exist regarding terminology: (1) the USGS and Reclamation use the same term and the definition of that term is the same for both agencies; (2) the USGS and Reclamation use the same term but the definition of that term differs between agencies; (3) the USGS and Reclamation use different terms when referring to the same definition of a subject; and (4) a term and its definition are used only by either the USGS or Reclamation, and hence, no contradiction or confusion should exist.

In a review and comparison of each agency's water-use terminology, it was found, as might be expected, that the two agencies most often use the same term to refer to the same definition (scenario 1). The reader is referred to the list of these in-common terms in the "Glossary" section of this report. These in-common terms will not be discussed further here. Additionally, under scenario 4, where terms and their definitions are exclusive to an individual agency, there is no conflicting terminology. Terms that are used by one agency but not the other are listed in table 2. Many of these agency-specific terms (1) are the result of legislative language that directs the individual water-use programs and are meant to label water-use components that are unique to the type or scope of water-use data being reported; or (2) have been deeply ingrained in the respective, independently developed programs over the preceding decades through published documents or long-standing database structures. Because the programmatic goals, objectives, and constituencies served are somewhat different for each agency, it should be expected that each agency would have a subset of unique terms and definitions that would accurately describe their respective efforts or reported data. The definitions for these agency-specific terms are listed in the "Glossary" section of this report.

Only one instance was found where different terms were used by the two agencies to refer to the same definition (scenario 3). The term "irrigation water requirement" (IWR) is used by the USGS to define the quantity of water that is necessary to supplement natural precipitation and soil moisture for healthy crop growth. Reclamation uses the term "net irrigation requirement" (NIR) to identify this crop need.

The more important scenario to expand upon here is scenario 2—where terms that are common to both agencies have slightly different definitions. These terms and their conflicting definitions are listed in table 3. These conflicting definitions may be subtle and are sometimes tied to the

Table 2. U.S. Geological Survey and Bureau of Reclamation terms that are used by one agency and not the other.

Only a U.S. Geological Survey term	Only a Bureau of Reclamation term
Beneficial use	Beneficial consumptive use
Conveyance loss	Colorado River System
Depletion	Cutoff date
Instream use versus offstream use	Cutoff flow
Irrigation water requirement	Effective precipitation
Non-consumptive use	Free water surface evaporation
Point of diversion	Fullness factor
Point of use	Incidental use
Water withdrawal	"Law of the River"
	Lower Colorado River mainstem
	Natural flow
	Net irrigation requirement
	Salvage
	Shortage lands
	Transbasin diversions (Exports)

Table 3. Crosswalk of terms with different definitions.

[See the "Glossary of Terms Used in this Report" section of this report for additional information. WBD, Watershed Boundary Dataset; HUC, hydrologic unit code; USGS, U.S. Geological Survey]

Term	U.S. Geological Survey definition	Bureau of Reclamation definition	
		Upper Basin	Lower Basin
Colorado River Basin	Watersheds or hydrologic basins that are identified by the WBD or HUCs as within the Upper Colorado and Lower Colorado regions, and contain the first 2-digit nomenclature of 14 and 15, respectively. The dividing point between Upper and Lower Colorado River Basins is at Lee Ferry on the Colorado River (1 mile below the Paria River in Arizona), also referred to as the Colorado River Compact Point.	Defined in the Colorado River Compact of 1922 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.	
Colorado River Basin tributaries	All rivers or streams that are located in hydrologic basins that naturally drain into the Colorado River. These areas entail all drainages that have HUCs that begin with 14 or 15 in the first 2-digit numbering scheme.	Reclamation excludes the mainstem below Lee Ferry from the definition used by the USGS.	
Consumptive use	Water that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise not available for immediate use. In terminology used by the USGS, does not include interbasin transfers.	A use or depletion of water due to human-caused activity, including interbasin transfers.	Diversions from the stream less such return flow thereto as is available for consumptive use in the United States or in satisfaction of the Mexican Treaty obligation.
Hydrologic basin	The land area that drains water to a stream, river, or lake. It is a land feature that can be identified by tracing a line along the highest elevations between two areas on a map, often a ridge. Also referred to as a "watershed" or "drainage basin." There are varying scales of hydrologic basins and they are depicted in maps that illustrate the boundaries and the numerical codes for the areas, referred to as "HUCs."	Defined in the Colorado River Compact of 1922 as "Colorado River System" or that portion of the Colorado River and its tributaries within the United States.	
Lower Colorado River tributaries	All rivers or streams that are located in hydrologic basins that naturally drain into the Colorado River below Lees Ferry (USGS gage site Compact point). These areas are identified by HUCs that begin with 15 in the first 2-digit number scheme.	All rivers or streams that are located in hydrologic basins that naturally drain into the Colorado River below Lee Ferry excluding the geographic areas included in the Lower Colorado River Mainstem. Lee Ferry, located in Arizona, is a point on the mainstem 1 mile below the mouth of the Paria River. Note Lee Ferry and Lees Ferry are not the same location.	
Return flow	Water that reaches a groundwater or surface-water source after release from the point of use, or the point of treatment, and thus becomes available for further use.	Water, diverted from the mainstem of the Colorado River, that returns to the mainstem by surface or subsurface means and which is available for use by other water users in the United States or in satisfaction of the Mexican Treaty obligation.	
Upper Colorado River Basin	Watersheds or hydrologic basins that are identified by the WBD or HUCs as within the subregion for the Upper Colorado River Basin, and contain the first 2-digit nomenclature of 14. The Upper Colorado River Basin is defined as upstream of Lees Ferry (USGS gage site) on the Colorado River. This site is upstream of the confluence with the Paria River.	Watersheds of hydrologic basins that are defined as upstream of Lee Ferry. Lee Ferry, located in Arizona, is a point on the mainstem 1 mile below the mouth of the Paria River. The Colorado River Compact of 1922 divided the Colorado River Basin into two subbasins, the Upper Basin and the Lower Basin, with Lee Ferry as the division point on the river.	
Water use	In a restrictive sense, the term refers to water that is withdrawn for a specific purpose, such as crop irrigation. More broadly, water use pertains to the interaction and influence that humans have on the hydrologic cycle, and includes elements such as diversion or withdrawals, transfers, deliveries, consumption, and return flows throughout the processes of use.	The interaction and influence that humans have on the hydrologic cycle, and includes elements such as diversion or withdrawals, transfers, deliveries, consumption, and return flows throughout the processes of use.	

legislative mandates driving the water-use data collection programs of the two agencies. When a term or definition is tied to the driving legislation or is the result of a long-established historical precedent, any changes to the term or definition would be problematic to the execution and continuity of the agencies' programs. There may be opportunities in the future to refine these terms or definitions to make them either more closely aligned or more clearly distinct. Either way, it should be incumbent upon each agency to be cognizant of this confusing or conflicting terminology, and every effort should be made to define these terms at every usage. This would ensure that readers or users of these data understand the meaning and application of the data or information provided.

Although the majority of water-use terms and definitions are common to both USGS and Reclamation, the fact that each agency has a unique mission and constituency has required development of terms and definitions that are unique to their respective programs. These unique missions and data collection requirements have resulted in the development of unique methods for compiling, analyzing, and reporting water-use information. A comparison of these programmatic methods is presented in the "Methods" section of this report.

Methods

The methods used by Reclamation and the USGS to estimate water use are explained in the water-use reports developed by the agencies, as well as other previously published guidance documents (for example, Hutson and others, 2007). This section of this report will identify and summarize the methods used to estimate water use for most of the major sectors of water use and will compare and contrast the methods used by the two agencies to maximize data quality. The "Opportunities for Future Coordination" section will highlight opportunities for collaboration and efficiency. Because some of the minor categories of water-use reporting are unique to one agency or the other, the methods used for those minor categories are not described in great detail but are described more generally in this report.

An important distinction between the USGS and Reclamation that has a significant influence on the methods used for water-use reporting is that the water-use categories reported by the two agencies are different, or in some cases, are aggregated differently. Table 4 shows a side-by-side listing of the reported water-use categories for each agency. In reviewing this table, it is important to keep in mind that, in most cases, the USGS reports total water withdrawal for each of the listed water-use categories whereas Reclamation reports total consumptive use.

Table 4. Categories included in water-use reporting.

U.S. Geological Survey categories	Bureau of Reclamation categories
	Agriculture
Irrigation (Crop and Golf)	Irrigation Use (Crop Only)
Not summarized	Stock Pond Evaporation Loss
Livestock	Livestock Use
Aquaculture	*Not summarized*
	Municipal and Industrial
Mining	Mineral
Thermoelectric Water Use	Thermal Electric
Hydroelectric Water Use	*Not summarized*
Public Supply Self-Supplied Domestic Self-Supplied Industrial Self-Supplied Commercial	Municipal and Industrial Other Uses (incorporates the four U.S. Geological Survey categories)
	Reservoir Evaporation
Not summarized	Mainstem/Major Reservoir Evaporation
	Minor Reservoir Evaporation
Wastewater Return Flow	*Not summarized*
	Export (Basin Transfers)
Not summarized	Outside System (Interbasin)
	Within System (Intrabasin)

Bureau of Reclamation's Water-Use Method Descriptions

As discussed earlier, Reclamation is only presenting water-use data compiled and estimated for the Colorado River System. Table 5 lists the 10 Reclamation water-use categories and provides a summary of data sources and methods used to estimate consumptive use in the seven Colorado River Basin States for consumptive uses and losses reporting. As mentioned earlier, the Water Accounting Report provides water-use data summed by user and diversion point, not by water-use category, so it is not described in table 5. All the data sources listed for each category are not always needed for each State; typically a combination of sources are used to estimate consumptive use. Reclamation collects and (or) estimates consumptive use data for all the Colorado River Basin States except New Mexico, which independently provides estimates of consumptive use each year using methods chosen by the State. The New Mexico estimates are reviewed and entered into Reclamation's CUL Report. The primary data sources for the 10 categories are Federal and (or) State agencies. The data for the municipal and industrial—other uses category is derived from per capita estimates from USGS water-use reports and population data interpolated or extrapolated from U.S. Census figures. Mineral resources use is based on data from USGS water-use reports that are published every 5 years; for the years without published values, USGS data are interpolated or extrapolated from the 5-year data. Site-specific data for thermal electric power use are collected from powerplant operators (if available), and data for exports outside (interbasin transfers) and within (intrabasin transfers) the Colorado River System are collected from ditch companies or State agencies, or determined from gaging records, if available.

Table 5. Bureau of Reclamation data sources, methods, and spatial and temporal information for its water-use categories.

[HUC, hydrologic unit code; USGS, U.S. Geological Survey]

Category	Data sources	Methods	Spatial	Temporal
Irrigation Use	Federal and State agencies	Reported acreage data; crop consumptive use estimates based on modified Blaney-Criddle	County, HUC, State	Total monthly use, annually
Stock Pond Evaporation Loss	Federal and State agencies	Historical reported surface area data; precipitation; estimated from provided data	County, HUC, State	Total monthly use, annually
Livestock	Federal and State agencies	Reported population and consumptive use rates; estimated from provided data	County, HUC, State	Total monthly use, annually
Mineral Resources Use	USGS water-use report and State agencies	Reported data; estimated from historical reported data	County, HUC, State	Total monthly use, annually
Thermal Electric Power Use	Federal and State agencies; direct contact with power provider	Reported data; estimates based on reported data	Site specific, aggregated to county, HUC, State	Total monthly use, annually
Municipal and Industrial Other Uses	U.S. Census Bureau, USGS water-use report and State agencies	Estimated from U.S. Census populations and per capita coefficients derived from USGS water-use reports	County, HUC, State	Total monthly use, annually
Mainstem Major Reservoir Evaporation	Federal and State agencies	Reported data; precipitation; estimates based on reported data	Site specific, aggregated to county, HUC, State	Total monthly use, annually
Minor Reservoir Evaporation	Federal and State agencies	Historical reported surface area data; precipitation, estimated from provided data	Site specific, aggregated to county, HUC, State	Total monthly use, annually
Exports Outside System Exports Within System	Federal and State agencies; direct contact for diversion information	Reported data; estimates fromhistorical records	Site specific, aggregated to county, HUC, State	Total monthly use, annually

Methods to "fill in" data gaps, including interpolating/extrapolating from historically reported data, are used when reported data are not available. As an example, USGS water-use reports issued after 1995 do not include HUC-based results, so since then, Reclamation has relied on 1995-based HUC per capita use coefficients to fill in HUC estimates for domestic and public supplies.

The discontinuation of previously available data sources and relying on independently funded (therefore intermittent) data collection efforts represent some of the challenges Reclamation has faced when estimating consumptive use on an annual basis. Many independent reports or data are not released on an annual basis (for example, U.S. Census, State agricultural geographic information system data layers, national Census of Agriculture from the U.S. Department of Agriculture [USDA] National Agricultural Statistics Service [NASS]; https://www.agcensus.usda.gov/), so data "filling" must be used to estimate data for the years between the years the data are reported. Another weak point in existing estimation methods is reliance on old reports to estimate factors such as agricultural incidental use, per capita use rates, livestock use rates, and basinwide annual to monthly reservoir evaporation distributions.

Methods used to estimate consumptive use predominately rely on theoretical calculations, so where quantitative measurements of water use are available, the measurements are preferentially used. The subsections under the "Upper and Lower Colorado River Basin Tributaries" and "Lower Colorado River Mainstem" sections of this report describe calculations for categories that are not adequately explained by table 5.

Upper and Lower Colorado River Basin Tributaries

In the tributary areas of the Colorado River Basin, records of diversions and return flows are not complete enough to allow direct calculation of consumptive water use. So in these areas, theoretical and indirect methods of estimating consumptive use are relied upon. The annual consumptive use of water in the New Mexico part of the Colorado River Basin is reported by the New Mexico Interstate Stream Commission. For Colorado River Basin tributary areas in Arizona, California, Colorado, Nevada, Utah, and Wyoming, the annual consumptive use of water is estimated using the methodologies described below.

Agriculture

Agricultural consumptive use is estimated using crop coefficient methods that calculate water use (inches per month) for particular crops in a given location based upon local weather data. To compute monthly and seasonal water volumes consumed by each crop, the usage rates are multiplied by estimates of irrigated acreage of each crop type. These volumes are reduced by the amount of the required water that is provided by precipitation, and the effect of irrigation water shortages.

The acreage of irrigated crops grown within each reporting area is estimated from data obtained from four sources:

1. County agricultural statistics generated by the NASS (https://www.agcensus.usda.gov/) provide annual crop acreage estimates generated from surveys from a sample of farm operators across the United States. Irrigation status information and the acreage of pasture land, which makes up a substantial portion of the irrigated lands in the Upper Colorado Basin, are not available from annual agricultural statistics. The aggregated data are summarized by county.

2. The NASS Census of Agriculture (https://www.agcensus.usda.gov/) provides both irrigation status and crop type information for all crops grown in the Colorado River Basin; the data are based upon an attempted complete enumeration of every farm operator in the country. The census also provides estimates of irrigated pasture land, which are not reported in county agricultural statistics. The Census of Agriculture is done on a 5-year repeat cycle for years ending in 2 and 7. As with agricultural statistics, data are summarized by county.

3. Irrigated crop maps produced by the States of Colorado, Utah, and Wyoming using remote sensing and field surveys are processed to provide irrigated crop acreage estimates. Starting in 2000, the State of Colorado has mapped irrigated crops for the Upper Colorado Basin on a 5-year repeat cycle, for years ending in 0 and 5. Utah has mapped irrigated acreage continuously using remote sensing and field surveys since the 1980s, with a different portion of the State mapped each year. Repeat cycles are typically between 5 and 7 years. Wyoming produced a map of irrigated acreage in the Green River Basin using 1982 and 1983 aerial photography, which was updated using satellite imagery acquired in 1999.

4. Reclamation has produced maps of irrigated crops within the Upper Colorado River Basin intermittently since the early 1990s. Reclamation worked with the Upper Basin States (Colorado, New Mexico, Utah, and Wyoming) to generate a 1:24,000 scale map of irrigated crops within the Upper Colorado Basin using aerial photography and extensive ground data in the early 1990s, then mapped irrigation status for the entire Upper Colorado River Basin using Landsat satellite imagery acquired in 1995. Reclamation also generated irrigated crop maps in more recent years to supplement data provided by the Upper Basin States. The Western Slope of Colorado was mapped in 2011 and 2012; portions of Utah in 2005, 2011, and 2012; and Wyoming in 2000 and 2005.

The procedure used by Reclamation to estimate agricultural consumptive uses and losses in the early 1970s relied on county agricultural statistics, the only reliable source for annual crop data, along with the less frequent Census of Agriculture. The county is the smallest level of spatial disaggregation presented in either of these two datasets, but county boundaries often do not respect watershed boundaries. Therefore, it was necessary to disaggregate county-level estimates into smaller reporting areas representing the spatial intersection of counties and HUC-8s (that is, county/HUC-8). This was accomplished by multiplying county-level irrigated acreage estimates by the proportions of irrigated acreage residing within each county's constituent HUCs. These proportions were calculated from irrigated acreage estimates developed in the 1960s.

In the 1980s, Reclamation and the Upper Basin States began generating their own digital irrigated acreage maps using a variety of remotely sensed imagery combined with ground reference data. Output maps are stored as digital vector and raster layers within geographic information systems to facilitate acreage calculations and other spatial analyses. Because the coverage of the irrigated crop maps derived using remote sensing is intermittent, these maps are used to supplement but not replace the procedure based upon county agricultural statistics and Census of Agriculture data. Acreages of specific irrigated crop types obtained using remote sensing for a given year are typically scaled to estimate acreages in subsequent years based upon ratios of acreages from agricultural statistics or Census of Agriculture data for the subsequent year to the year of the mapping with remote sensing.

In the Lower Colorado Basin, diversion and return flow records from the Water Accounting Report are used to estimate consumptive use along the mainstem of the Colorado River. For the tributaries, a regionally calibrated Blaney Criddle formula is used to estimate NIR using irrigated crop acreage values that are still calculated using agricultural statistics and Census of Agriculture data. Because irrigated pasture values are only reported in the Census of Agriculture, irrigated pasture values for the years surveys are not taken are interpolated or extrapolated from the two most recent censuses.

At least one representative National Weather Service Cooperative Observer Program weather station was selected to represent mean weather conditions for agricultural lands within each county/HUC-8. Using records of temperature, precipitation, and frost dates, an irrigated crop consumptive use rate (inches per month) is computed for each major crop in each of the reporting years using the modified Blaney-Criddle ET formula as described in Soil Conservation Service (SCS) Technical Release No. 21, "Irrigation Water Requirements," revised September 1970 (USDA, SCS, 1970). To determine NIR rates, the effective precipitation (inches per month) is subtracted from the crop consumptive use rates. Effective precipitation for the Upper Basin is computed using the SCS method that is also referenced in SCS Technical Release No. 21 (USDA, SCS, 1970). The monthly values of NIR rates (converted to feet per month) multiplied by the estimates of irrigated acreage yield the final values of NIR volumes (in acre-feet).

In the low desert regions of Arizona within the Lower Basin, a regionally calibrated BlaneyCriddle formula is used to estimate the NIR instead of the modified Blaney-Criddle formula. This departure is based on the research results of Erie and others (1982) who developed seasonal crop consumptive use factors for the lower elevation desert areas. Effective precipitation is derived from criteria developed for the area by former Utah State Engineer Wayne D. Criddle (Erie and others, 1982).

All of these theoretical NIR calculations are based on the assumption that a full water supply is available to all irrigated fields during the crop growing season. However, Reclamation estimates 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 insufficient water being available to meet junior water rights or a lack of distribution facilities. The degree to which these lands experience shortages varies widely from year to year, depending in large part on the magnitude of runoff. An estimate of the short-supply service lands was made for irrigation service areas covering the Upper Colorado Basin, primarily on the basis of reports and investigations collected for the 1971 comprehensive framework study (Upper Colorado Region State-Federal Interagency Group, 1971). A streamgaging station is selected within each service area and the magnitude of the recessional portion of the annual hydrograph is used as an index to select the date at which consumptive use calculations are terminated for the short-supply lands. This is known as the indicator gage method.

Comprehensive framework studies (Lower Colorado Region State-Federal Interagency Group, 1971; Upper Colorado Region State-Federal Interagency Group, 1971) of the incidental use of water associated with irrigation indicate that this use varied between 5 and 29 percent of the NIR, depending upon the location of the study area within the Colorado Basin. This range of percentages has been used in the Upper Basin to adjust the NIR. In the Lower Basin, a single 15 percent value was used from 1971 to 1990 (derived from data provided in table 5; Lower Colorado Region State-Federal Interagency Group, 1971) to adjust the NIR. This percentage was increased to 20 percent for the years 1991–2005.

Reservoir Evaporation

Reclamation maintains a comprehensive list of all reservoirs in the Colorado River Basin. The list, which is based primarily on the National Inventory of Dams database (U.S. Army Corps of Engineers, 2014), includes the latitude, longitude, elevation, and surface area at total capacity for each reservoir.

Monthly water-surface area is obtained for those reservoirs for which records are available. For the entire basin, annual free water surface (FWS) evaporation rates are used to determine reservoir evaporation. The FWS evaporation values are taken from National Oceanic and Atmospheric Administration Technical Report NWS 33, "Evaporation Atlas for the Contiguous 48 United States" (Farnsworth and others, 1982, map 3 of 4). An account is taken of precipitation and salvage to determine net evaporation rates. The annual FWS evaporation rates are distributed monthly based on an average basin monthly distribution. For unmeasured reservoirs, the annual net evaporation rates are applied to the estimates of average annual water-surface area to yield the values of annual reservoir evaporation. For those reservoirs lacking records (that is, are unmeasured), a fullness factor is estimated on the basis of reservoir use and historical hydrologic conditions. These fullness factors are then used to obtain estimates of average annual water surface area for the unreported reservoirs. According to Reclamation's plan of study and methods manual, the fullness factors were developed for the 1981–85 CUL report and are included in the Technical Appendix Volume 1 (Bureau of Reclamation, 1992).

An exception to this procedure is the determination of evaporation from what are called the mainstem reservoirs (that is, Flaming Gorge, Blue Mesa, and Morrow Point Reservoirs, and Lake Powell) in the Upper Colorado River Basin. For these reservoirs, monthly reservoir evaporation is taken from Reclamation's hydrologic database. Records of monthly evaporation applied at these sites are based on results from past pan-evaporation studies that are adjusted based on limited mass-transfer method measurements (Jacoby and others, 1977) and maintained by Reclamation's Upper Colorado Region water operations group.

Lower Basin mainstem reservoirs include Lake Mead, Lake Mohave, Lake Havasu, Senator Wash Reservoir, and reservoirs behind various diversion dams along the mainstem. Monthly reservoir evaporation is taken from Reclamation's hydrologic database maintained by the Lower Colorado Region's water operations group. Historically, these records were based on pan-evaporation studies but more recently the records have incorporated micrometeorological studies conducted by the USGS (for example, Westenburg and others, 2006).

Stockpond Evaporation and Livestock Water Use

Stockpond surface areas are estimated using the methods in SCS publication, "Livestock Water Use" (USDA, SCS, 1975). The stockpond areas are subdivided by county using the livestock population distribution. The livestock population distribution is further subdivided to county/HUC-8 scale based on the irrigated lands average distribution. The same procedure used to calculate evaporation from unmeasured reservoirs is used to estimate stockpond evaporation.

Livestock population data for cattle, sheep, horses, and hogs are taken from annual State agricultural statistics and the Census of Agriculture. Consumption rates for the various livestock are derived from various reports, including the publication "Livestock Water Use" (USDA, SCS, 1975).

Basin Transfers

Nearly all the basin transfers (as termed "transbasin diversions") both out of (exports) and into (imports) the Colorado River System are measured at streamgaging stations maintained by the USGS, State agencies, or local water commissioners and users. The remainder are estimated on the basis of past records and capacity of facilities. Basin transfers are reported under the export category and are considered a consumptive use with no flow returning back to the reporting area. Exports are further divided into two subcategories: (1) outside system (interbasin) and (2) within system (intrabasin). The outside system includes water that is removed from the Colorado River System whereas the within-system subcategory includes water that is moved between reporting areas but does not leave the Colorado River System. The within-system consumptive use total for the Colorado River System will always be zero because an export from one reporting area is an import to another. Imports into the system are accounted for and reported as a negative export. Due to the large number of measurements, this area of basin consumptive use is considered to be quite accurately determined. CUL Reports account for water use in the area where water is used with the exception of the basin transfers out of the system, which are reported where the basin transfer is first diverted rather than where it is used outside the system.

Lower Colorado River Mainstem

The annual consumptive use of water from the mainstem within the Lower Colorado River Basin (fig. 1) and exports out of the basin are taken from the annual Water Accounting Report. The Water Accounting Report tabulates water use by individual water user and State but does not assign a use category. For inclusion in the CUL Report, consumptive use from the Water Accounting Report is first categorized into one of three consumptive use and loss categories—irrigation, municipal and industrial, or exports—based on the predominant water use of each water user, and summarized in the reporting area, for example, Mainstem Below Lee Ferry.

The water-use information compiled for the operation, maintenance, and administration of the Colorado River mainstem below Lee Ferry is based on measurements and is, therefore, considered to be accurate and complete. These data are under constant review and are being continually upgraded. Pursuant to the Consolidated Decree of the United States Supreme Court in *Arizona v. California*, 547 U.S. 150 (2006), the Water Accounting Report presents water use for each diverter from the mainstem at the point of diversion, not at the point of use.

U.S. Geological Survey Water-Use Method Descriptions

Since 1950, the USGS has published water-use data in the National Compilations; the latest report released is for the year 2010 (Maupin and others, 2014). The National Compilations contain spatially varying aggregated information that is developed using data collected by numerous private, local, State, and Federal entities. Standard methods and techniques used to compile and aggregate these data have been in use since about 1995 and are outlined in Bradley (2017). Both reported and estimated withdrawals constitute the body of data that is used to aggregate water use by category for various spatial areas (county, State, HUC-4 in early reports, and HUC-8 in later reports) in the United States. The USGS Colorado River Basin-specific water-use report, "Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010" (Maupin and others, 2018), uses the same methods and data sources as the National Compilations. However, additional efforts were made to aggregate data by hydrologic units (HUC-8s) and additional categories of use that are not included in the 2000–2010 National Compilations. For example, the report includes data on consumptive use for irrigation and thermoelectric power generation as well as withdrawals aggregated by HUC-8 for all categories. Again, methods and data sources are the same for both reports but the difference between the two is in the scope (categories) and scale (HUC-8) that are reported in the Colorado River Basin report versus the National Compilations for 1995–2010. The list of USGS water-use categories and data sources in table 6 represents what the Colorado River Basin work entails. Consult the online matrix of USGS national water-use efforts (https://water.usgs.gov/watuse/WU-Category-Changes.html) to see the content of National Compilation reports, keeping in mind HUC-8 data were only reported until 1995.

The 12 USGS water-use categories in table 6 (golf course and crop irrigation are considered separate categories but are combined in the National Compilations and denoted as "irrigation") are used to describe water use in the United States. Data for these uses are aggregated as total withdrawals from groundwater or surface water, and are summed by county, HUC-8, and State depending on the year of compilation. National compilation reports also list primary cooperating agencies that have served as the main data sources for reported data (Maupin and others, 2014).

The entire list of data sources and methods for all USGS water-use categories was too lengthy to be shown in table 6. The primary data sources in each of the 12 water-use categories are shown and include mostly Federal and (or) State agencies. However, for select categories (aquaculture, livestock, mining, and thermoelectric), data were collected and developed into aggregate datasets and documented nationally by the NWUIP (Lovelace, 2009a, b, and c; Diehl and others, 2013; Diehl and Harris, 2014). These data may be used in the National Compilations as well as for the Colorado River Basin work and are generally used unless other data are available that are deemed more accurate, but the inclusion of these data is at the discretion of each USGS water-use specialist in States across the country.

Water-use data are collected and aggregated for the largest categories of use using data reported directly from the purveyors (such as for public supply, municipal wastewater return flows, and thermoelectric and hydroelectric power facilities). For areas where actual measured data are unavailable, the data are estimated by applying coefficients derived from site-specific or ancillary data to compute water use. These types of estimation methods are used in the self-supplied domestic, commercial, industrial, livestock, mining, and aquaculture categories.

Water withdrawals for several water-use categories include a combination of both reported and estimated data. The USGS 5-year National Compilations and the report "Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010" (Maupin and others, 2018) use a significant amount of reported data for population, public-water supply withdrawals, irrigated acres, power generation, livestock populations, wastewater return flows, and quantities of mined materials. In many cases, the Federal and State agencies that collect these data have seen a decrease in both funding and personnel resources, which can decrease or limit the frequency and spatial extent of data collection efforts. The extent and detail of reported data vary by State, requiring additional work in some States to meet the requirements of the National Compilations and other study efforts such as the Colorado River Basin Focus Area Study. USGS internal documentation was compiled for each State as part of the National Compilation effort in 2010 (Maupin and others, 2014) and serves as a starting point for understanding the sources of data and methods used for each of the compilation categories.

Challenges with compiling withdrawal data include unknown errors in the reported data (for example, population and water supply withdrawal data) and use of older data than the compilation timeframe. For example, crop acreage data from the Census of Agriculture (USDA, NASS, 2014a) are collected every 5 years for years ending in 2 and 7. These are years offset from the USGS National Compilation years (years ending in 0 or 5) and may present some factor of error due to extrapolation. The lack of site-specific data about water sources in most of the water-use categories increases the difficulty in converting county-level data to the HUC-8 areas, especially in western States where counties are typically very large and water users (people, crops, livestock, industries, electrical facilities) may be distributed unevenly.

As mentioned before, the report "Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010" (Maupin and others, 2018) includes 2010 estimates only for irrigation and thermoelectric power consumptive use. After the 1995 National Compilation, those estimates were discontinued due to resource limitations for preparing the estimates. Through the Water Census and the "Colorado River Basin Focus Area Study," as well as water-use science efforts at the National level, the USGS is reinstating consumptive-use estimates for the irrigation and thermoelectric power categories.

Table 6. U.S. Geological Survey data sources, methods, and spatial and temporal information for its water-use categories.

[HUC, hydrologic unit code; NWUIP, National Water Use Information Program]

Category	Data sources	Methods	Spatial	Temporal
Public Supply	Federal and State agencies, or direct contact with facilities	Withdrawal data available for most very large, large, and medium systems; withdrawals estimated for small and very small systems	Site specific and (or) aggregated; county, HUC, and State	Total annual withdrawals, every 5 years
Self-Supplied Domestic	Federal and State agencies, facility deliveries, previous compilations	All assumed to be groundwater; estimated from county populations and per capita coefficients	County, HUC, State	Total annual withdrawals, every 5 years
Self-Supplied Industrial	Federal and State agencies, Hoover list,[1] direct contact with facilities	Reported withdrawal data; estimates based on number of employees and Standard Industrial Classification water-use coefficient	Site specific or aggregated; county, HUC, and State	Total annual withdrawals, every 5 years
Self-Supplied Commercial	State agencies, Hoover list,[1] previous compilations	Reported withdrawal data; estimates based on reported data or employee numbers and coefficients	County, HUC, State	Total annual withdrawals, every 5 years
Livestock	Federal and State agencies, NWUIP provided data	Reported withdrawal data; NWUIP provided data; estimated from provided data	County, HUC, State	Total annual withdrawals, every 5 years
Mining	Federal and State agencies, NWUIP provided data, direct contact for withdrawal information	Reported data; provided data surveys; estimates from reported data	County, HUC, State	Total annual withdrawals, every 5 years
Aquaculture	Federal and State agencies, NWUIP provided data, direct contact for withdrawal information	Reported data; provided data surveys; estimates from reported data	County, HUC,State	Total annual withdrawals, every 5 years
Irrigation, Crop	Federal and State agencies, local water conservation and irrigation districts, academia	Reported data;estimates based on crop irrigation water requirements (Blaney-Criddle) and consumptive use and irrigation system efficiency	County, HUC, State	Total annual withdrawals, every 5 years
Irrigation, Golf	Federal and State agencies, local water conservation and irrigation districts, direct contact with golf course superintendents	Reported data; estimates based on turf irrigation requirements (Blaney-Criddle) and consumptive use and irrigation system efficiency	Site specific or aggregated; county, HUC, and State	Total annual withdrawals, every 5 years
Thermoelectric	Federal and State agencies, NWUIP provided data, direct contact for withdrawal information. Consumptive use estimates taken from Diehl and Harris (2014)	Reported data; provided data; consumptive use estimation methods described in Diehl and others (2013)	Site specific, aggregated to county, HUC, and State	Total annual withdrawals, every 5 years
Hydroelectric	Federal and State agencies, direct contact for withdrawal information	Reported data; estimates based on reported data	Site specific, aggregated to county, HUC, and State	Total annual withdrawals, every 5 years
Wastewater Return	Federal and State agencies, direct contact for withdrawal information	Reported data	Site specific, aggregated to county, HUC, and State	Total annual withdrawals, every 5 years

[1]The Hoover list is a commercially available database sold by Dun and Bradstreet (http://www.dnb.com/products/marketing-sales/dnb-hoovers.html) that the U.S. Geological Survey purchases for information on industry water use and production.

The following paragraphs describe in more detail the generalized data sources and methods used to compile and aggregate water-use data for the major water-use categories reported by the USGS. The reader is reminded that the approach can vary from State to State on the basis of the water-use programs in each State and (or) the availability of other reliable data sources for the identified categories. These individual method descriptions are provided to allow comparison to those method descriptions provided by Reclamation in the preceding sections.

Public Supply

Data are compiled from State agencies (including water resource departments, State engineer offices, water permitting offices and health departments), conservation boards, corporate commissions, development commissions, water authorities, cities, local entities, and facility records showing reported annual withdrawals by source and total population served. These data are aggregated to the various reporting areas (county, HUC-8). Deliveries to domestic users are determined using percentage customer-base information or other ancillary information. Domestic delivery data are used to construct per capita use coefficients that are then applied for estimating self-supplied domestic withdrawals.

Self-Supplied Domestic

Populations using self-supplied domestic sources (mostly rural populations) are computed as the difference between the county or HUC-8 total population and the public-supply population served for the same geographic area types. The self-supplied domestic withdrawals are computed using the self-supplied domestic population and the per capita use coefficients derived from the public-supply deliveries to domestic users.

Self-Supplied Industrial

Data from State agencies (water resource departments, permitting offices, State engineer offices), conservation boards, water authorities, Federal agencies, water commissions, water districts, and a database purchased by the USGS NWUIP (Hoover, by Dun and Bradstreet; http://www.dnb.com/products/marketing-sales/dnb-hoovers.html) which includes industrial facility listings with ancillary information on the number of employees, produced commodities, and locations. Some facilities are contacted directly for verification. Estimation methods (to fill in data gaps from reported data) include using employee populations and water-use coefficients on the basis of the commodity production at facilities.

Self-Supplied Commercial

Data sources include State agencies (water resource departments, State engineer offices, departments of health) and urban water management plans. Within the Colorado River Basin, only selected counties and areas were completed for some States. Estimation methods include using coefficients-of-use based on ancillary data such as size of community or entity.

Livestock

Data sources include State agencies (water resource departments, State engineer offices), USDA Census, and NWUIP datasets (Lovelace, 2009a), as well as metered withdrawal data. Estimates are based on livestock demand coefficients and livestock population if water withdrawal is not metered.

Mining

Data sources include State agencies (water resource departments, State engineer offices), water conservation boards; oil and gas conservation commissions; bureaus of mines and geology; departments of business and industry; departments of water rights; and divisions of oil, gas, and mining facilities that monitor and report water use individually. The USGS NWUIP also has developed independent datasets that estimate water use for this category (Lovelace, 2009c). Estimation methods applied in the NWUIP dataset use mining water-use coefficients based on mining commodity and quantity of material removed.

Aquaculture

Data sources include State and Federal fish hatcheries, State agencies (engineer offices), or NWUIP datasets (Lovelace, 2009b). NWUIP estimation methods use type of rearing operation (flow-through raceways, rearing tanks, and so on) and water-use coefficients applied to quantity of fish production. Hatchery-use data generally are reported from measured data.

Hydroelectric

Data sources include direct reports from dam operators and reflect the total amount of water passed through the powerplant that is used to produce electricity. The data do not include evaporation losses from the reservoir above a hydroelectric dam. Some data for the Colorado River Basin Focus Area Study come from State agencies (water resources) or water commission boards.

Wastewater

Data are compiled from the U.S. Environmental Protection Agency-maintained wastewater treatment plant discharge records (https://www.epa.gov/npdes/municipal-wastewater). This water-use category includes only publicly owned treatment works or sewage treatment plants, not industrial discharges.

Irrigation Withdrawals (Crops and Golf Courses)

Due to the diversity of sources reporting irrigated agriculture or golf course water use across the United States, there are numerous types of data and methods used to measure or estimate this water-use category. Data sources include State agencies (water resource departments, State engineer offices, divisions of taxation, agriculture statistics offices),

conservation boards, water commissions, water authorities, Federal agencies (for example, Reclamation, USDA Farm Services Agency), universities, irrigation districts, conservancy districts, and extension agencies. The sources of data in the Colorado River Basin are similarly diverse. The method for estimating irrigation withdrawals is determined by the USGS water-use specialists in the individual States, and is dependent upon the availability of measured data or selection of the best available input datasets for calculating the irrigation water requirements (IWR). The IWR is an estimate of the amount of irrigation water needed to fully water a healthy crop after consideration of natural precipitation. For the USGS, the IWR is the crop's irrigation consumptive use. Irrigation withdrawals, however, are a mix of reported metered withdrawal volumes and estimates that are based on crop and grass (golf course) IWRs (calculated using a Blaney-Criddle formulation), climate data, distribution and amount of irrigated acres, and irrigation system efficiencies/losses. Estimated irrigation withdrawals (where no measured diversion data are available) are determined by calculating the IWR and adding back the estimated system losses related to the efficiency of the identified irrigation method (for example, flood versus sprinkler). Withdrawals by source (for example, groundwater versus surface water) are disaggregated from estimates on the basis of ancillary information on irrigation water delivery sources.

Knowledge of the number of acres of irrigated land, and the crops being grown on those acres, is a critical input dataset for the calculation of the IWR. The Golf Course Superintendent Association of America provides data on the number of golf course irrigated acres (Golf Course Superintendents Association of America, 2009), and IWRs are estimated using Blaney-Criddle methods. The amount and distribution of irrigated agricultural land across the United States is determined from numerous data sources including land cover digital datasets such as the National Land Cover Database (USGS, 2011), Cropland Data Layer (USDA, NASS, 2014b), and locally derived digital datasets and regional maps derived from remote imagery and (or) ground-based field mapping. The report "Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010" (Maupin and others, 2018) includes irrigation withdrawals and consumptive use (that is, IWR) estimates that are developed using crop-specific irrigated acres, golf course acres, precipitation, irrigation system efficiencies, and either the modified Blaney-Criddle method (Bureau of Reclamation, 1992) or, in the case of the desert areas of Arizona, a regionally calibrated Blaney-Criddle equation. Golf courses and crop

irrigation are compiled separately in all Colorado River Basin States except for Wyoming and California. The Maupin and others (2018) report utilizes a combination of field-verified and aerial photography mapping efforts (Arizona), the Colorado Decision Support System (Colorado) land cover distribution, or existing geospatial datasets (for example, Buto and others, 2014) to locate irrigated croplands. The USGS IWR is an estimate of irrigated crop water requirements calculated using the selected Blaney-Criddle method, minus effective precipitation, which is assuming a full water supply and healthy crop and soil conditions. Because of the large range of elevations in the upper part of the Colorado River Basin (for example, in the State of Colorado), the USGS occasionally employs the elevation adjustment to adjust Blaney-Criddle results. The elevation correction increases crop IWR by 10 percent for every 1,000 meters of elevation, prior to subtraction of effective precipitation. IWR values calculated by the USGS do not include estimates of incidental system losses (that is, transpiration from phreatophytes along canal banks, canal leakage, and evaporation) because the USGS does not consider these a crop-water need. These incidental system losses, based on expected efficiencies of identified irrigation methods, are added back to the IWR to estimate irrigation withdrawals where no measured withdrawal information is available.

Thermoelectric Power Generation

Data sources include data reported by powerplant operators, data generated by the NWUIP (Diehl and others, 2013; Diehl and Harris, 2014), and Energy Information Administration data on power production. Data are a mix of metered (reported) data and estimates based on models from Diehl and others (2013) and Diehl and Harris (2014). Power production data are provided solely through Energy Information Administration reports for exclusively steam-generating (not cogeneration) plants.

As part of the models by Diehl and others (2013), estimates of consumptive use at thermoelectric plants were developed using linked heat and water budgets and are used to complement reported thermoelectric water withdrawals and consumption. The heat- and water-budget models produced withdrawal and consumption estimates, including thermodynamically plausible ranges of minimum and maximum withdrawal and consumption, for 1,290 thermoelectric power generating plants in the United States for 2010 (Diehl and Harris, 2014). Powerplants were categorized for estimation of water consumption in two tiers. First, generating units were assigned to categories on the basis of the technology used to generate electricity. These generation-type categories are combustion steam, combined cycle, nuclear, geothermal, and solar thermal. Second, cooling systems were separately categorized as either wet cooling towers or surface-water cooling systems, and the surface-water cooling systems were subcategorized as cooling ponds, lakes, and rivers (Diehl and others, 2013). Calibrated model data for thermoelectric plants in Nevada are used in the Colorado River Basin Study; otherwise, data (both withdrawals and consumptive use) are collected and reported directly from plant operators.

Basin Transfers

The USGS considers water to be used when it is applied to a specific beneficial use. A transfer of water from one basin to another is not technically an application of water to a specific category of use, but is simply moving the water from one location to another. Therefore, in the typical USGS national water-use summary (5-year report cycle starting in 1950), water that is withdrawn and transported across basin boundaries (across regional or subregional scales, for example, 2-digit HUC scale [HUC-2]) is accounted for in the basin where it is applied to one of the defined categories of use (table 6). When water is withdrawn and used within a smaller geographic scale (for example, HUC-8), it is accounted for in that watershed. Interbasin transfers of water out of the Colorado River hydrologic basin to metropolitan and agricultural areas in California, Colorado, New Mexico, Utah, and Wyoming have not been aggregated in the USGS database as a use within the Colorado River Basin; instead, the water is accounted for in the watersheds where it is applied to a defined-use category. This is how the data are stored in the USGS Aggregated Water-Use Database System, which is used for the 5-year national reports. The USGS does have a national Site-Specific Water-Use Database (SWUDS, part of the National Water Information System; https://waterdata.usgs.gov/nwis) that can be used to document water movement from point of diversion to use and return. Although the Site-Specific Water-Use Database currently does not have sufficient data to allow this type of water tracking nationally, it is the desire of the USGS to populate this database as it moves toward true water budgeting across the United States. The report "Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010" (Maupin and others, 2018) includes a summary of the magnitude of water that is diverted out of the HUC-2 Colorado River hydrologic basins, but no tabulations are provided of specifically where, or for what purpose, that water is used.

Compare and Contrast Each Agency's Methods

This section of the report compares and contrasts the methods used by the USGS and Reclamation to produce water-use information in the Colorado River Basin, whether the information be water withdrawals or consumptive-use estimates. The first basic contrast is that the two agencies differ in the water-use sectors that they report and some of these sectors are aggregated on different temporal and spatial scales. Both agencies report livestock, thermoelectric cooling water, and mining water use, and they use similar definitions and methods for these sectors of use. Both agencies also report irrigation water use, but the USGS defines irrigation to include golf courses, while Reclamation does not. Both agencies report exports of water outside of the hydrologic basin (interbasin transfers) but in different ways. Because the USGS aggregates data by sector of use and at the point of use, water exported from the basin is not totaled in any water-use category within the originating basin but at the point of use (even if outside the State where

the diversion occurs). Additionally, and more importantly, the USGS water-use databases do not store exports per se. By contrast, Reclamation considers water exports from the basin as 100 percent consumptively used and aggregates this use at the point of diversion (within the hydrologic basin). In addition, the USGS characterizes public-supply systems, self-supplied domestic water use, self-supplied commercial, and self-supplied industrial water use as separate sectors, while Reclamation combines these categories into one "municipal and industrial—other uses" sector. Finally, the USGS characterizes wastewater return flows, aquaculture, and instream water use for hydroelectric power generation, while Reclamation only reports municipal wastewater return flows within the Lower Colorado River mainstem and aggregates those flows with the other return flows reported in the Water Accounting Report. Reclamation characterizes stock pond evaporation loss, mainstem and major reservoir evaporative loss, and minor reservoir evaporative loss, while the USGS currently does not. The fact that USGS and Reclamation programs report on different sectors of water use, and that these sectors are aggregated at different temporal and spatial scales, makes direct comparison of the two agencies' data difficult. However, the purpose of each agency's water-use program and the constituencies served dictate the need for both methods of water-use reporting.

The second basic contrast deals with the scale at which the USGS and Reclamation compile water use information. The USGS utilizes the same definitions, water-use sectors, and methods within the Colorado River Basin that it applies throughout the rest of the United States. The USGS must follow established programmatic protocols to develop consistent and comparable nationwide data. By contrast, legislative drivers require Reclamation to utilize different methods for water-use estimation for different areas in the Colorado River Basin. Water Accounting Reports for the mainstem of the Lower Colorado River below Lee Ferry are based on measurements of diversion and return flow and the data are compiled for each individual water user. Conversely, in the rest of the basin, except for that portion in New Mexico, estimates of water use are calculated using coefficients or models and the Water Accounting Report data are aggregated under the water-use categories that are described in table 5 (for example, irrigation use). Reclamation uses consumptive-use estimates generated by the State of New Mexico for the New Mexico portion of the Upper Colorado River Basin.

The third basic contrast deals with the type of information that the agencies produce. The USGS produces information primarily on water withdrawals for its 12 sectors of water use and currently produces consumptive-use information only on irrigation and thermoelectric cooling water uses. Conversely, due to legislative mandates, Reclamation focuses exclusively on consumptive-use estimates for its 10 reported water-use sectors in the Colorado River Basin. This is a fundamental difference in approach (and constituency served) that again makes direct comparison of agency data challenging. The definition utilized by the USGS for "water use" specifies that it "… pertains to the interaction of humans with and influence on the hydrologic cycle, and includes elements such as water withdrawal, delivery, consumptive use, wastewater release, reclaimed wastewater, return flow, and instream use" (USGS, 2018). Using this definition, each agency is characterizing an important feature, or several important features, of water use, but neither agency is comprehensively characterizing water use in the Colorado River Basin. So, the remainder of this section will compare the methods utilized for consumptive-use estimation where the two agencies methods and data are more directly comparable.

Reclamation estimates consumptive use for the "municipal and industrial—other uses" sector using a HUC-8 scale per capita consumptive use rate for public supply and self-supplied domestic, industrial, and commercial categories reported in the USGS "Estimated Use of Water in the United States in 1995" (https://pubs.er.usgs.gov/publication/cir1200). The derived per capita use rate is multiplied against the target-year population estimate reported by the U.S. Census Bureau. Although these per capita consumptive use rates have not been reexamined in the last 20 years, primarily because the USGS has not reported deliveries and other data on a HUC basis since 1995, they still represent a referenceable methodology. Similarly, the Reclamation consumptive-use estimate for "mineral resources" use is taken directly from data reported under the USGS's mining category which, similar to municipal and industrial estimates, were last reported on a HUC basis in the 1995 publication. Currently, the USGS does not estimate consumptive use information for these water-use sectors.

Reclamation estimates consumptive use for "thermal electric power cooling water" by collecting net use information from various power companies or obtaining estimates from historical records. The USGS currently estimates "thermoelectric power generation cooling water" withdrawals and consumptive use either from direct reporting from a facility (before 2010) or, more recently, by means of a linked heat and water budget model that the agency developed and documented in 2013 (Diehl and others, 2013). Plant-by-plant consumptive-use estimates are available for calendar year 2010 in a report that the USGS released in 2014 (Diehl and Harris, 2014). The USGS methods were developed to fulfill requirements of the U.S. Government Accountability Office (U.S. Government Accountability Office, 2009).

Both Reclamation and the USGS employ similar methodologies (using Blaney-Criddle to calculate the irrigation requirement) for estimating agricultural irrigation withdrawals and consumptive use; however, the selection of, and sources for, input datasets have varied and applications of the Blaney-Criddle method have varied slightly. For Reclamation, irrigated acreage is determined from best available sources of data—State agricultural statistics, the national Census of Agriculture, and geographic information system databases maintained by Reclamation and by the States of Colorado, Utah, and Wyoming. Consumptive-use estimates are then generated using the modified Blaney-Criddle method using local weather station data. An exception to this method is applied in the "low desert" regions of Arizona, where a regionally calibrated Blaney-Criddle formula is used to estimate

crop consumptive use. Effective precipitation is subtracted from the consumptive-use estimates to generate net irrigation requirement (NIR) values. To account for the effect of water shortage on consumptive use, Reclamation stops calculating NIR in the summer when declining flows at nearby "indicator streamgages" reach minimum threshold levels. Associated incidental use (for example, evaporation and phreatophytic losses along canals) is then calculated as a percentage of the calculated NIR and added to the total agricultural consumptive use. In the Colorado River Basin, the USGS reports IWR (similar in practice to Reclamation's NIR) for irrigated cropland and irrigated golf courses. Acreages of these land cover classes are derived from field verified and aerial photography mapping efforts (Arizona), provided by the Golf Course Superintendent Association of America, downloaded from the Colorado Decision Support System (Colorado) (http://cdss.state.co.us/Pages/CDSSHome.aspx), or extracted from existing geospatial datasets (Buto and others, 2014). The IWR is calculated as modified Blaney-Criddle ET values minus effective precipitation, which assumes a full water supply and healthy crop and soil conditions. Because of the large range of elevations in the upper part of the basin, the USGS occasionally employs the elevation adjustment to the modified Blaney-Criddle results prior to subtraction of effective precipitation. The elevation adjustment increases crop IWR estimates by 10 percent for every 1,000 meters of elevation. The USGS-calculated IWR values do not include estimates of incidental uses (for example, evaporation and phreatophytic losses along canals) because the USGS does not consider these a crop-water need.

Table 7 compares consumptive water-use data reported by Reclamation and the USGS for seven HUC-8s along the Colorado, Uncompahgre, and Gunnison Rivers on the Western Slope of Colorado. These HUC-8s cover a wide range of elevations, with the three highest elevation HUC-8s containing only forage crops (pasture with some alfalfa). Crop diversity increases somewhat at the lower elevation HUC-8s, with up to 27 percent of the irrigated lands in corn, beans, small grains, and orchards/vineyards (NASS, https://www.agcensus.usda.gov/).

In table 7, the two "Reported water-use volumes" columns contain the irrigation consumptive water-use values reported by Reclamation in its CUL Reports and by the USGS in its "Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010" report. Differences in water-use volumes are due to the different definitions for this category of water-use, different estimates of irrigated acreage, and differences in the crop ET models employed (elevation adjustment) by the two agencies and the weather datasets that the agencies select for use in these models. Reclamation's consumptive-use estimates are reduced to account for the effects that precipitation and water shortages have on reducing consumptive use, but also are increased to account for incidental use. Reclamation added 20 percent (105,484 acre-feet) to the total calculated consumptive use values from all seven hydrologic units to account for incidental use and subtracted only about 1 percent (6,031 acre-feet) to account for precipitation and water shortages. The USGS IWR values do not include estimates of incidental use. The USGS IWR values report seasonal crop ET estimates reduced by effective precipitation.

The irrigated cropland acreages reported by the USGS in table 7 were derived from 2010 irrigated crop maps produced by the State of Colorado (http://cdss.state.co.us/Pages/CDSSHome.aspx). Because the 2010 Colorado crop map was not available soon enough to meet Reclamation's reporting schedule, Reclamation estimated 2010 irrigated acreage from county agricultural statistics and Census of Agriculture data in combination with mapped acreages from 2005. Proportionally large errors in

Table 7. Comparison of Bureau of Reclamation (Reclamation) and U.S. Geological Survey (USGS) 2010 agricultural water-use estimates for seven 8-digit hydrologic units (HUC-8s) on Colorado's Western Slope.

[Data provided by David Eckhardt, Bureau of Reclamation, written commun., May, 2017; and Tamara Ivahnenko, U.S. Geological Survey, written commun., May 2017. m, meter; acre-ft, acre-foot; NIR, net irrigation requirement; mod B-C, modified Blaney-Criddle; ft, foot; IWR, irrigation water requirement]

HUC-8	Mean elevation (m)	Reported water use volumes		Irrigated acreage		Irrigation requirement (depth)	
		Reclamation consumptive use (acre-ft)	USGS consumptive use (acre-ft)	Reclamation irrigated acres	USGS irrigated acres	Reclamation NIR from mod B-C (ft)	USGS IWR from mod B-C (ft)
14010001	2,401	76,049	49,096	66,757	53,731	0.951	0.914
14010002	2,480	20,761	7,169	16,904	7,637	1.020	0.939
14010003	2,118	17,529	6,463	7,715	6,820	1.950	0.948
14010005	1,672	187,116	233,998	120,853	108,302	1.415	2.161
14020004	1,855	73,125	49,085	35,700	32,369	1.590	1.516
14020005	1,691	112,878	78,208	50,097	45,824	1.822	1.707
14020006	1,837	138,606	115,095	79,133	77,391	1.412	1.487
All	1,861	626,063	539,113	377,159	332,074	1.396	1.623

Reclamation acreage estimates can occasionally occur in high elevation areas (as shown in table 7 for HUC-8 14010002) if agricultural statistics show large differences in crop acreage from one year to the next. Such variations can result from fluctuations in nonirrigated cropland acreages or changes in forage crop classification conventions from year to year.

Data in the "Irrigation Requirement" columns standardize the water-use estimates generated by both methods to IWR, which is the reported measurement from the USGS modified Blaney-Criddle analyses. Reclamation's NIR volume is calculated by subtracting incidental use from its consumptive use, then adding any calculated shortage. For 2010, shortage was minor (0–3 percent) for all seven HUC-8s reported in table 7. The "Irrigation Requirement" values from both models are then converted from volume (acre-foot) to depth (foot) by dividing acre-foot volumes by the number of irrigated acres. The resulting values allow for a comparison of model results that are similar in meaning, and for which the effect of different irrigated acreage estimates has been removed.

The Reclamation and USGS irrigation requirement depth estimates generated using the modified Blaney-Criddle approach are generally similar, but outliers such as the HUC-8s 14010003 and 14010005 occur when the weather data driving the models differ substantially. In the case of HUC-8 14010003, Reclamation replaced missing weather data from the primary weather station used to characterize weather conditions with default weather data that were substantially warmer and drier than historical averages. Expected shifts in weather data associated with elevation (established by other weather stations) were also applied to the default weather data used in the Blaney-Criddle calculations. Reclamation is working to improve its protocol for dealing with missing weather data. For HUC-8 14010005, both the Reclamation and USGS weather datasets contain good data, but the weather stations selected by the USGS were chosen to optimize characterization of lower elevation lands along the Colorado River, whereas Reclamation included a higher elevation station to characterize mean weather conditions of all agricultural lands in the hydrologic unit.

The final method comparison worth mentioning is reservoir evaporation. Reclamation estimates evaporation from major reservoirs in the Upper and Lower Colorado River

Basins, as well as evaporation from stock ponds. The methods used are the annual FWS evaporation rates documented in National Oceanic and Atmospheric Administration Technical Report NWS 33 and, for the large mainstem reservoirs, monthly evaporation rates are based on past pan-evaporation studies adjusted based on limited mass-transfer based measurements. Currently, the USGS does not estimate evaporation loss from either large reservoirs or from stock ponds.

In summary, the methods comparison highlights the fact that Reclamation and the USGS have established different approaches to the characterization of water-use information, whether that characterization deals with water withdrawals or consumptive use. These different approaches are grounded in the regulatory reporting requirements imposed on each agency, the availability of consistent water-use information at national versus regional scales, and the different missions and constituencies served by each agency's programs. Much of the methodological differences originate from a programmatic need to understand different aspects of water use (for example, the requirement for Reclamation to report mainstem reservoir evaporative losses and the requirement for the USGS to report golf course irrigation consumptive use). The analysis in this report identified few areas of duplication of effort because the agencies often use data produced by the other agency where that information is appropriate and available. One notable area of exception is the estimation of consumptive use associated with irrigated croplands. The two agencies are using similar methods but different supplemental datasets to estimate consumptive use, which results in different numbers. Considering the importance of this sector of water use, the users of this information are fortunate that the agencies are testing and comparing the methods. This comparison provides insights into the sensitivity of the choice of input datasets. Users of the information can use the knowledge gained through the comparison of these methods to inform the decisions they make concerning water use.

Opportunities for Future Coordination

In the previous sections of this report, we have provided an overview of the legislation that drives the water-use programs for both the USGS and Reclamation. Also described in this report are the four primary report products that provide water-use information for the Colorado River Basin (two from USGS and two from Reclamation) and a detailed discussion that compares and contrasts the terminology and methods used for collecting, compiling, analyzing, and reporting each agency's water-use information.

The comparison shows that the programs of the two agencies serve different mission objectives, cover different geographic scopes (national versus single basin), have somewhat different stakeholders and user communities, and collect and report different types of data. Within the Lower Basin, Reclamation's water accounting program is specifically designed to administer the water rights and water delivery requirements defined for the Lower Colorado River mainstem. Reclamation's CUL Report meets different legislative reporting requirements and provides critical data in support of basin-wide long-term planning studies within the entire Colorado River Basin. The USGS NWUIP reports water withdrawals and deliveries across the entire United States to document the distribution and volume of water required to meet the needs of specific categories of use. The USGS report "Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010" (Maupin and others, 2018) summarizes water withdrawals, deliveries, municipal return flows, and selected consumptive uses at the hydrologic watershed level for the entire basin.

Within the Colorado River Basin, two important differences exist between the water-use programs of the two agencies. Reclamation collects and reports information with a focus on the consumptive use of water. Water transferred outside of the hydrologic basin is treated as a 100 percent consumptive use of Colorado River water. The USGS focuses primarily on water withdrawals, but also includes consumptive-use estimates for select categories of water use. For the USGS, water originating from an interbasin transfer is aggregated under the appropriate category of use in the part of the receiving basin where it is applied to that use; no records link the use of this water back to the diversion point in the exporting basin. This has caused some confusion when users of the data have tried to compare USGS national water-use data with Reclamation Colorado River data. In the USGS water-use report for the Colorado River Basin ("Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010"), transfers of water out of the Basin are acknowledged and included in a table showing total water use. In this respect, interbasin transfers are included in the USGS water-use summary for the Colorado River Basin.

The USGS also currently provides a 1-year snapshot of water withdrawal as average daily use (in million gallons per day), compiled at 5-year intervals. Reclamation compiles annual summaries of water use (in acre-foot per year), and the reporting period varies in different parts of the Colorado River Basin (again driven by legal mandates). Even with these key differences, the indepth comparison of the two agencies' programs provided by this report shows that the agencies currently share information and identifies additional opportunities for collaboration, sharing of information, and increasing efficiency.

Current sharing of data is exemplified in the numerous USGS surface-water gaging stations that supply Reclamation near-real-time information on streamflow and diversion rates through the USGS National Water Information System (https://waterdata.usgs.gov/nwis). These data are critical for managing the river, accounting for water use, and planning future releases. The USGS also is conducting a well inventory of the Colorado River floodplain and tributary aquifers within the Lower Basin (https://az.water.usgs.gov/projects/LCRS/). The collected data will assist Reclamation in accounting for groundwater use in this area. In conjunction with this well inventory effort, the USGS is working with Reclamation to develop a process for including these data in existing accounting methodologies. In addition, the mineral resource consumptive use data included in the CUL Report are based on published data from the USGS water-use reports. Reclamation and the USGS also have begun to work collaboratively to improve estimates of municipal and industrial uses.

The USGS utilizes Reclamation data to summarize water-use and power data related to hydroelectric generation. The USGS hydropower water-use numbers are provided directly from plant operators and reflect the volume of water passing through the facilities' turbines. In addition, records of water diverted by major Reclamation facilities are used by the USGS to quantify withdrawals. There is substantial collaboration and exchange of information between the USGS and Reclamation through the Colorado River Basin Salinity Control Forum (http://coloradoriversalinity.org/). Irrigated agricultural water use has a significant impact on salinity loading to streams in the basin. Reclamation develops salinity loading estimates and provides these to the USGS, and the USGS compares the estimates to instream measurements and load models to evaluate the trends in salinity and the effectiveness of mitigation efforts. The USGS and Reclamation also coordinate closely in developing recommendations for high-flow experiments (HFEs) through the Grand Canyon (https://www.usbr.gov/uc/rm/gcdHFE/index.html). The USGS monitors real-time sediment flux in the Paria and Colorado Rivers below Glen Canyon Dam and works iteratively with Reclamation technical staff on sediment transport models. The models are used to develop recommendations

for Reclamation and Interior on the optimal timing, peak flow, and duration of HFEs. Potential effects on other resources are also identified. HFEs are scheduled in either spring or fall when sufficient sediment has accumulated in the river to promote sand bar aggradation and beach building. HFEs have an impact on power generation and the timing and volume of water deliveries from the Upper Basin to Lake Mead and must be factored into the annual accounting under existing compact agreements. Stakeholders with the Glen Canyon Dam Adaptive Management Program (https://www.usbr.gov/uc/rm/amp/background.html) are also kept informed of resource conditions and the characteristics of potential HFEs throughout the decision-making process.

Prior to 1995, the USGS had a long history of compiling and distributing information on consumptive water use. Going forward, the USGS has plans to increase the amount of consumptive water-use information that it compiles and delivers. Recent examples include the USGS's revised methodology for estimating consumptive water use by thermoelectric powerplants and irrigated agriculture. For example, the USGS has developed a heat-energy balance model that computes thermoelectric consumptive use at the plant level using cooling system characteristics, energy production, and fuel consumption (Diehl and others, 2013). Reclamation has relied on historical averages when powerplant water-use data provided by the operator are not available. Obtaining data from powerplant operators is becoming more difficult, so Reclamation could use the USGS heat-energy balance model to improve its estimate of powerplant consumptive use.

Reclamation may also benefit from advances the USGS has made in estimation of ET from irrigated lands, the largest consumptive use in the Colorado River Basin. The USGS has developed the Operational Simplified Surface-Energy Balance (SSEBop) model that applies a simplified energy balance algorithm to satellite data to compute ET from soil and vegetation. The SSEBop model is the USGS effort to derive irrigation consumptive water use using estimates of actual ET (ETa) computed from satellite thermal-band data (Senay and others, 2013). The ETa data are produced for the contiguous United States monthly or seasonally, depending on the satellite data used. For the USGS report "Estimates of Water Use and Trends in the Colorado River Basin, Southwestern United States, 1985–2010" (Maupin and others, 2018), monthly 2010 data were compiled using Landsat-scale (30 meter) ETa data from SSEBop (Singh and others, 2014) and annual data were summarized from the monthly data. The basinwide gridded product depicts ETa across the landscape, regardless of whether lands are irrigated (croplands/golf courses/parks, and so on) or not

(rangeland/riparian/forested). These ETa values are estimates of total annual actual ET from the surface without regard to water source, and do not include estimates of incidental use. Using the landscape ETa product, digital datasets from the NASS Cropland Data Layer (USDA, NASS, 2014b) are used as a reference to identify the irrigated lands for which ETa estimates are summarized. In some areas, other sources of land-cover distribution are evaluated and incorporated into this process to supplement and substantiate the irrigated croplands identified by the Cropland Data Layer (Colorado Decision Support System, Colorado) (http://cdss.state.co.us/Pages/CDSSHome.aspx) and field verified or aerial photography mapping efforts (Arizona) (Buto and others, 2014). The ETa data, originally expressed as depth of water (millimeters/year), are converted to a volume (thousand acre-feet). This method was found to be accurate and applicable for irrigation consumptive use in the arid west (Maupin and others, 2012). The USGS, Reclamation, and the Colorado River Basin States, are collaborating in multiple efforts to compare and evaluate various energy balance remote sensing methods, including SSEBop, which estimate irrigated agricultural consumption. Reclamation will evaluate the impacts of adopting the methods which best estimate agricultural consumptive use in the Colorado River Basin.

Reclamation and the USGS are actively exploring methods to improve the estimation of water use in the municipal and industrial sector. The USGS has developed methods to better quantify self-supplied industrial withdrawals by sector, per capita water withdrawals, and consumptive use coefficients for public supply and rural domestic populations. Reclamation derives per capita water-use coefficients from public supply consumptive use and population data that were reported by the USGS in 1995. Both agencies agree that these coefficients, and possibly the methodology used to calculate municipal and industrial use, need to be updated.

Regarding the use of differing terminology, it is clear that some of the terms used by the USGS and Reclamation are dictated by the legislative language that drives the individual agency programs. The analysis and comparison of terms contained in this report have helped identify terminology where conflicting terminology exist. Although a few of these conflicting terms are embedded in the respective programs due to legal mandates or programmatic history, this comparison effort has illuminated these conflicting definitions and highlights the need for each agency to clearly define the meaning and application of specific data types at each use so that readers or users of the data know what the numbers represent and how they may be used or compared. Opportunities also exist to be vigilant and consistent in the use of common terms and definitions so as to avoid confusion among the user community.

Summary and Way Forward

As might be expected, both the U.S. Geological Survey (USGS) and Bureau of Reclamation (Reclamation) are constantly looking to improve the techniques and methods they use for estimating water use under a number of the reported categories. It will be important going forward for these agencies to coordinate these method-improvement efforts to avoid duplication and identify areas where unified methodologies will provide the best available data to meet the needs of the agencies and their stakeholders.

The USGS and Reclamation are working together to compare and validate the irrigation consumptive use values generated using the Operational Simplified Surface-Energy Balance (SSEBop) remote-sensing technology. The irrigation requirement values generated from the SSEBop actual evapotranspiration estimates are consistently smaller than those generated using the modified Blaney-Criddle method. A number of factors are likely driving these differences (for example, the Blaney-Criddle assumption that a field is completely and evenly watered) and the USGS is participating in "blind" comparisons in the Colorado River Basin including calibration against a ground-based network of eddy covariance towers measuring evapotranspiration currently being installed by Reclamation. It is hoped that remote sensing techniques will lead to a regionally consistent, reliable, accurate, and timely means to determine ET and consumptive water use in irrigated croplands.

As the USGS moves back toward hydrologic unit code-based reporting (and site-specific compilations) of water-use information, it would benefit both agencies to work toward a common framework on the temporal and spatial scales of data compilation and reporting. A common framework would yield more consistent and comparable data and facilitate data sharing between all user communities. Moving toward a common temporal reporting schedule with all water-use data providers would reduce the overall effort for water-use data compilation and constrain the errors inherent in old or out-of-sync data sources. The ability of the agencies to accomplish this common framework is, in part, dependent on the availability of monetary resources.

Additionally, a coordinated effort to improve mapping of the distribution of irrigated agricultural land, thereby allowing improved estimates of agricultural consumptive use, would serve both agencies, stakeholders, and the users of water-use information. Mapping the points of diversion for irrigation, as well as measuring return flows from irrigated lands, are needed to tighten up the site-specific tracking of water use and help balance the water budget at various scales.

Although both the USGS and Reclamation meet their mission responsibilities and serve their user communities in different ways, occasional review and comparison of Federal programs are prudent to identify opportunities for coordination and efficiency and to adapt current efforts to match evolving technology and user needs. This report is a valuable contribution to that end. An additional benefit derived from this comparison effort is the formation of a joint USGS/Reclamation water-use team that will continue to work collaboratively

to expand the opportunities for coordinating and improving the timeliness, accuracy, and consistency of water-use information, not just in the Colorado River Basin but across the western United States where both agencies are active. This continued collaboration will benefit the user communities of both agencies and the Nation as a whole.

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Glossary of Terms Used in this Report

The Glossary presents a full list of the terms used in this report and their definitions. The symbol U/R indicates that both the U.S. Geological Survey (USGS) and the Bureau of Reclamation (Reclamation) use the term, U indicates that the term is only used by the USGS, and R indicates that the term is used only by Reclamation.

Basin transfers Diversion from the Colorado River System to areas outside or within the drainage area. These diversions are reported as exports regardless of the type of use. The "Consumptive Uses and Losses Report" divides exports into two subcategories: (1) outside system (interbasin) and (2) within system (intrabasin). The outside system includes the water that is removed from the Colorado River System; the within-system subcategory includes water that is moved between reporting areas but does not leave the Colorado River System. The within-system total will always be zero because an export from one reporting area is an import to another. The actual consumptive use of within-system water in the Exports category is included in other categories such as Irrigated Agriculture. (*See* **Transbasin diversions**). **(R)**

The human-induced movement of surface water from one hydrologic unit to another, other than the natural downstream surface-water drainage in a stream network. Hydrologic units are defined under the Watershed Boundary Dataset (WBD) (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/watersheds/dataset/?cid=nrcs143_021616). Depending on scale (for example, 2-digit versus 8-digit hydrologic unit codes [HUCs]), basin transfers could be designated as "interbasin" (outside of) or "intrabasin" (within) with respect to the designated hydrologic-unit scale. **(U)**

Beneficial consumptive use (R) The consumption of water brought about by human endeavors including 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.

Beneficial use (U) A legal term used to denote the authority or right to utilize real property, including water, in any lawful manner to gain a profit, advantage, or enjoyment from it. In a nonlegal sense, it is the use of water to benefit people or nature and therefore satisfies some or all of the needs for a particular type of use, such as irrigation.

Colorado River Basin Defined in the Colorado River Compact of 1922 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. **(R)**

The region encompassed by all natural surface-water hydrologic drainage areas that fall within HUCs that begin with 14 or 15 as defined in the WBD. (*See* **Hydrologic unit**) The WBD is described in the following publication: U.S. Geological Survey and U.S. Department of Agriculture, Natural Resources Conservation Service, 2013, Federal Standards and Procedures for the National Watershed Boundary Dataset (WBD) (4 ed.): U.S. Geological Survey Techniques and Methods 11–A3, 63 p., https://pubs.usgs.gov/tm/tm11a3/. **(U)**

Colorado River Basin tributaries All rivers or streams that are located in hydrologic basins that naturally drain into the Colorado River. These areas entail all drainages that have HUCs that begin with 14 or 15 in the first 2-digit numbering scheme. **(U)**

Reclamation excludes the mainstem below Lee Ferry from the above definition. **(R)**

Colorado River System (R) Defined in the Colorado River Compact of 1922 as that portion of the Colorado River and its tributaries within the United States of America.

Consumptive use Water that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise not available for immediate use. In terminology used by the USGS, interbasin transfers are not included. **(U)**

A depletion of surface water or groundwater due to human-caused activity, including interbasin transfers. For agriculture, consumptive use is the sum of net irrigation requirement plus incidental use. **(R)**

As defined by the U.S. Supreme Court in *Arizona v. California*, 547 U.S. 150 (2006) and used in the "Colorado River Accounting and Water Use Report: Arizona, California and Nevada" report—Diversions from the stream less such return flow thereto as is available for consumptive use in the United States or in satisfaction of the Mexican Treaty obligation. **(R)**

Conveyance loss (U) Conveyance loss is defined by the USGS as water that is lost in transit from a pipe, canal, conduit, or ditch by leakage or evaporation. Generally, the water is not available for further use; however, leakage from an irrigation ditch, for example, may percolate to a groundwater source and be available for further use. (*See* **Incidental use**)

Cutoff date (R) The date at which a certain flow occurs. (*See* **Cutoff flow**)

Cutoff flow (R) A level of flow which is used to determine the end of irrigation. It is assumed that when the water flow drops below this level, that certain portions of land (*See* **Shortage lands**) will no longer be irrigated due to diversion facilities or junior water rights.

Depletion (U) The act of using more water than is available or naturally sustainable, either from surface water or groundwater sources. Some western States define depletion as water that is sent elsewhere (out of the State, to a different watershed, and so on) to meet demands that are not met by available water resources. (*See* **Beneficial consumptive use**)

Diversion (U/R) The act of removing water from a surface-water body or groundwater resource to be used elsewhere. It entails physically removing or redirecting water from a surface-water body, such as a canal diversion from a reservoir or river for purposes of irrigation, or a well that pumps water from the ground to be delivered to customers elsewhere.

Effective precipitation (R) Precipitation occurring during the growing season that is available to meet evapotranspiration (ET) requirements of crops. It does not include precipitation lost through deep percolation below the root zone or through surface runoff.

Evapotranspiration Also called ET, is the sum of the amount of water lost to the atmosphere from evaporation and transpiration from soil surfaces and plant leaves. Included in ET is water lost from the ground surface, evaporation from the capillary fringe of the groundwater table, transpiration of groundwater by plants whose roots tap the capillary fringe of the groundwater table, and evaporation from the plant leaves. **(U)**

The amount of water used by vegetative growth in transpiration and building of plant tissue, together with evaporation from soil and plant surfaces in a specified time period. **(R)**

Free water surface evaporation (R) Commonly estimated by multiplying the observed pan evaporation by a coefficient.

Fullness factor (R) A coefficient used to adjust a maximum reservoir surface area to an average annual reservoir surface area.

Groundwater (U/R) Water that lies beneath the surface of the ground in pores and crevices in rock and soil. Groundwater is derived from water that flows or seeps downward and saturates soil and rock, and is the supply to springs and wells.

Hydrologic basin The land area that drains water to a stream, river, or lake. It is a land feature that can be identified by tracing a line along the highest elevations between two areas on a map, often a ridge. Also referred to as a "watershed" or "drainage basin." There are varying scales of hydrologic basins and they are depicted in maps that illustrate the boundaries and the numerical codes for the areas, referred to as hydrologic units. **(U)**

See **Colorado River System (R)**

Hydrologic unit (U/R) An area subdivision established by the United States Water Resources Council (Council established in 1962, 42 U.S. Code, Chapter 19B, Subchapter I, 1962a) providing a hierarchical classification of hydrologic drainage basins of successively smaller and smaller size, with assigned identification numbers that are called HUCs. The HUCs are based on the hierarchical nesting of 2 digits identifying the drainage basins of varying scale. The four basic classifications for the areas in decreasing scale are: regions, subregions, accounting units, and cataloging units. Each HUC consists of 2- to 8-digits based on the four levels of classifications in the hydrologic unit system. The first level of classification (regions)

uses the first 2 digits of the HUC, and identifies 21 water-resource regions. The second level of classification entails using the next 2 digits making a 4-digit number and identifies the 222 subregions in the United States. The levels continue and build on the hierarchical system and identify increasingly smaller hydrologic basins (Seaber and others, 1987).

Today, with the use of geographic information systems technology, a nationally consistent geospatial dataset known as the WBD is available. The WBD has further subdivided the HUCs to provide 10-digit and 12-digit HUCs that identify even smaller drainage areas. The WBD is available and maintained online at https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/water/watersheds/dataset/.

Incidental use (R) Consumptive use that can be attributed to meeting the net irrigation requirement. These losses include phreatophyte growth in and along canals and laterals, and evaporation from the canals and laterals.

Instream use versus offstream use (U) Instream use is a water use that occurs in place without being withdrawn or diverted. For example, hydroelectric power generation or navigation are beneficial uses of water that occur in the channel. Other instream uses include water used for water-quality improvement, fish propagation, or recreation. Sometimes called in-channel use. Offstream use is a water use that occurs after water is diverted or withdrawn from the source, for purposes such as public supply, industrial, irrigation, livestock, thermoelectric power generation, and other uses. Sometimes called off-channel use.

Interbasin transfers Interbasin transfer is a term that is used to indicate there is an altered hydrologic regime. It refers to the transport of water out of the natural hydrologic flow regime. For this report, interbasin transfers are those quantities of water that are artificially moved from one hydrologic basin to another through pipes, tunnels, canals, or pumps that are constructed, maintained, and managed for the purposes of supplying water to meet demand in a hydrologic basin outside of the one from which the water originates. The quantities and timing of the movement of water through the artificial channels are highly regulated under compacts, contracts, and laws. **(U)**

See **Basin transfers (R)**

Irrigation water requirement (U) The quantity of water that is necessary to supplement natural precipitation and soil moisture for healthy crop growth. Net irrigation water requirement is that amount of water needed to meet plant needs based on climate, soils, and cropping pattern data. Gross irrigation water requirement is the net irrigation water requirement plus that amount of water that is lost in transit while getting water to the crops; information about irrigation system efficiency and conveyance losses are used to determine gross irrigation water requirements. (*See* **Net irrigation requirement**)

Law of the River (R) A term that collectively refers to the numerous compacts, Federal laws, court decisions and decrees, contracts, and regulatory guidelines that are used to manage and oversee operation of the Colorado River. The documents stipulate how water is apportioned, regulated, managed and used among the seven basin States and Mexico.

Lower Colorado River Basin Watersheds of hydrologic basins that are defined as downstream of Lee Ferry. Lee Ferry, located in Arizona, is a point on the mainstem 1 mile below the mouth of the Paria River. The Colorado River Compact of 1922 divided the Colorado River Basin into two subbasins, the Upper Basin and the Lower Basin, with Lee Ferry as the division point on the river. For purposes of water-use reporting, the Lower Basin has been further subdivided into mainstem and tributary areas that are defined individually. **(R)**

The region downstream of the confluence of the Colorado and Paria Rivers encompassed by all natural surface-water hydrologic drainage areas that fall within HUCs that begin with 15, as defined in the WBD. **(U)**

Lower Colorado River mainstem (R) Also termed the "Lower Colorado River mainstream." The main channel and those geographic areas in close proximity to the main channel of the Colorado River in the Lower Colorado River Basin, located below Lee Ferry. Lee Ferry, located in Arizona, is a point on the mainstem 1 mile below the mouth of the Paria River. Within the Lower Basin the term "mainstream," as defined by the Supreme Court in *Arizona v. California*, 547 U.S. 150 (2006), is often used interchangeably with the more commonly used term "mainstem."

Lower Colorado River Tributaries All rivers or streams that are located in hydrologic basins that naturally drain into the Colorado River below Lees Ferry (USGS gage site located immediately above the mouth of the Paria River). These areas are identified by HUCs that begin with 15 in the first 2-digit number scheme. **(U)**

All rivers or streams that are located in hydrologic basins that naturally drain into the Colorado River below Lee Ferry excluding the geographic areas included in the Lower Colorado River mainstem. Lee Ferry, located in Arizona, is a point on the mainstem 1 mile below the mouth of the Paria River. Note Lee Ferry and Lees Ferry are not the same location. **(R)**

Natural flow (R) Calculated as gaged flow corrected for the effects of upstream reservoirs and depletions.

Net irrigation requirement (R) The quantity of water, exclusive of effective growing season precipitation, winter precipitation stored in the root zone, or groundwater that is required to be applied by irrigation to meet the ET needs of the crop. It also may include water requirements for germination, frost protection, prevention of wind erosion, and plant cooling. Crop consumptive use is that amount of water needed to meet plant needs based on climate, soils, and cropping pattern data. Irrigation consumptive use is defined as the net irrigation requirement plus incidental uses. (*See* **Irrigation water requirement**)

Non-consumptive use (U) A term used to refer to water that is used without diminishing the available supply. It includes water that is withdrawn for use that is not consumed or lost. For example, hydroelectric power generation is considered by USGS to be a non-consumptive use. However, no typical non-consumptive use of water is entirely non-consumptive because there are losses, for example, the evaporation associated with maintaining a reservoir at a specified elevation to support hydroelectric power generation.

Point of diversion (U) The point of diversion is that point on the surface of the earth where water is diverted from a surface or groundwater source for an intended use. A main canal headgate, an irrigation diversion on a river, or a well is a point of diversion.

Point of use (U) The point of use is the location where the water is applied for the intended use, such as a crop field or an industrial plant. The point of use may or may not be near the point of diversion.

Return flow Water that reaches a groundwater or surface-water source after release from the point of use or the point of treatment, and thus becomes available for further use. **(U)**

Water diverted from the mainstem of the Colorado River that returns to the mainstem by surface or subsurface means and which is available for use by other water users in the United States or in satisfaction of the Mexican Treaty obligation. **(R)**

Salvage (R) Water that was consumptively used before a reservoir came into existence. This includes water used by natural vegetation or people living on the site.

Shortage lands (R) Irrigated lands that normally do not receive a complete irrigation season of water. This may be because of inadequate diversion and storage facilities or insufficient water being available to meet junior (low priority) water rights.

Transbasin diversion (Exports) (R) *See* **Basin Transfers**

Upper Colorado River Basin The region upstream of the confluence of the Colorado and Paria Rivers encompassed by all natural surface-water hydrologic drainage areas that fall within HUCs that begin with 14, as defined in the WBD. **(U)**

Watersheds of hydrologic basins that are defined as upstream of Lee Ferry. Lee Ferry, located in Arizona, is a point on the mainstem 1 mile below the mouth of the Paria River. The Colorado River Compact of 1922 divided the Colorado River Basin into two subbasins, the Upper Basin and the Lower Basin, with Lee Ferry as the division point on the river. **(R)**

Water loss (U/R) Water that is unavailable for immediate use due to reservoir or channel evaporation, ET from phreatophyte growth along channels, or operational inefficiencies. (*See also* **Consumptive use**, **Conveyance loss**, **Evapotranspiration**, and **Incidental use**)

Water use In a restrictive sense, the term means water that is withdrawn for a specific purpose, such as crop irrigation. **(U)**

More broadly, "water use" pertains to the interaction and influence that humans have on the hydrologic cycle, and includes elements such as diversion or withdrawals, transfers, deliveries, consumption, and return flows throughout the processes of use. **(U/R)**

Water withdrawal (U) Water removed from a groundwater or surface-water source for use.

Water use categories (R) Water use categories as reported in Reclamation's "Consumptive Uses and Losses Report."

Agriculture

Irrigation Water used in association with irrigated agricultural lands where either surface or groundwater is supplied. Includes incidental use of water associated with irrigation.

Livestock The daily amount of water consumed by animals. Incidental uses and waste are not taken into account.

Stock Pond Evaporation Water that is evaporated from the stock pond.

Export (Basin Transfers)

Interbasin (Outside System) Water that is removed from the Colorado River System (the hydrologic basin).

Intrabasin (Within System) Water that is moved between reporting areas but does not leave the Colorado River System. The actual consumptive use of within-system water in the Exports category is included in other categories such as Agriculture or Municipal and Industrial.

Reservoir Evaporation

Water that is evaporated from all human-made water bodies except stock ponds and mainstem reservoirs. Includes accounting for precipitation and salvage.

Mainstem/Major Reservoir Evaporation A subset of reservoirs for which reservoir evaporation loss is charged to either the Upper or Lower Basin but not to individual States. The Upper Basin mainstem reservoirs are Flaming Gorge, Blue Mesa, Morrow Point, and Lake Powell. Lower Basin mainstem reservoirs are Lake Mead, Lake Mohave, Lake Havasu, Senator Wash, and "other."

Minor Reservoir Evaporation The "other" minor reservoirs include the reservoirs behind the Headgate Rock, Palo Verde, Imperial, Laguna, and Morelos diversion dams.

Municipal and Industrial

Mineral Resources Water used for extraction of minerals.

Other Uses Water used for urban, rural, or other industrial uses not included in mineral resource and thermal electric use.

Thermal Electric Power Water used in the powerplant and to transport material to the plant (such as in a coal slurry pipeline).

Water-Use categories (U)

Aquaculture Water used in association with the raising of aquatic organisms such as finfish and shellfish for food, restorations, or conservation purposes. Aquaculture production includes controlled feeding, sanitation, and harvesting procedures in ponds, flow-through raceways, cages, net pens, or tanks. Water is self-supplied from surface or groundwater sources.

Commercial Water used at a commercial establishment such as a shop, office, hospital, or school. Water may be provided by a self-supplied source or publicly supplied. Typically potable water is used, but nonpotable water may be used for outdoor irrigation at a commercial establishment.

Domestic Water for residential household uses such as drinking, cooking, cleaning, bathing, and sanitary functions. It also includes outdoor residential uses such as lawn and garden irrigation. The water may come from either a self-supplied source (usually a well) or a publicly supplied source such as a municipality or public water purveyor.

Hydroelectric Water Use Water used in the generation of electricity at plants where the turbine generators are driven by falling water.

Industrial Water used for industrial processes such as fabrication, washing, and cooling, as well as water that is incorporated into a product. Water may be self-supplied by a resource onsite, or delivered to the industrial facility from a water supplier.

Irrigation Water that is applied by an irrigation system to support crop and pasture growth, or to maintain vegetation on recreational lands such as parks and golf courses. This category includes water applied for pre-irrigation, frost protection, chemical application, weed control, and various other purposes, as well as that amount of water necessary to meet onsite (field) demand after losses incurred during transport such as conveyance losses.

Livestock Water used in association with livestock operations such as feedlots, dairies, or poultry farms. The category does not include aquatic animal rearing operations. (*See* **Aquaculture**) The water is used for various on-farm purposes such as watering, cooling, cleaning, and sanitation. Water is self-supplied from surface or groundwater sources.

Mining Water used for the extraction of minerals in the form of solids, liquids, or gases, including quarrying, milling, washing, screening, and floatation of mined materials, as well as reinjecting extracted water for secondary oil recovery. Water is self-supplied from surface or groundwater sources.

Public Supply Water withdrawn and treated to established standards by public and private entities and delivered to homes, businesses, or other entities for daily use, as well as to public facilities for public use.

Reservoir Evaporation Water that is evaporated from a reservoir surface.

Thermoelectric Water Use Water used in the process of generating electricity with steam-driven turbine generators at facilities that burn fuels such as natural gas, oil, or nuclear generating facilities. Water is used for cooling and maintenance processes and typically is self-supplied, except where a publicly owned municipality or industry may provide some water.

Wastewater Return Flow Water that is treated and returned to a water body or groundwater source. It may be released from a publicly owned treatment works or an industrial facility that treats the water it uses before releasing it.

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Page 2: Hoover Dam bypass by Bureau of Reclamation.

Page 4: Cattle in irrigated field by Saeid Tadayon, U.S. Geological Survey.

Page 6: Dairy cows by Saeid Tadayon, U.S. Geological Survey.

Page 9: Spinach field by Bureau of Reclamation.

Page 11: Imperial Dam and All American Canal Headworks by Bureau of Reclamation.

Page 14: Irrigation canal by Saeid Tadayon, U.S. Geological Survey.

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Page 23: Upper left, Palo Verde Diversion Dam by Bureau of Reclamation. Lower right, Lake Powell by Bureau of Reclamation.

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Page 28: Agricultural field by Saeid Tadayon, U.S. Geological Survey.

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