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Documentation of Methods and Inventory of Irrigation Data Collected for the 2000 and 2005 U.S. Geological Survey *Estimated Use of Water in the United States,* Comparison of USGS-Compiled Irrigation Data to Other Sources, and Recommendations for Future Compilations

Scientific Investigations Report 2011-5166

U.S. Department of the Interior
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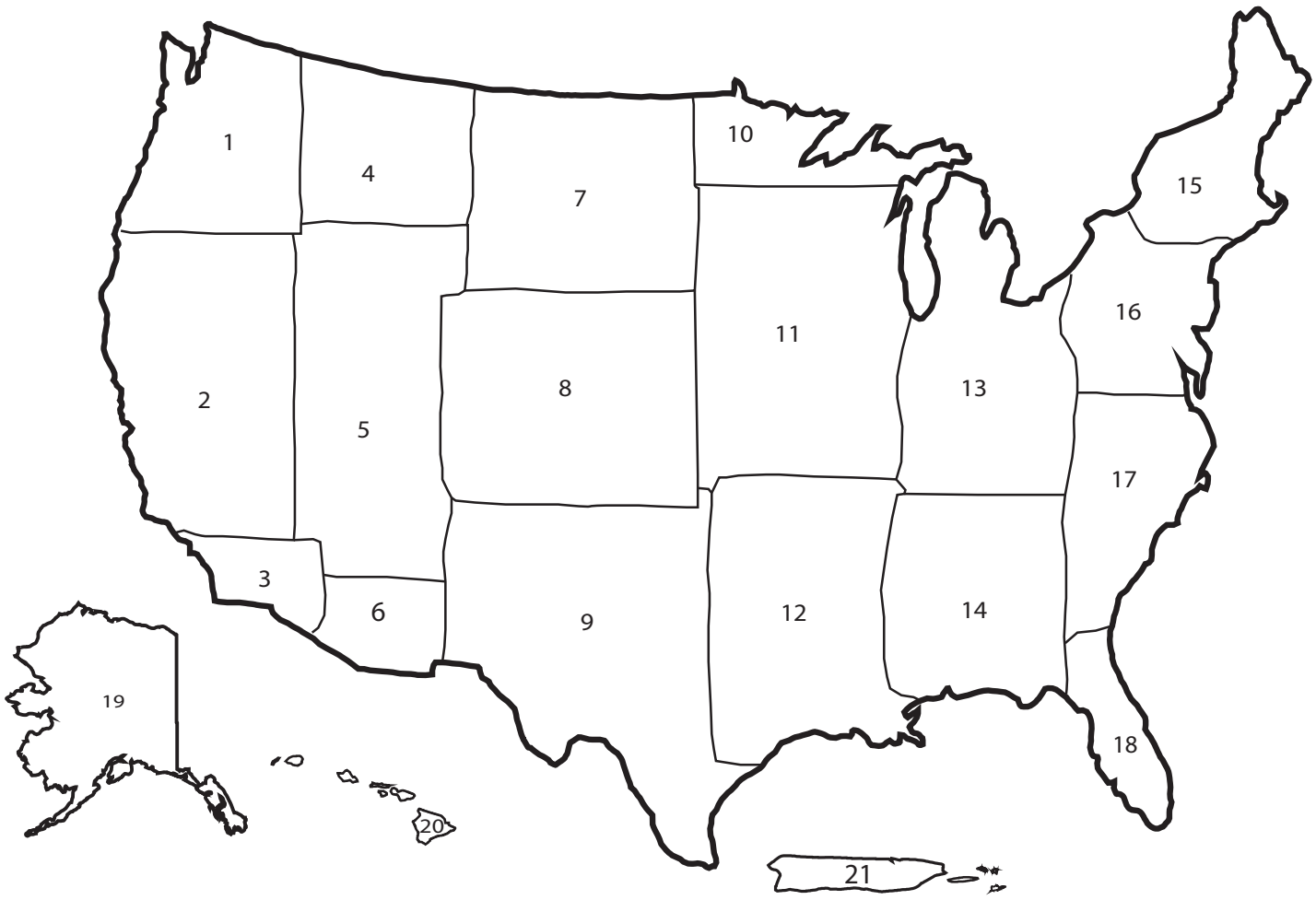

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COVER
Photo collage of agriculture across the continental United States, Alaska, Hawaii, and Puerto Rico.

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KEN SALAZAR, Secretary

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Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	.001562	square mile (mi^2)
	Volume	
gallon (gal)	3.785	liter (L)
acre-foot (acre-ft)	325,851	gallons (gal)
million gallons (Mgal)	3,785	cubic meter (m^3)
million gallons (Mgal)	3.07	acre-feet (acre-ft)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	43,450	cubic feet (ft^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
gallon per day (gal/d)	3.785	liter per day (L/d)
gallon per minute (gal/min)	0.06309	liter per second
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
million gallons per day (Mgal/d)	1.121	thousand acre-feet per year (thousand acre-ft/yr)
million gallons per day (Mgal/d)	1.547	cubic feet per second (ft^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
thousand acre-feet per year (thousand acre-ft/yr)	0.8921	million gallons per day (Mgal/d)

Acronyms and Abbreviations

ADWR	Arizona Department of Water Resources
AWUDS	Aggregate Water Use Data System
CDL	Cropland Data Layer
ET	evapotranspiration
FAO	Food and Agriculture Organization
FSA	Farm Service Agency
FRIS	Farm and Ranch Irrigation Survey
GIS	Geographic Information System
HUC	hydrologic unit code
IIWEM	Indirect Irrigation Withdrawal Estimation Method
NASS	National Agricultural Statistics Service
NWUIP	National Water Use Information Program
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WSC	Water Science Center

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Abstract

Every five years since 1950, the U.S. Geological Survey (USGS) National Water Use Information Program (NWUIP) has compiled water-use information in the United States and published a circular report titled "Estimated use of water in the United States," which includes estimates of water withdrawals by State, sources of water withdrawals (groundwater or surface water), and water-use category (irrigation, public supply, industrial, thermoelectric, and so forth). This report discusses the impact of important considerations when estimating irrigated acreage and irrigation withdrawals, including estimates of conveyance loss, irrigation-system efficiencies, pasture, horticulture, golf courses, and double cropping.

This report also documents the methods and data sources used by the USGS Water Science Centers (WSCs) for estimating irrigated acreage and irrigation withdrawals reported in the 2000 and 2005 USGS 5-year water-use compilations. For the 2005 USGS water-use compilation, the most common sources used by WSCs for obtaining irrigated crop acreage were the 2002 Census of Agriculture, 2003 Farm and Ranch Irrigation Survey (FRIS), National Agricultural Statistics Service (NASS), universities, and local and State agencies. In this report, the authors compare USGS-compiled irrigated acreage to Census of Agriculture- and FRIS- reported irrigated acreage. Nationwide irrigated acreage increased from the 1997 to 2007 Census of Agriculture estimates by about 1 percent and from the 1998 to 2008 FRIS estimates by about 9 percent. Conversely, total irrigated acreage decreased from the 2000 to 2005 USGS water-use compilations by about 2 percent.

An indirect method for estimating irrigation withdrawals is presented and results are compared to the 2005 USGS-reported irrigation withdrawals for selected States. This method is meant to demonstrate a way to check data reported or received from a third party, if metered data are unavailable. Of the 11 States where this method was applied, 8 States had estimated irrigation withdrawals that were within 15 percent of what was reported in the 2005 water-use compilation, and 3 States had estimated irrigation withdrawals that were more than 20 percent of what was reported in 2005. Recommendations for improving estimates of irrigated acreage and irrigation withdrawals also are presented in this report. Conveyance losses and irrigation-system efficiencies should be considered in order to achieve a more accurate representation of irrigation withdrawals. Better documentation of data sources and methods used can help lead to more consistent information in future irrigation water-use compilations. Finally, a summary of data sources and methods used to estimate irrigated acreage and irrigation withdrawals for the 2000 and 2005 compilations for each WSC is presented in appendix 1.

Introduction

The U.S. Geological Survey (USGS) has collected and compiled data on water withdrawals in the United States at 5-year intervals since 1950 as part of the National Water Use Information Program (NWUIP) at *http://water.usgs.gov/watuse/wunwup.html* (MacKichan, 1951, 1957; MacKichan and Kammerer, 1961; Murray, 1968; Murray and Reeves, 1972, 1977; Solley and others, 1983, 1988, 1993, 1998; Hutson and others, 2004; Kenny and others, 2009). Summaries of estimated withdrawals from 1950 to 2005 are available from the USGS circular report series titled "Estimated use of water in the United States." These data are reported by the USGS Water Science Center (WSC) for each individual State, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands to the NWUIP by categories of water use and the source of water (surface water and groundwater). The primary water-use categories are irrigation, public supply, domestic, commercial, industrial, mining, livestock, aquaculture, and thermoelectric-power generation. For the USGS 5-year water-use

compilation, reporting of water-use data by county is required. In some compilation years, WSCs reported water use by more detailed eight-digit hydrologic unit code (HUC) and (or) principal aquifers. The goals of the NWUIP are to document trends in withdrawals and irrigated acreage; to develop a nationwide water-use database; and to provide water-use information to local, State, and Federal agencies as well as universities and other groups for scientific research. Information on trends in water use is necessary in evaluating current (2011) and potential future water needs.

For the 2000 and 2005 USGS water-use compilations, water-use data were reported for the categories of public supply, domestic, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric-power generation. Estimates for the mining, livestock, and aquaculture categories, however, were optional elements for some WSCs in 2000. The largest water withdrawals in the United States were for thermoelectric power and irrigation in 2000 and 2005. For 2000, total thermoelectric power and irrigation withdrawals were about 219 and 153 million acre-ft/yr, respectively (Hutson and others, 2004). For 2005, total thermoelectric power and irrigation withdrawals were about 225 and 144 million acre-ft/yr, respectively (Kenny and others, 2009). For the category of irrigation, WSCs reported irrigation water withdrawals (surface water and groundwater) and irrigated acreage by system type—sprinkler, micro-irrigation, and surface (flood) systems (table 1).

Irrigation water withdrawals can be affected by factors such as crop type, climate, method of irrigation, irrigation-system efficiencies, soil conditions, and availability of water. Nearly all WSCs estimate and report total irrigation withdrawals based on little or no metered data because the majority of irrigation withdrawals are not metered in the United States. WSCs should use the best possible information available on irrigation withdrawals for their study area. Some of the published sources that can be used to develop irrigation estimates are the U.S. Department of Agriculture (USDA) Census of Agriculture (U.S. Department of Agriculture, 2004a) and the Farm and Ranch Irrigation Survey (FRIS; U.S. Department of Agriculture, 2004b). Some WSCs also acquire data from sources such as universities; local, State, and Federal agencies; and others. Without sufficient documentation on methods and sources of data used to develop irrigation water-use estimates, uncertainty may exist when comparing information in the irrigation category of the water-use circulars among States or when understanding the effects of changes in methods or data sources on irrigation water-use trends over time within a State.

Water-withdrawal data at the State and county level are compiled by individual WSCs and stored in the Aggregate Water Use Data System (AWUDS), a USGS database designed specifically to store water-use information for the USGS water-use compilations. The irrigation section of the AWUDS database includes information on water withdrawals by source, consumptive-use and conveyance-loss estimates (optional), irrigated acreage by system type (surface (flood) irrigation, sprinkler irrigation, or micro-irrigation (drip)), and provides information on crop and golf course acreage and withdrawals (if reported separately; table 1). County-level data from AWUDS for all published categories of use for the years 1985, 1990, 1995, 2000, and 2005 may be downloaded at *http://water.usgs.gov/watuse.* State-summary data are available from the USGS circular series titled "Estimated use of water in the United States." Water-use circulars for 1950–2005 are available at *http://water.usgs.gov/watuse/50years.html*.

Purpose and Scope

The purpose of this report is to document the data sources and methods used by each WSC to estimate crop irrigated acreage and irrigation withdrawals, to compare irrigation data reported in the 2005 USGS water-use compilation to data available from other published sources, to make recommendations about available sources of data and methods used to estimate irrigation withdrawals and irrigated acreage, and to recommend guidelines for documenting methods and data sources for future water-use compilations. Recommendations are presented to improve documentation, improve accuracy and consistency of estimates of the number of irrigated acres and amounts of irrigation withdrawals, unify methods of data reporting, and suggest potential useful sources of data that could be used for future USGS water-use compilations. In an effort to better document the methodology and data sources used by individual WSCs to estimate irrigated acreage and irrigation withdrawals in the 2000 and 2005 USGS water-use compilations, information from each WSC was collected and compiled in this report. Details were evaluated for each WSC's reported irrigation information.

Irrigation data are difficult to compare among compilation years, which may be owing to changes in sources for irrigated acreage and changes in methods for estimating irrigation withdrawals. In some cases, documentation provided by the WSCs regarding reported irrigation estimates might not adequately explain the methods and data sources used for that compilation. Lack of documentation makes evaluation and use of the estimates problematic. Some of the issues that were addressed during the inventory of the documentation of irrigation data sources and methods follow:

- Is it clear from the provided documentation exactly how each WSC estimated irrigation withdrawals and irrigated acreage?
- Why are the USDA Census of Agriculture (U.S. Department of Agriculture, 2004a and 2009a) and FRIS (U.S. Department of Agriculture, 2004b and 2009b) reports showing increases in the United States' irrigated acreage between 2002 and 2007 (Census of Agriculture), and between 2003 and 2008 (FRIS), while the USGS is showing a decline in irrigated acreage between 2000 and 2005 USGS water-use compilations?
- Were golf course withdrawals included in the reported total irrigation withdrawals in USGS water-use compilation data? If so, can they be

Table 1. Required elements for the irrigation category of the 2005 National Water Use Information Program at the county level.

[Adapted from Hutson, 2007]

Data element	Irrigation	
	Crop	Golf course[1]
Groundwater withdrawals	Required	Required
Surface-water withdrawals	Required	Required
Consumptive use	Optional	Optional
Conveyance loss	Optional	Optional
Acres irrigated—sprinkler (x 1,000)	Required	Required
Acres irrigated—micro-irrigation (x 1,000)	Required	Required
Acres irrigated—surface (x 1,000)	Required	Required
Reclaimed wastewater	Null-values allowed	Null-values allowed

[1] Golf course irrigation is not required to be separated from crop irrigation; if they are separated, they must follow the same reporting as crop irrigation.

separated out based on reported information? Should golf course data be included in irrigation or another category?

- Are irrigated pasture and horticulture acreage included in the USGS water-use compilation? Are they included in the irrigation categories of the Census of Agriculture (U.S. Department of Agriculture, 2004a and 2009a), FRIS (U.S. Department of Agriculture, 2004b and 2009b), or other datasets?
- Where are horticultural crops making a big difference in the USGS water-use compilation irrigated acreage?
- What impact does double cropping (planting more than one crop being grown on a parcel of land in the same year) have on total irrigated acreage in States where double cropping can occur?
- Does every State have a National Agricultural Statistics Service (NASS) office that helps compile data for the Census of Agriculture and FRIS surveys?
- Are there datasets or methods that could assist WSCs? What would they include?

This report presents other available data sources that may be used to estimate irrigated acreage and irrigation withdrawals and also provides a guide to documentation of methods and data sources for future irrigation estimates for USGS water-use compilations. Sources of irrigation information and methods to estimate withdrawals are presented, owing to the limited amount of resources available to WSCs to support development of irrigation estimates for USGS water-use compilations. This may assist WSC personnel in locating appropriate sources of information as well as unifying referenced sources of irrigation data in the USGS water-use compilation. In this report, a guide has been created to help each WSC create clear documentation of methods and datasets used to estimate irrigation withdrawals and irrigated acreage. More consistent use of irrigation data sources and improved documentation of methods and data sources used will strengthen the irrigation data in the USGS water-use compilation and improve confidence in analysis of trends reflected in these data.

Terminology

The terms and units used in this report are similar to those used in USGS water-use circulars; terms are defined in the glossary at the end of this report. Withdrawal estimates represent the total amount of water removed from the water source, regardless of how much of that total is consumptively used. In most cases, some fraction of the total withdrawal will be returned to the same or a different water source after use and is available for other withdrawals.

Annual water-use data are expressed in this report in million gallons per day (Mgal/d) and acre-feet per year (acre-ft/yr). Units of millions or billions of gallons per day do not represent actual daily rates, but rather are used to express total amounts as an average daily rate for 1 year. For example, irrigation water may be applied only during parts of the year and at variable rates; therefore, the actual rate of application at any given time during the growing season is different from the average daily rate based on 365 days in a year.

The water-use data in this report are rounded to two significant figures. All values are rounded independently, so the sums of individual rounded numbers may not equal the totals. Percentage changes discussed in the text are calculated from unrounded data and are expressed as integers.

Sources for Estimating Irrigated Acreage and Irrigation Withdrawals used by USGS Water Science Centers in the United States

This section introduces the most common data sources used by USGS WSCs to estimate irrigated acreage and irrigation withdrawals for the 2000 and 2005 USGS water-use compilations. Details for each State are located in appendix 1.

USGS WSCs are required to report irrigated acreage to the NWUIP every five years ending in "0" and "5." Acreage is reported by irrigation method (surface (flood) irrigation, sprinkler irrigation, or micro-irrigation (drip)) for each county to facilitate summarizing the total irrigated acreage for the State. In order to estimate irrigated acreage for the 2005 USGS water-use compilation, WSCs obtained information from the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a), 2003 FRIS (U.S. Department of Agriculture, 2004b), NASS (U.S. Department of Agriculture, 2005), field verification, various State agencies (for example, Department of Natural Resources, Department of Water Resources), universities, and a combination of these sources.

The Census of Agriculture is published by the USDA every five years, ending in "2" and "7." Questionnaires are sent to farm operators requesting information on land ownership, crop types, whether or not crops are irrigated, and the value of farm-operation sales, among other questions. This questionnaire was sent to the "Census Mail List," compiled from a list of ranchers and farmers from NASS, which was based on information acquired from prior agricultural censuses. An "Area Frame Study" then was conducted by NASS where landowners of selected tracts throughout the United States were interviewed by NASS employees. The results of the Area Frame Study then were compared to the Census Mail List, and a coverage adjustment was developed based on the completeness of received data (U.S. Department of Agriculture, 2004a). This methodology for estimating crop acreage by the USDA began with the 2002 Census of Agriculture report.

The FRIS report is published by the USDA every five years, ending in "3" and "8." The 2003 FRIS gathered irrigated-acreage data by mailing surveys to a sample of landowners across the country. The information received from the surveys was compared with information from other sources, including the 2002 Census of Agriculture. FRIS made similar adjustments to the data as were made by the 2002 Census of Agriculture. The 2003 FRIS reported acreage irrigated by various system types for entire States, but not at the county level (U.S. Department of Agriculture, 2004b).

NASS publishes a reference called "Agricultural Statistics" each year for agricultural data, including acreage by crop type. These data are collected through surveys sent to farm operators and supplemented with information from the Census of Agriculture, FRIS data, and NASS field offices (U.S. Department of Agriculture, 2005). A list of States with annual "Agricultural Statistics" is located in appendix 2, table 2–3.

In addition to using these three main published sources of information on irrigated acreage, some WSCs collect irrigated-acreage estimates directly using field verification. In Arizona, for example, the WSC field-verifies selected groundwater basins for crop type, irrigation-system type, irrigation-system efficiency, and source of irrigation water, in cooperation with the Arizona Department of Water Resources (ADWR). These data are entered into a Geographic Information System (GIS) ESRI ArcGIS™ geodatabase where irrigated acreage is calculated and the information is stored for future use. There are some State agencies that conduct field verification as well. Many of the State agencies do not field-verify crops for the entire State, but often just a few basins or counties, with the locations selected to supplement the prior year's field verification or information from the Census of Agriculture or FRIS. There are agencies in some States that require farmers to permit and report irrigated acres either monthly or annually. Some WSCs have access to similar datasets and use them in the irrigation-withdrawal estimates.

Irrigated golf course acreage is not included in the Census of Agriculture, FRIS, or NASS publications and is an optional element in the USGS water-use compilations. To estimate irrigated acreage associated with golf courses, many of the WSCs first determined the number of holes or yards in golf courses throughout the State and then multiplied this by a factor to convert holes or yards to acres. In some cases, the WSC had a digitized GIS map of the golf courses, which could be used to calculate the acreage for each golf course. Some States had agencies that required permitted golf courses to report irrigated acreage.

Irrigation withdrawals are the most important element to be reported in the irrigation category of the NWUIP. WSCs must report groundwater and surface-water withdrawals, by county, for irrigation purposes. In previous USGS water-use compilations, prior to the 1995 water-use compilation, WSCs also were required to report conveyance loss and consumptive use associated with irrigation. In the 2000 and 2005 USGS water-use compilations, however, these values were no longer required to be estimated and reported, although some WSCs did continue to include them (table 1). The main sources of information used by WSCs to estimate irrigation withdrawals included FRIS-application rates, appropriate State agencies, and metered or power-consumption data, if available.

In many cases for the 2005 USGS water-use compilation, the WSC applied a water-use coefficient to the estimated acreage in order to estimate total irrigation withdrawals. This coefficient is often obtained from sources such as FRIS, scientific-journal articles, outputs from evapotranspiration (ET) models, or by using a State average that has been used in previous reports. Several WSCs used the FRIS estimates of quantity of water and applied them to irrigated acreage, by State and irrigation method. The 2003 FRIS only reports irrigation water applied to a field, and does not estimate the amount of water that was withdrawn from the source, where a

percentage can be lost owing to conveyance loss or irrigation-system inefficiency.

Some WSCs use numerical models to estimate crop water use, and subsequently irrigation withdrawals, once irrigated acreage has been estimated. A few WSCs use a model based on the Blaney-Criddle formula (Blaney and Criddle, 1950) to estimate reference ET. The inputs into the Blaney-Criddle formula include latitude of farm location, total monthly precipitation and average monthly temperature, crop type, and crop planting and harvesting dates. The Blaney-Criddle method produces estimates of the consumptive-water requirement by crop type for each month and for the entire growing season. The consumptive-water requirement estimate from the Blaney-Criddle-based method is combined with other variables such as conveyance losses and irrigation-system efficiencies to estimate total irrigation withdrawals for a growing season.

Reporting requirements for total irrigation withdrawals include estimates of the quantity of water from surface-water and groundwater sources. In States where surface water is measured by Federal agencies, such as the USGS or the U.S. Bureau of Reclamation, or a State agency, the groundwater withdrawals are estimated by subtracting gaged surface-water withdrawals from total irrigation crop needs (assumed to equal irrigation withdrawals). Some States have State agencies with permitting or registration programs that require water users to put meters on their wells and report water used, from a monthly to an annual basis, and these metered groundwater withdrawals can be subtracted from total crop-irrigation needs (withdrawals) to estimate surface-water withdrawals.

For WSCs that include irrigation withdrawals for golf courses in the irrigation totals, surface-water and groundwater sources should be estimated and reported separately for the USGS water-use compilation. The most common method that WSCs used to estimate golf course withdrawals in the 2005 USGS water-use compilation was to apply an irrigation coefficient to the acreage or number of holes in the State. Some golf courses have metered wells that are reported to a State agency. In some cases, WSCs were able to contact golf course superintendents to obtain information about irrigation withdrawals.

Key Considerations for Better Estimation of Irrigation Withdrawals and Irrigated Acreage

There are several key elements necessary for better estimates of irrigation withdrawals and irrigated acreage. Among these are quantifying conveyance losses and the efficiency of the irrigation system being used, including irrigated pasture, horticulture, and golf courses in total irrigated acreage estimates, and determining if double cropping is occurring. Excluding conveyance loss and irrigation-system efficiency may lead to an underestimation of irrigation withdrawals if they are based on crop-irrigation requirements alone. For some States, the exclusion of irrigated pasture, horticulture, golf course acreage, and double cropping from total irrigated acreage may considerably underestimate the actual total irrigated acreage and subsequently affect estimated total irrigation withdrawals. Each of these key elements is discussed in greater detail in the following sections.

Conveyance Loss and Irrigation-Application Efficiency

Conveyance losses (water lost while in transport to irrigation systems) and irrigation-system efficiencies (the fraction of applied water that is not consumed by the crop) are two elements that should be evaluated when estimating irrigation withdrawals. Efficiencies of the application of irrigation are an embedded component of overall irrigation water use, and the estimate of total irrigation withdrawals for all States, regardless of size, may be significantly affected by the inclusion or exclusion of these losses.

When water is diverted from its source and conveyed through pipelines and canals, losses may occur along the way. This loss, known as conveyance loss, may be considerable, particularly when water is conveyed over a long distance. Common sources of conveyance loss can include evaporation, canal overflow, spills owing to operator error, and seepage loss through canals or pipelines (fig. 1). When water is transferred over long distances, all contributing factors of conveyance loss can compound along the way; thus, significant amounts of water can be lost. In an arid environment, conveyance loss also can be increased by evaporation in canals exposed to the elements. As an example of the effect of evaporation on open water in arid environments, minimum and maximum monthly water evaporation of 3.6 in. (February 1998) and 9.9 in. (June 1999), respectively, occurred in Lake Mead (Westenburg and others, 2006). Monthly evaporation rates were higher for the months of May–October in Lake Mead (Westenburg and others, 2006), a time when many States would apply most of their irrigation water. Another source of conveyance loss is vegetation growing along canals (fig. 2). In some areas, irrigation canals can cause riparian corridors where, without the consistent supply of water being provided from the canal, plants with high water demand could not survive. All of these major sources, among others, can contribute to total conveyance loss in an irrigated area.

In areas where site-specific or gaged conveyance-loss data do not exist, the amount of water lost may be estimated using conveyance-loss coefficients that are dependent upon the condition of the conveyance system, the distance the water is being transferred, and potential environmental losses. The inclusion of conveyance losses may significantly increase the estimate of total irrigation withdrawals. In some circumstances, it can double the amount of water applied to a field compared to plant water demand alone, in regions where conveyance losses are high.

Figure 1. Unlined irrigation canal in Yuma County, Arizona. (Photograph by Brandon T. Forbes, U.S. Geological Survey.)

Figure 2. Irrigation canal with riparian vegetation growing along the banks in Yavapai County, Arizona. (Photograph by Saeid Tadayon, U.S. Geological Survey.)

Water withdrawn from sources near fields often does not have as much conveyance loss when compared to water that is transported over long distances. It is not uncommon for groundwater-irrigation wells to be within a relatively close distance to the field that is being irrigated. Irrigation water can be diverted adjacent to the field and can be transported under a pressurized-pipe system or directly into the irrigation system, which tends to have a lower conveyance loss owing to the more efficient transport systems. In areas where the irrigation water is diverted adjacent to the field, conveyance losses may be considered negligible and the majority of losses are considered to be occurring because of the irrigation-system efficiency, not conveyance loss.

Since the 1995 USGS water-use compilation, conveyance losses are no longer required to be reported separately in the AWUDS database; therefore, most States no longer report conveyance loss and most did not document the quantity of water lost in conveyance. It can be difficult to determine which States included conveyance losses in their estimates for total irrigation in the recent USGS water-use compilations because it is not specifically discussed in the documentation for most States. Assuming conveyance losses are negligible statewide likely is an oversimplification, which can lead to an underestimation of total irrigation withdrawals.

Irrigation-system efficiency is determined by dividing the amount of water consumed by crops by the total amount of irrigation water applied to the crops. Irrigation-system type (for example, surface (flood), sprinkler, and micro-irrigation (drip)), system age, system structure (for example, lined or unlined canals and center-pivot or side-roll sprinklers), availability of water, crop type being irrigated, soil type, soil salinity, over-irrigation, and operator error are some of the factors that may reduce irrigation-system efficiency (fig. 3). Additionally, irrigators may intentionally over-irrigate their crops for pre-irrigating, frost protection, weed control, and leaching salts from soils. Climatic conditions that can affect irrigation efficiencies are wind speed, relative humidity, and air temperature (Hutson, 2007). Quantifying the efficiency of an irrigation system is difficult, but published ranges of values by system characteristics are available and may be used to help better refine irrigation-withdrawal estimates.

Once irrigation water has entered the field-level-irrigation system and is applied to a field, the crops may not consume all the irrigation water applied and a portion may be considered lost. When a farmer irrigates a crop, water often is applied until the needs of the crops are satisfied. The type of irrigation system determines the volume of excess water that needs to be applied to the field to supply the entire crop. In many cases, excess water needs to be applied to ensure the crop is getting the amount of water necessary for optimum growth and yield, regardless of irrigation-system type. Some of the excess water may run off the field, some may evaporate, and some may infiltrate below the root zone, all contributing to the total amount of withdrawn irrigation water that is not used by the plant (fig. 4). Howell (2003; table 2) presented ranges of values of irrigation efficiencies by type of system used for irrigation.

Pasture and Horticulture

Pasture can be a large source of irrigated acreage in some States, and the decision to include or exclude irrigated pasture can greatly affect the total estimated irrigated acreage and irrigation withdrawals within a State. Some USGS WSCs, however, do not clearly document whether irrigated pasture is included in estimates of total irrigated acreage. Also, local knowledge and (or) field investigation is needed to determine whether pasture in an area is irrigated. Factors to consider are drought and rainfall in a given irrigation season, because with adequate rainfall, pasture and grazing lands could need less or no irrigation than in a normal or dry year.

An example of how pasture acreage can contribute to total irrigated acreage can be seen when evaluating information from Colorado for 2007. The USDA reports 2,867,957 total irrigated acres with 571,192 irrigated-pasture acres (U.S. Department of Agriculture, 2009a; fig. 5); almost 20 percent of Colorado's total irrigated cropland can be classified as irrigated pasture. Throughout the United States in 2007, more than 5 million acres of pasture were estimated to be irrigated by the Census of Agriculture (U.S. Department of Agriculture, 2009a), making up about 9 percent of the total irrigated land nationally. Depending upon irrigation-application rates and methods used to irrigate, irrigated pasture can generate large water demands nationwide (fig. 6).

Horticulture comprises a smaller, but growing, number of acres nationwide compared to pasture, but can be a very large user of water per acre compared to field crops (fig. 7). The reported total area used for horticultural crops in the United States increased from 351,617 acres in 1998 to 609,473 acres in 2008 (U.S. Department of Agriculture, 2009b). Plants growing in greenhouses need more water than if they were growing outside because of elevated temperatures. In warm and arid regions, alfalfa can use 5 ft of water over the year as compared to some greenhouses that reported using over 10 ft of water per acre (Masters and others, 2010). Since the majority of horticultural operations are located where temperatures are warm—California, Florida, and Texas are the top three producers (fig. 8)—total water demand by these operations can be significant when included in county and State totals.

Greenhouse irrigation-system efficiencies also need to be considered when estimating horticulture contribution to total irrigation withdrawals. Since many greenhouses contain potted plants that are not all within the same container of soil, water can be lost during irrigation within the spaces between plants. Overhead sprinklers are one of the least efficient methods of irrigation found in greenhouses. Sprinkler systems have exhibited efficiencies as low as 9 percent in some cases (Neal, 1992). Irrigation systems that apply water directly to the root zone, such as drip systems and capillary mats are far more efficient than other horticultural-irrigation systems, with efficiencies ranging from 50 to 75 percent (Neal, 1992).

Figure 3. Siphon tubes irrigate a cotton field near Gila Bend, Arizona. (Photograph by Saeid Tadayon, U.S. Geological Survey.)

Figure 4. Tailwater from a sorghum field in Maricopa County, Arizona. (Photograph by Saeid Tadayon, U.S. Geological Survey.)

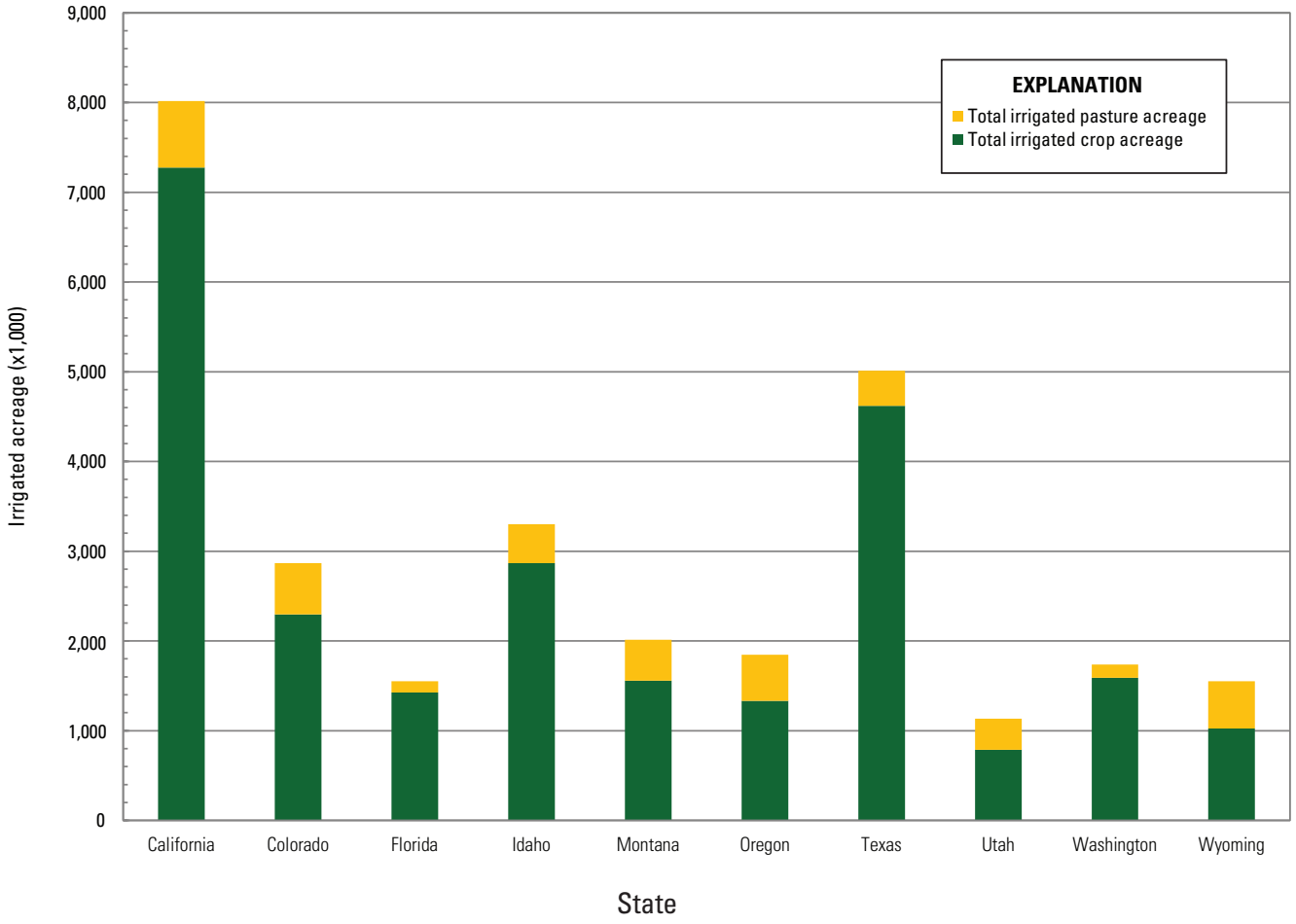

Figure 5. Total irrigated crop acreage and irrigated pasture acreage for U.S. Geological Survey Water Science Centers that reported over one million irrigated acres and with irrigated pasture making up at least 6 percent of the total irrigated acreage.
[Data from 2007 Census of Agriculture. (U.S. Department of Agriculture, 2009a)]

Figure 6. Pasture irrigated by a center-pivot sprinkler system in Cochise County, Arizona. (Photograph by Saeid Tadayon, U.S. Geological Survey.)

Figure 7. Outside view of Eurofresh Farms greenhouses (top) and inside view of tomatoes grown inside Eurofresh Farms in southeastern Arizona (bottom). (Photographs courtesy of and used with permission of Eurofresh Farms, Willcox, Arizona.)

Golf Courses

The inclusion of golf courses can increase reported irrigated acreage and withdrawal totals within a State, because many golf courses are located in areas of the country where warm weather dominates and irrigation is required. Included golf course irrigation withdrawals can increase total irrigation withdrawals by up to tens of thousands of acre-feet. Irrigation-application rates on golf courses may be higher than field crops owing to the aesthetic value of keeping the sod greener and well maintained. Since including golf courses is optional in the USGS water-use compilation, and is not always separated in AWUDS, it is difficult to evaluate the impact that golf course acreage and withdrawals have on water use nationwide. Additionally, golf courses are not always addressed in each WSC's water-use documentation, leaving unanswered questions regarding whether the acreage and withdrawals are included in the report. Golf courses may use water from groundwater or surface-water sources, purchased water from a public supplier or irrigation district, reclaimed water from a wastewater-treatment facility, or a combination of these sources. Without sufficient documentation, it is difficult to know how much of an impact this category can have on nationwide irrigation water use.

There were 14 WSCs contacted for this study that document that they do not include golf course acreage or withdrawals in reported irrigation totals, with an additional 8 WSCs unsure whether golf course data were included in reported totals, and could not be separated from agricultural values if they were included. In 2005, the remaining 31 WSCs reported over 770,000 irrigated golf course acres and over 1,150,000 acre-ft withdrawn in 2005. The States that report the largest number of golf course acres are Florida, California, South Carolina, and North Carolina, in descending order. Some States that have large golf industries and do not include golf course data in the water-use compilation are Arizona, Texas, and Nevada, among others. Using USGS NWUIP data to evaluate national trends in golf course water use is problematic because of this lack of consistent reporting. Proper documentation and consistent inclusion of golf courses in USGS water-use compilations would strengthen the development of 5-year golf course water-use trends within the USGS compilations.

Using the golf course data that was included in AWUDS, the impact of not including golf courses in irrigation totals is different depending upon the amount of irrigation water withdrawn by a State. For the 21 WSCs that reported less than 120,000 acre-ft/yr in 2005, 16 compiled separate golf course irrigation estimates (fig. 9). Of these 16 states, 10 had golf course withdrawals that account for more than 30 percent of their total irrigation-water withdrawal. Golf course irrigation can have an especially large influence on total irrigation-water withdrawals for smaller States with relatively small irrigation-water withdrawals. For these States, long-term water-use trends may not accurately be understood if golf courses are not consistently estimated, reported, and documented in USGS water-use compilations.

For the 17 WSCs that reported between 120,000 and 2 million acre-ft/yr in 2005, 7 compiled separate golf course irrigation estimates (fig. 10). Of these seven States, four had golf course withdrawals account for more than 10 percent of their total irrigation-water withdrawals. While having a less appreciable effect on total irrigation withdrawals than in States with lower irrigation water use, golf course withdrawals in these States still can play an important role in accurately accounting for the States' overall water use. For these States, long-term water-use trends may be established, but without considering golf course irrigation these trends could underestimate approximately 10 percent of the total withdrawals. In North Carolina, for example, golf course irrigation withdrawals account for 31 percent of the State's 327,000 acre-ft/yr of total irrigation water use in 2005.

For the 15 WSCs that reported above 2 million acre-ft/yr in 2005, 6 compiled a separate golf course irrigation estimate (fig. 11). Of these six States, five had golf course withdrawals account for less than 1 percent of their total irrigation-water withdrawals. For States with the largest agricultural water use, golf course irrigation withdrawals generally did not appreciably affect the irrigation water-use totals. However, Florida reported golf course irrigation as accounting for more than 10 percent of its total irrigation water use. The substantial golf course irrigation for Florida is equal to the total agricultural withdrawals (crops and golf courses) for the 16 smallest States combined. States with a sizeable amount of tourism such as Arizona and Texas may also have relatively high golf course irrigation withdrawals. For most large irrigation-water-using States, however, golf course irrigation withdrawals will only marginally affect their total irrigation water-use estimate.

Double Cropping

When evaluating the total irrigated acreage within a State, double cropping may need to be considered. If the growing season is long enough, double and triple cropping can occur, and the irrigated acreage is counted each time the acreage is irrigated, reflecting the total irrigated acreage for that year (Hutson, 2007; U.S. Department of Agriculture, 2009a; fig. 12). Double cropping also increases irrigation-withdrawal totals in a State. In warm, arid environments in the west, fields may produce up to four crops in a single calendar year, potentially quadrupling the amount of water that needs to be applied to that given field in a year. Information is available to assist in estimating double cropping in States where it is occurring. The Cropland Data Layer (CDL; U.S. Department of Agriculture, 2010a) produced by the USDA is a GIS raster depicting areas of crop acreage by crop types. This layer can predict areas that can produce more than one crop per year. States where double cropping occurs generally are warm weather States with longer growing seasons. In many States where double cropping occurs, irrigation could be required at some point during the year, which would cause them to have higher irrigation-application rates per acre than States where only a single crop may

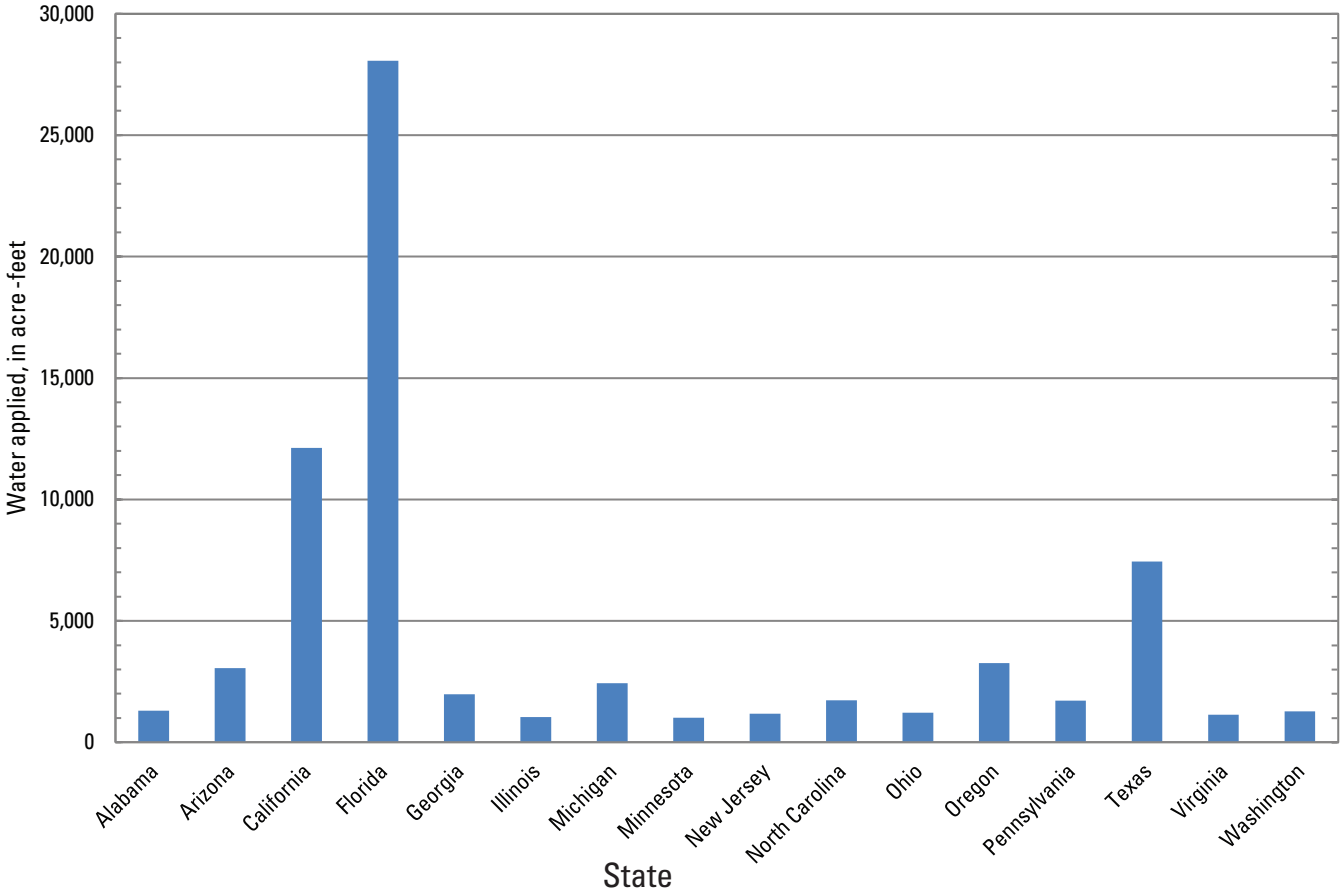

Figure 8. Water applied to horticultural crops in States with over 1,000 acre-feet of horticultural water use in 2008 (U.S. Department of Agriculture, 2009b).

be grown. Assuring that double-cropping acres are included in estimates in States in which it is occurring is essential in estimating irrigated acreage and irrigation withdrawals.

Sources of Data and Methods Used to Inventory the 2000 and 2005 Irrigation Data

Information was compiled on the sources of data and methods used by each WSC for collecting and reporting irrigated acreage and irrigation withdrawals for the 2000 and 2005 USGS water-use compilations. These sources include data from AWUDS, methods described in appendix 1, water-use reports published by individual States, the USGS circular report on nationwide water use (Kenny and others, 2009), and personal communications with personnel in most of the WSCs. Information from all these sources provided the most comprehensive analysis of methods and data for the irrigation category of the USGS water-use compilation to date.

Every WSC must gather data within its State, estimate irrigated acreage and irrigation withdrawals, and document the methods and sources used in developing these estimates for every five years ending in "0" and "5." WSCs are required to document the sources of data and methods used to estimate irrigated acreage and irrigation withdrawals. After compiling the data, documenting the methods used to estimate the data, and entering required data into AWUDS, the WSC sends the information to its regional water-use specialist for review. Irrigated acreage by system type; conveyance loss and consumptive use, if estimated; and irrigation withdrawals by source are entered into AWUDS and are made available to the public online as a spreadsheet at *http://water.usgs.gov/watuse/data/2005/index.html*. This information was used to review sources and methods used by each WSC to estimate irrigated acreage and irrigation withdrawals.

There were 12 WSCs that also published separate reports based on their 2005 State water-use compilations. The WSCs that released reports on 2005 water-use data include Alabama (Hutson and others, 2009), Arkansas (Holland, 2007), Colorado (Ivahnenko, 2009; Ivahnenko and Flynn, 2010), Florida (Marella, 2009), Georgia (Fanning and Trent, 2009), Louisiana (Sargent, 2007), Oklahoma (Tortorelli, 2009), Puerto Rico (Molina-Rivera and Gomez-Gomez, 2008), South Dakota (Carter and Neitzert, 2008), Washington (Lane, 2009), West

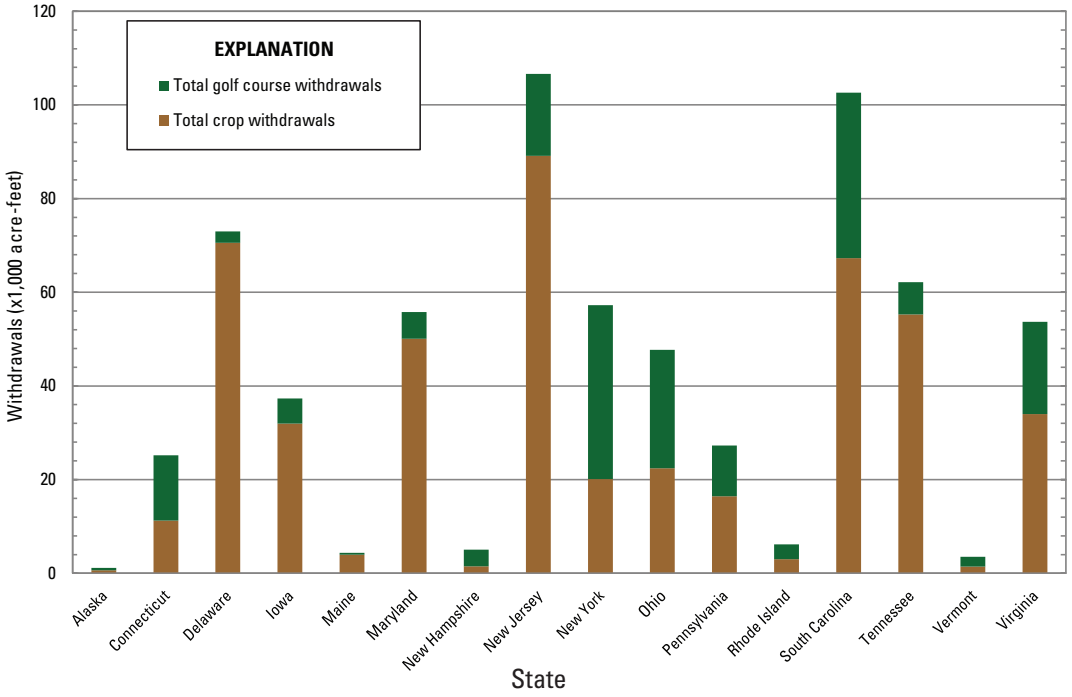

Figure 9. Crop and golf course withdrawals for States that reported less than 120,000 acre-feet of water withdrawals for irrigation and that reported crop and golf course withdrawals separately in the 2005 U.S. Geological Survey water-use compilation. (Data from 2005 U.S. Geological Survey National Water Use Information Program.)

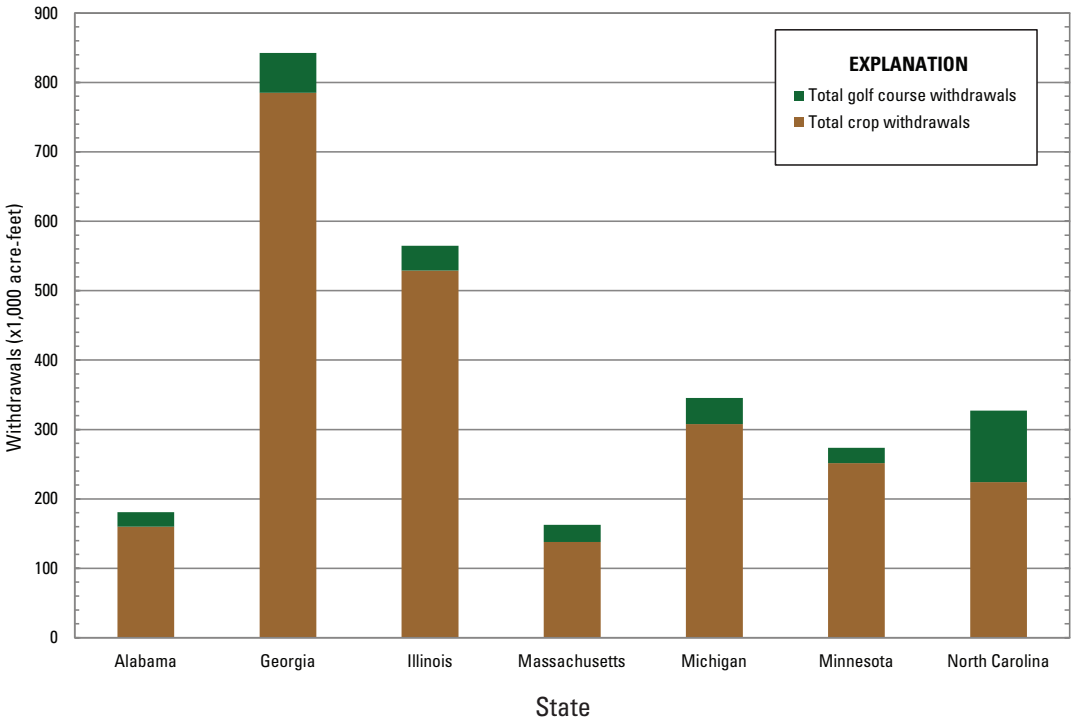

Figure 10. Crop and golf course withdrawals for States that reported between 120,000 and 2 million acre-feet of water withdrawals for irrigation and that reported crop and golf course withdrawals separately in the 2005 U.S. Geological Survey water-use compilation. (Data from 2005 U.S. Geological Survey National Water Use Information Program)

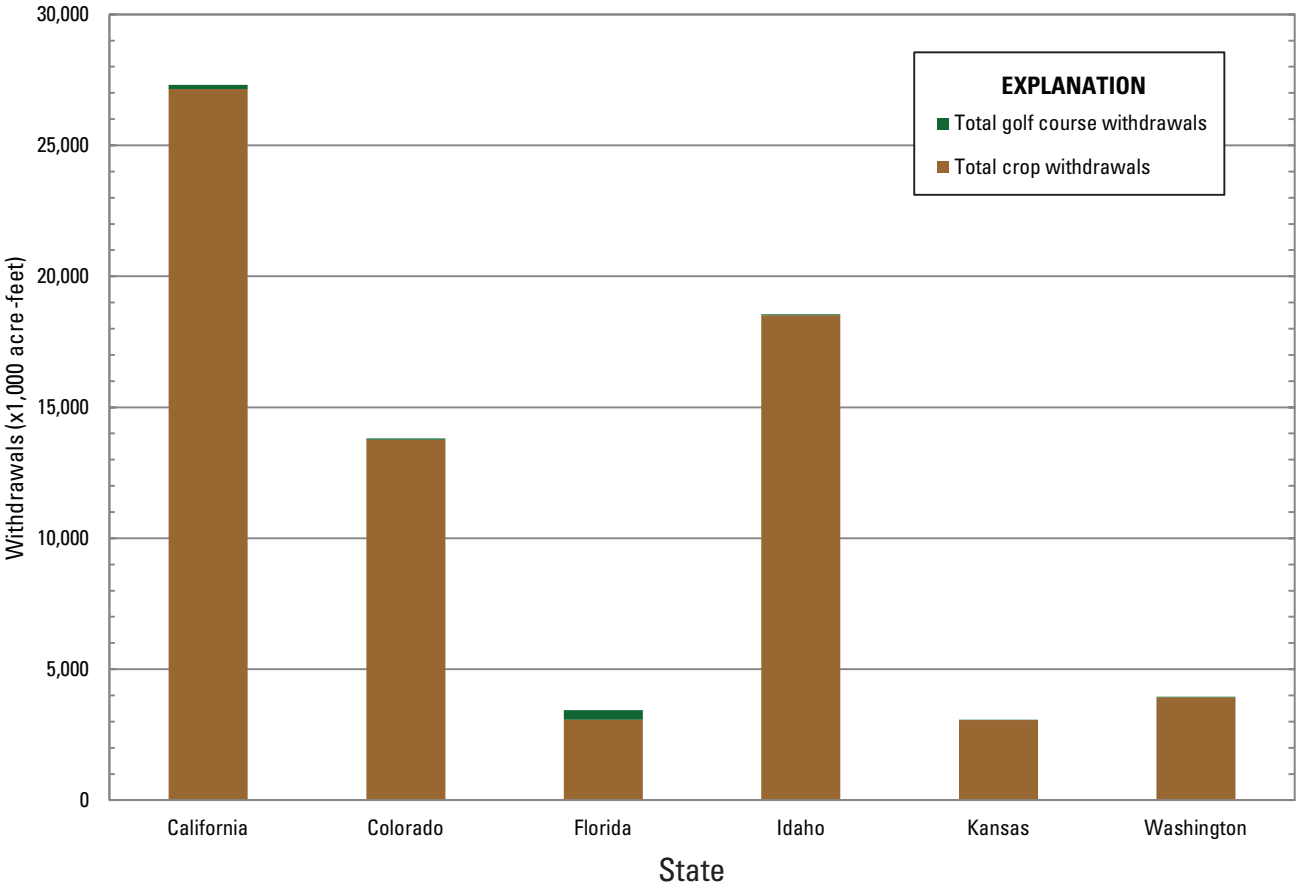

Figure 11. Crop and golf course withdrawals for States that reported between 2 and 30 million acre-feet of water withdrawals for irrigation and that reported crop and golf course withdrawals separately in the 2005 U.S. Geological Survey water-use compilation. [Data from 2005 U.S. Geological Survey National Water Use Information Program]

Figure 12. Double cropping of corn over a wheat crop that was not tilled before the corn crop was planted, in Cochise County, Arizona. (Photograph by Saeid Tadayon, U.S. Geological Survey.)

Virginia (Atkins, 2007), and Wisconsin (Buchwald, 2009). These reports present sources of data and methods used in all of the required water-use reporting categories, including irrigation, and were collected and used to compare data in this report.

Additionally, 39 WSCs were contacted through phone interviews to help better understand the data sources and methods used for the irrigation category for the 2005 USGS water-use compilation. The 39 WSCs collected data for 42 States; some WSCs collect data for multiple States and (or) territories. Contact with the WSCs that estimated and compiled the data for the irrigation category of their compilation provided clarification and elaboration on sources and methods used by the WSCs. This information is included in appendix 1.

Information reported in the 1997, 2002, and 2007 Census of Agriculture reports (U.S. Department of Agriculture, 1999a, 2004a, and 2009a); 1998, 2003, and 2008 FRIS reports (U.S. Department of Agriculture, 1999b, 2004b, and 2009b); 2005 NASS report (U.S. Department of Agriculture, 2005); and 2009 CDL data was collected and reviewed for comparison to 2005 USGS water-use data. The 2009 CDL maps the type and location of planted crops in the conterminous United States. The source of imagery was provided by the Indian Remote Sensing satellite, IRS-P6, known as Resourcesat-1 (Johnson and Mueller, 2010). The satellite imagery was cross-referenced with a sample of field-verified data from the Farm Service Agency's (FSA) "Common Land Unit" across the country. The 2009 CDL is a 56-meter resolution raster-based product that can be imported and used in a GIS program.

Comparison of Data and the Number of Irrigated Acres Reported by USGS to USDA Data

Many WSCs used information published in the Census of Agriculture (U.S. Department of Agriculture, 2004a and 2009a) or FRIS (U.S. Department of Agriculture, 2004b and 2009b) reports to estimate the irrigated acreage. There are differences between the irrigated acreage reported in the USGS water-use compilation and the USDA reports. Depending upon the WSC, the USGS water-use compilation may or may not include irrigated acreage for pasture, golf course irrigation, or horticultural acreage in the total irrigated-acreage estimates. The Census of Agriculture (U.S. Department of Agriculture, 2004a) and FRIS (U.S. Department of Agriculture, 2004b) reports also include estimates of irrigated-pasture acreage, but do not include irrigation data for golf courses. The 2003 FRIS (U.S. Department of Agriculture, 2004b) did include horticultural operations in their reports, but the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) did not. The Census of Agriculture released a report "2009 Census of Horticultural Specialties" (U.S. Department of Agriculture, 2010b) that presents information on types of horticultural crops being grown, the area of the operation, and the amount of water applied, among others.

It can be difficult to directly relate USGS-reported irrigated acreage to information from the USDA reports owing to the different years and possibilities and variations of categories that may be included. No clear relations or trends can be established when comparing data from the USGS, Census of Agriculture, and FRIS on a state-by-state level (fig. 13–17). At the nationwide level, the Census of Agriculture reports an increase in irrigated acreage between 2002 and 2007 of more than 1 million acres (about 2 percent). FRIS reports an increase between 2003 and 2008 of more than 2 million acres (about 4 percent), while the USGS estimates have decreased by over 1 million acres (about 2 percent) between 2000 and 2005 (fig. 18). Total irrigated acreage reported by the USGS remains larger than the irrigated acreage reported by the Census of Agriculture and FRIS reports. While many WSCs do use the Census of Agriculture and FRIS reports to estimate irrigated acreage, many of the States with the largest irrigated acreage (California, Texas, and Florida, among others) do not use either report, which could be contributing to the differences in total irrigated acreage for the three reports. Another reason for this difference could be that data were compared between data sources that were not conducted for the same year (for example, 2002, 2003, and 2005). There is the possibility of variability in acreage numbers from year to year, which could be contributing to the difference in trends among values reported by the USGS, the Census of Agriculture, and FRIS.

Comparison of Estimates of Irrigation Withdrawals from Indirect Methods to Data Reported in the USGS Water-Use Compilations

The inventory of sources of data used for reported irrigated acreage and irrigation withdrawals for the 2000 and 2005 USGS water-use compilations conducted in this study indicates that WSCs are using many different sources of data to estimate total irrigation water use. To increase confidence in reported irrigation withdrawals, particularly for States that receive withdrawal data directly from other agencies, or to estimate irrigation withdrawals for a State where withdrawal data are unavailable, irrigation estimates could be generated with an indirect method, using crop consumptive use and other ancillary irrigation data (Hutson, 2007). This method can be used as a check for the irrigation-withdrawal data received from other sources. In the next sections, an Indirect Irrigation Withdrawal Estimation Method (IIWEM) is tailored to this comparison using available irrigation data to estimate irrigation withdrawals. This method can be used to compare irrigation withdrawals reported to the WSC from another agency,

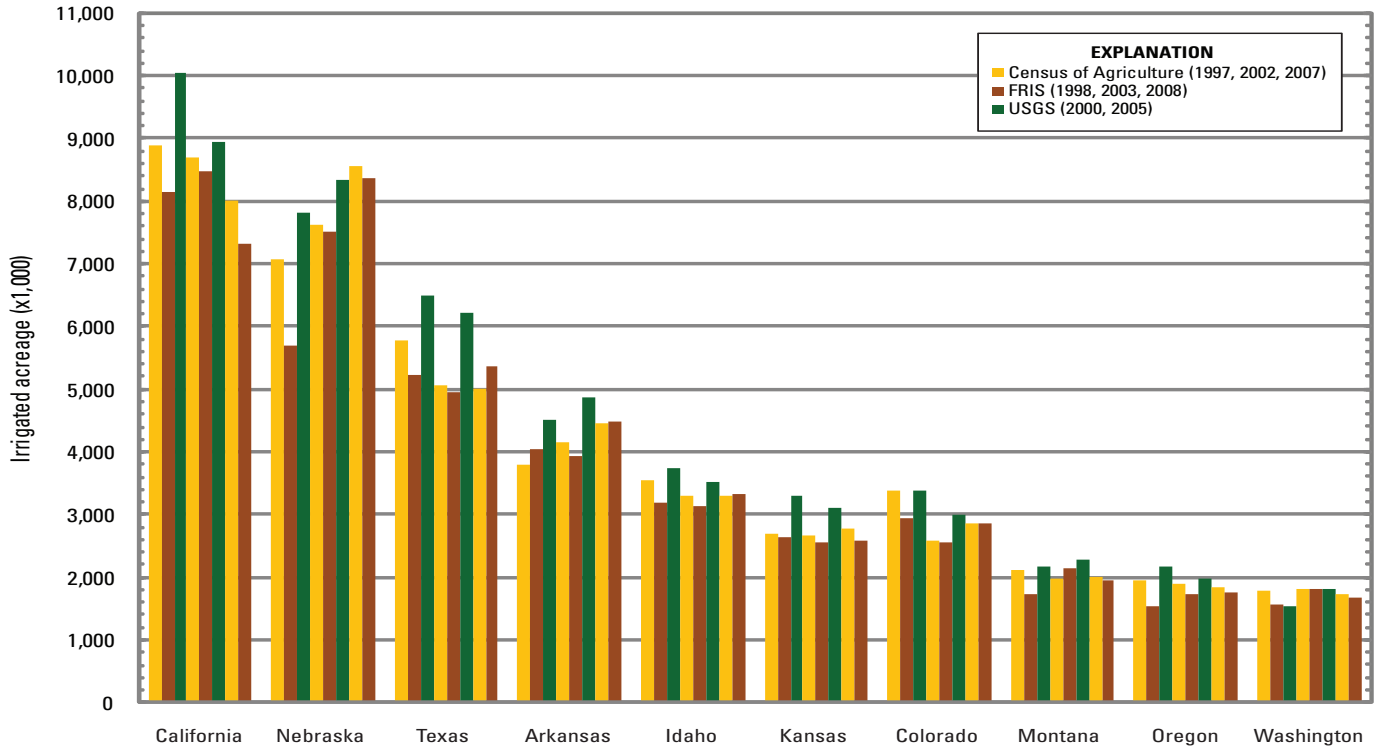

Figure 13. Comparison of irrigated crop acreage reported in the 1997, 2002, and 2007 Census of Agriculture; 1998, 2003, and 2008 Farm and Ranch Irrigation Survey (FRIS); and 2000 and 2005 U.S. Geological Survey (USGS) National Water Use Information Program for states that reported over 1.75 million irrigated acres in 2005. To facilitate comparison, the irrigated golf course acreage was removed from USGS-reported total irrigated acreage, if known. (Data from U.S. Department of Agriculture, 1999 a,b, 2004a,b, 2009a,b; Hutson and others, 2004, 2009.)

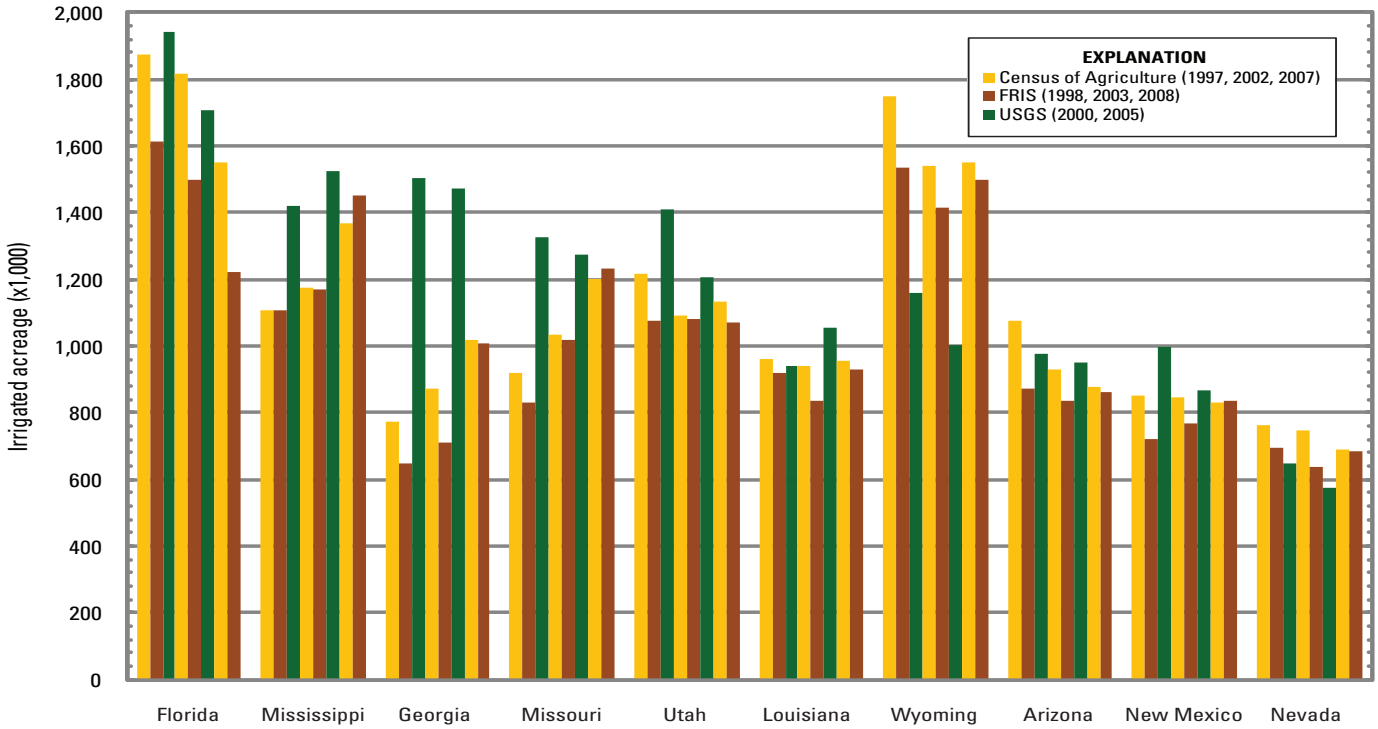

Figure 14. Comparison of irrigated crop acreage reported in the 1997, 2002, and 2007 Census of Agriculture; 1998, 2003, and 2008 Farm and Ranch Irrigation Survey (FRIS); and 2000 and 2005 U.S. Geological Survey (USGS) National Water Use Information Program for states that reported between 500,000 and 1.75 million irrigated acres in 2005. To facilitate comparison, the irrigated golf course acreage was removed from USGS-reported total irrigated acreage, if known. (Data from U.S. Department of Agriculture, 1999a,b, 2004a,b, 2009 a,b; Hutson and others, 2004, 2009.)

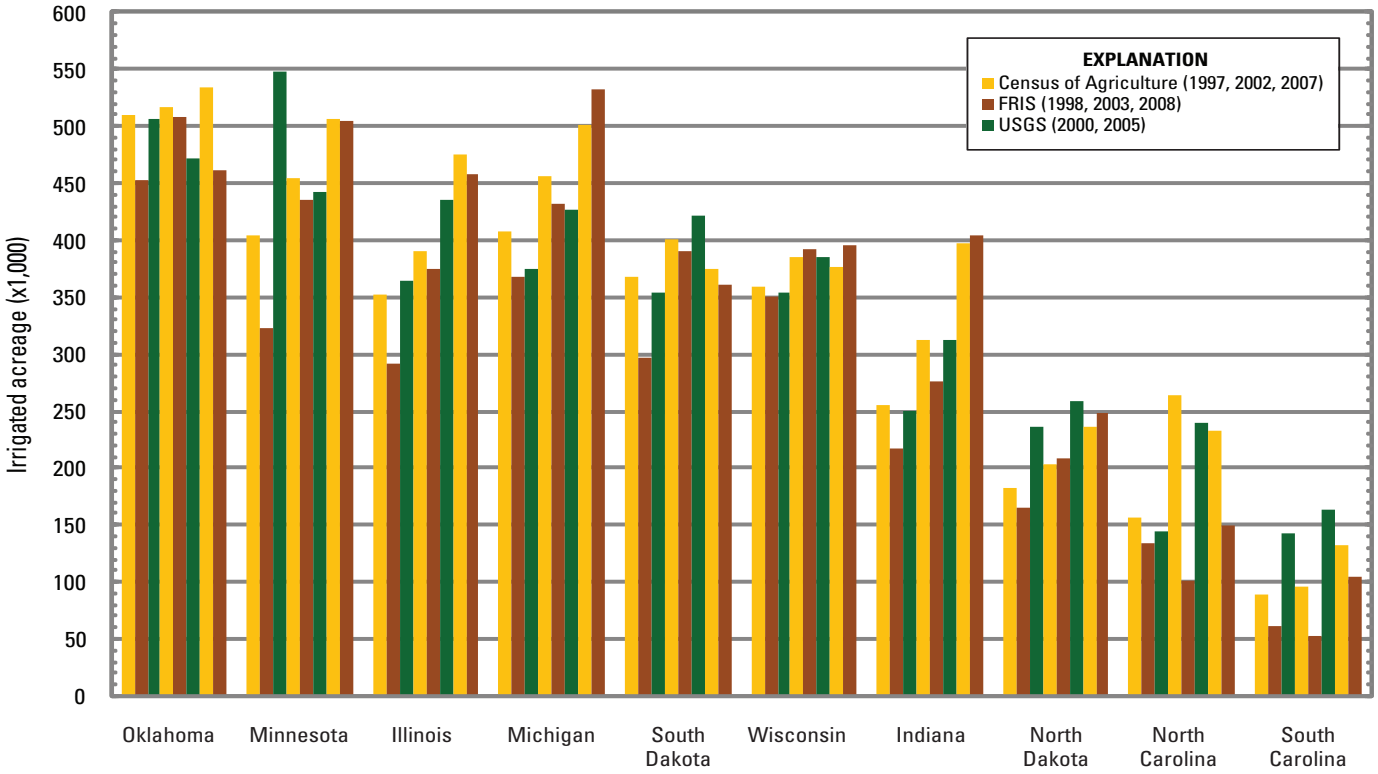

Figure 15. Comparison of irrigated crop acreage reported in the 1997, 2002, and 2007 Census of Agriculture; 1998, 2003, and 2008 Farm and Ranch Irrigation Survey (FRIS); and 2000 and 2005 U.S. Geological Survey (USGS) National Water Use Information Program for states that reported between 125,000 and 500,000 irrigated acres in 2005. To facilitate comparison, the irrigated golf course acreage was removed from USGS-reported total irrigated acreage, if known. (Data from U.S. Department of Agriculture, 1999a,b, 2004 a,b, 2009a,b; Hutson and others, 2004, 2009.)

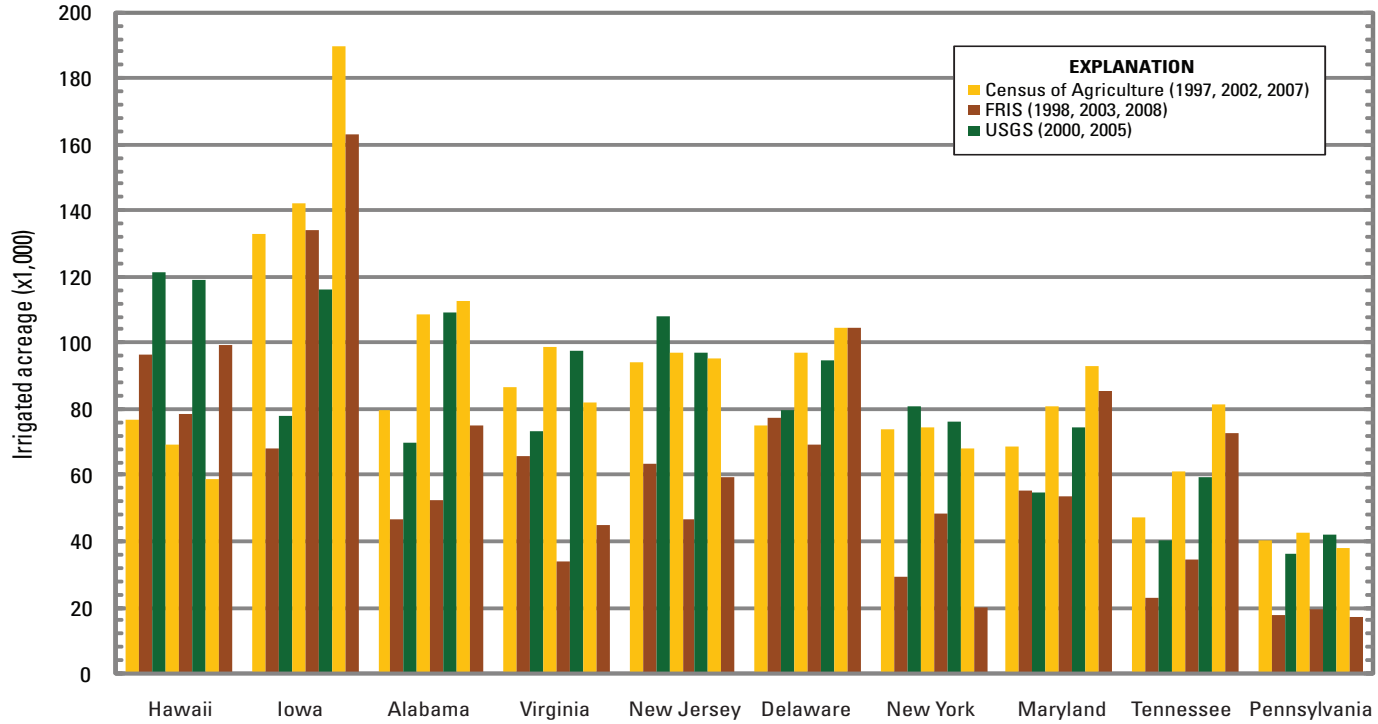

Figure 16. Comparison of irrigated crop acreage reported in the 1997, 2002, and 2007 Census of Agriculture; 1998, 2003, and 2008 Farm and Ranch Irrigation Survey (FRIS); and 2000 and 2005 U.S. Geological Survey (USGS) National Water Use Information Program for states that reported between 41,000 and 125,000 irrigated acres in 2005. To facilitate comparison, the irrigated golf course acreage was removed from USGS-reported total irrigated acreage, if known. (Data from U.S. Department of Agriculture, 1999a,b, 2004a,b, 2009a,b; Hutson and others, 2004, 2009.)

or to estimate irrigation withdrawals independently at the State and (or) county level. Comparisons of reported irrigation withdrawals for selected States using the 2005 USGS water-use compilation data with estimates developed using the IIWEM are presented in the following sections.

Using an Indirect Method for Estimating Irrigation Withdrawals at the State Level

The IIWEM calculates withdrawals using total acreage by crop type in a State, crop water demand for the growing season, and a coefficient that quantifies total losses in the irrigation system.

Irrigation withdrawals are estimated for each crop in each basin using the relation based on the equation presented in Tadayon (2005):

$$W = (A \times C) / L \quad (1)$$

where

W is irrigation withdrawals, in acre-feet, for a particular crop;
A is irrigated acreage of each crop in the specified State, in acres;
C is the consumptive-water requirement for each individual crop, in feet; and
L is considered to be all the potential water loss occurred while irrigating (for example, conveyance loss, irrigation-system efficiency, over watering, irrigation system age and condition, among others) in decimal fraction.

Published values are used in this study for irrigation-system efficiency (Howell, 2003; table 2).

An important variable in equation 1 that has both a large impact on estimated irrigation withdrawals and significant

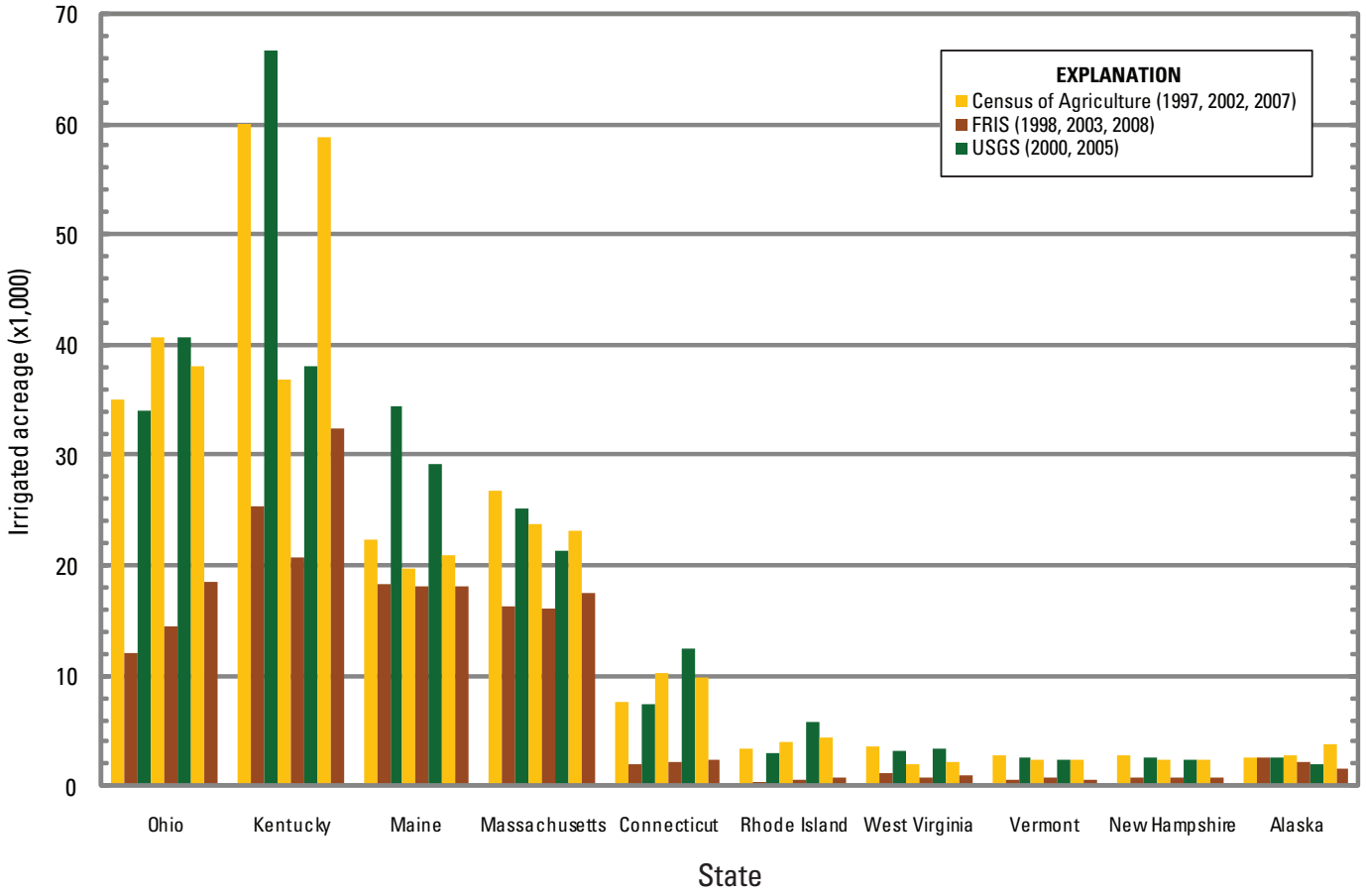

Figure 17. Comparison of irrigated crop acreage reported in the 1997, 2002, and 2007 Census of Agriculture; 1998, 2003, and 2008 Farm and Ranch Irrigation Survey (FRIS); and 2000 and 2005 U.S. Geological Survey (USGS) National Water Use Information Program for states that reported less than 41,000 irrigated acres in 2005. To facilitate comparison, the irrigated golf course acreage was removed from USGS-reported total irrigated acreage, if known. (Data from U.S. Department of Agriculture, 1999 a,b, 2004 a,b, 2009 a, b; Hutson and others, 2004, 2009.)

uncertainty is *L*, the total potential losses, which incorporates both the efficiency of the irrigation system and conveyance losses. This represents the ability of the particular irrigation water conveyance system coupled with the efficiency of the irrigation system to transport water from the withdrawal or diversion point and deliver it to the roots of plants. If a farmer has an adequate supply of water, they usually will divert or withdraw water until the required amount of water is delivered to each plant. The decimal fraction for variable *L* needs to account for the losses incurred when adequately supplying the entire crop with irrigation water. This leads to excess water being removed from the source, which decreases total irrigation efficiency when compared to crop water demand alone. Choosing an appropriate irrigation efficiency addressing these and other factors is important in accurately estimating irrigation withdrawals. Irrigation practices, crops being irrigated, availability of water, the condition of the irrigation system, and the type of irrigation system all need to be evaluated when using this method to estimate the total potential losses assigned in a given area. A case study conducted in Arizona in 2009, which uses this method, is described in appendix 3.

Application of the Indirect Irrigation Withdrawal Estimation Method

Application of the IIWEM can be divided into three steps: (1) locating a data source for irrigated acreage by crop type, (2) acquiring and (or) computing yearly crop consumptive use, and (3) acquiring and (or) computing overall irrigation-system efficiencies including conveyance losses.

Locating a Data Source of Irrigated Acreage by Crop Type

Selecting a data source for irrigated acreage by crop type, within a State during the growing season, is the first step in

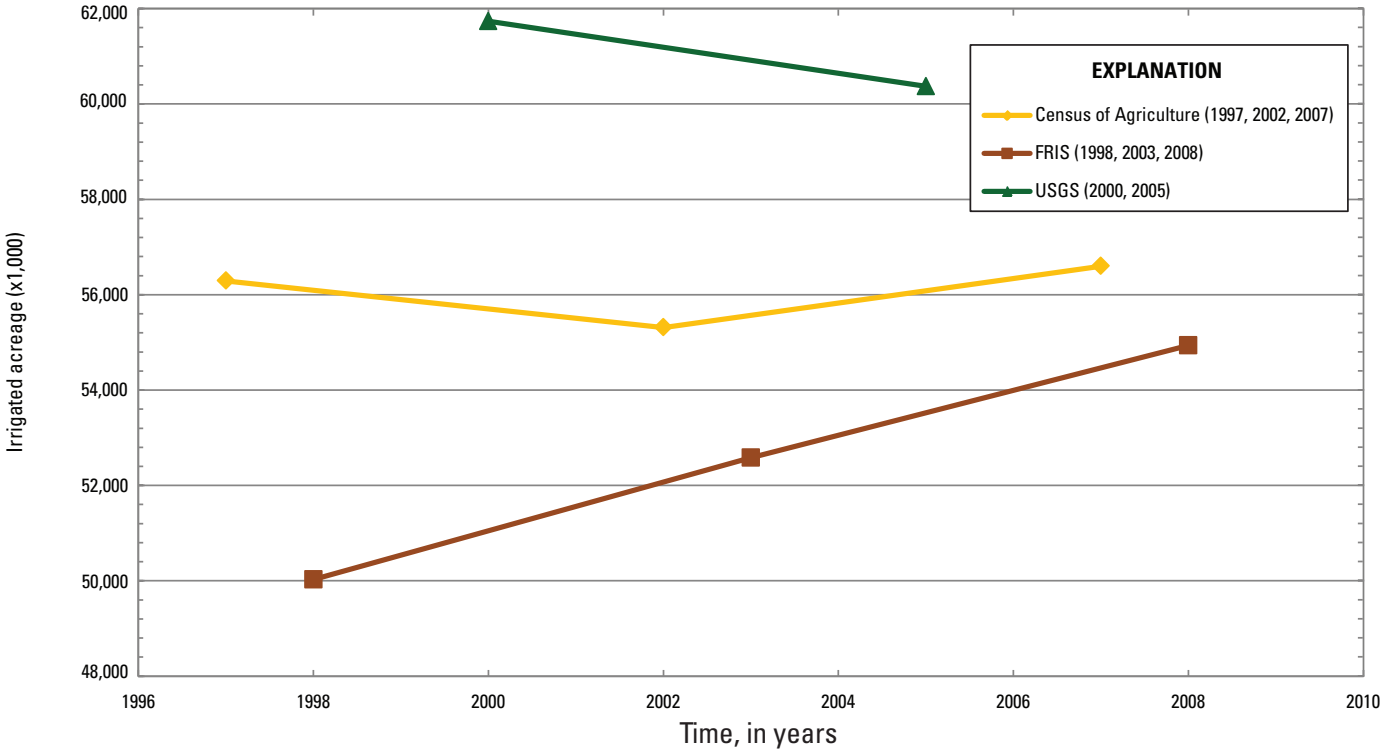

Figure 18. Comparison of total irrigated crop acreage reported in the 1997, 2002, and 2007 Census of Agriculture; 1998, 2003, and 2008 Farm and Ranch Irrigation Survey (FRIS); and 2000 and 2005 U.S. Geological Survey (USGS) National Water Use Information Program for the entire Nation. To facilitate comparison, the irrigated golf course acreage was removed from USGS-reported total irrigated acreage, if known. (Data U.S. Department of Agriculture, 1999 a,b, 2004 a,b, 2009 a,b; Hutson and others, 2004, 2009)

using the IIWEM. Many States do not collect irrigated acreage by crop type in the 5-year compilations because it is not a required category. When using the IIWEM, irrigated acreage, by crop type is required to refine consumptive-use estimates because different crops consume different amounts of water throughout the growing season. Many national agencies report agricultural acreage, which can be used for this method, some on a yearly basis (U.S. Department of Agriculture, 2005) and others every five years (U.S. Department of Agriculture, 2009a). The most important part of finding a data source for acreage to be used in this method is that it should be identified as acreage that was irrigated during the growing season. Many data sources of agricultural acreage can classify crop acreage as planted, harvested, irrigated, or any combination involving these, or other terms, for total acres per crop. These different categories of agriculture acreage need to be recognized, especially in States where crops are not always irrigated owing to sufficient rainfall and soil moisture. It also is common to see certain crop types in a State that are not irrigated when other crops are irrigated throughout the year. For example, winter wheat is grown during colder and wetter winter months and may not need irrigation in some States, whereas summer crops like cotton may need irrigation. This all needs to be recognized when estimating irrigated acreage by crop type. In States where this method was applied for this comparison, irrigated acreage was estimated using various sources of data (table 3).

The 2009 CDL was used as the source of irrigated acreage in the IIWEM for some States where irrigation is required for the majority of crops. These States include Arizona and Utah. With local knowledge of irrigation practices in a State, the CDL may be used as a source for irrigated acres in additional States. To generate an estimate for irrigated acreage using the CDL, certain areas delineated in the raster need to be removed (for example, urban, water surface, forested, barren, and others). Once unnecessary attributes are discarded, total acreage by crop type can be calculated using the CDL raster. If it is known that a certain crop does not need to be irrigated because there is adequate rainfall and soil moisture for crop growth, then this can be subtracted from total irrigated acreage within the CDL.

In States where irrigation is not necessarily required for all crops in a growing season, other sources of available irrigated-acreage data were collected and used in the IIWEM. These States include California, Florida, Idaho, Montana, New Mexico, Oregon, Texas, Washington, and Wyoming. NASS (U.S. Department of Agriculture, 2005) reported irrigated-acreage data for many of the States in the 2005 water-use compilation, while the FRIS (U.S. Department of Agriculture, 2009b) provided estimates of irrigated acreage for 2003 and 2008, and was another source of available data (table 3). The different datasets used in this comparison are considered acceptable because the irrigated-acreage data gathered for this comparison agrees well with what was reported in the 2005 water-use compilation (fig. 19). There was only one State where the irrigated acreage estimated for the IIWEM was very different from what was reported for the 2005 water-use compilation. The irrigated acreage estimated for Utah was 17 percent higher than the irrigated acreage reported in the 2005 water-use compilation. The rest of the States where the comparison was conducted had irrigated-acreage estimates within 11 percent of what was reported by WSCs in 2005. The numbers used for creating figure 19 are presented in appendix 2, table 2–2.

Crop Consumptive-Use Information

The second step in using the IIWEM is to find or estimate crop consumptive-use information, by crop type, for the year being studied. If actual crop consumptive-use values are not available, there are some ET methods that can be used to estimate the crop consumptive use. One source is the modified Blaney-Criddle ET method, based on monthly rainfall and temperature data, to estimate crop consumptive use (U.S. Bureau of Reclamation, 2003). Precipitation and temperature data are available from numerous sources, depending upon the region of the country. The U.S. Bureau of Reclamation also publishes a yearly summary of consumptive-use data for field crops for many western States using the Penman-Monteith ET method along with remotely sensed and field-verified information (U.S. Bureau of Reclamation, 2003). The Penman-Monteith ET method is another regression calculation for estimating ET. These ET methods work for different regions of the United States. In some States, a local agency may publish crop consumptive-use data. In other States, various agencies and universities are studying plant water use and those data can be a source for estimates of crop water use. Annual crop water demand can be estimated from these published sources, and the deficit of water not supplied by effective precipitation (the precipitation that is effective in meeting the consumptive-use needs of a crop that may not be equal to the total precipitation) can be considered to be met by irrigation. The Food and Agriculture Organization of the United States (FAO) offers information on crop consumptive use in the "Crop evapotranspiration—Guidelines for computing crop water requirements" paper (Allen and others, 1998). For this comparison, all consumptive-use data sources for each State were collected, and the most current and complete dataset containing consumptive-use estimates for major crops in each particular State was used (table 3).

Information about Estimating Potential Irrigation Water Losses

In the third and final step, irrigation-system type, irrigation-system efficiencies, and conveyance losses need to be determined. These are the elements that can greatly affect total irrigation withdrawals and have to be estimated, which can be a source of uncertainty in the method. FRIS (U.S. Department of Agriculture, 2009b) reports irrigation-system distribution by State. This irrigation-system distribution can be extrapolated to

all crop acreage where irrigation is occurring. For example, in some parts of a State, it may be known that a certain county has no crops irrigated by micro-irrigation (drip) systems. Therefore, crops in this county can be excluded from the micro-irrigation distribution and the weighted distribution of sprinkler and surface (flood) only would be applied. Aerial photos are another useful way to identify the type of irrigation system being used in a particular area. Irrigation canals can be seen from aerial photos, and center-pivot irrigation systems are easily recognizable. However, in the comparisons presented in this report owing to little local knowledge of irrigation practices in various States, the irrigation-system distribution of sprinkler, micro-irrigation (drip), and surface (flood) reported in 2005 was used in the IIWEM. The area-weighted averages were multiplied by the total number of acres in each State to determine the acreage associated with each irrigation-system type.

Once the distribution of irrigation systems in the State is determined, irrigation-system efficiencies were assigned using published values of efficiency for each system. To simplify the estimates of irrigation withdrawals for all comparisons, efficiencies for each system, 90 percent for micro-irrigation, 80 percent for sprinkler and center-pivot systems, and 70 percent for surface (flood), were taken from published values estimated by the USDA (Howell, 2003; table 2).

Conveyance losses were determined using the estimates reported in the 1985, 1990, and 1995 data from the AWUDS database, when it was mandatory to estimate conveyance loss in the irrigation category of the 5-year water-use compilation. The conveyance-loss coefficient estimated in those 3 years was averaged over the 3 years and used for the comparison conducted in this study. Since this is the only source of conveyance-loss data for these comparisons and there is little knowledge of the condition and methods of irrigation water conveyance occurring in the various States, this dataset was used.

Comparison-Method Results

Results from the IIWEM were compared to irrigation data reported by selected States in the 5-year water-use compilation for 2005. Because much of the data in the 5-year water-use compilation are collected from data sources outside the USGS, comparison to estimates from an independent method like this one may provide a valuable check on the reasonableness of those reported values.

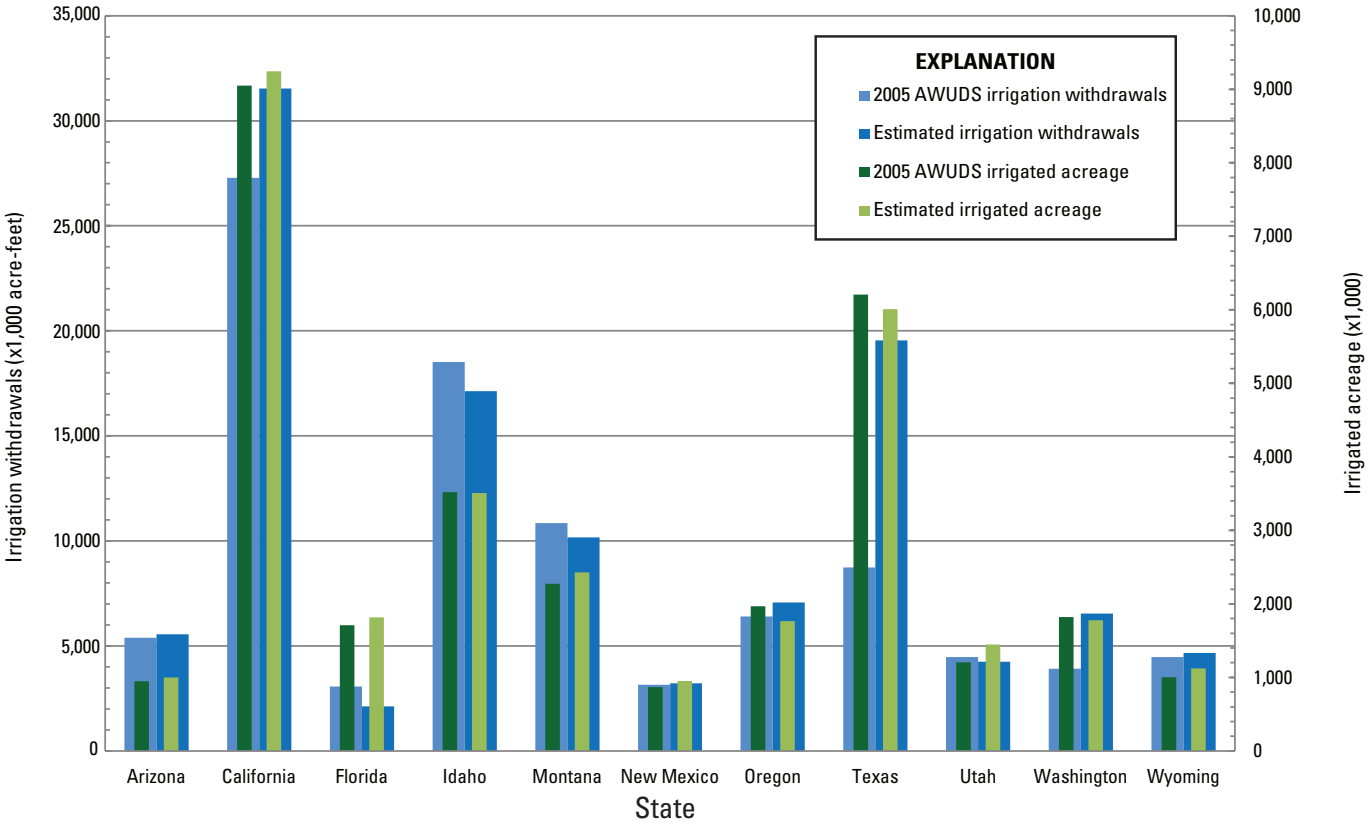

Figure 19. Comparison of irrigated acreage and irrigation withdrawals reported in Aggregate Water Use Database System (AWUDS) for 2005 to irrigated acreage estimated using sources from table 2 and irrigation withdrawals estimated using the Indirect Irrigation Withdrawal Estimation Method (IIWEM). The irrigated acreage and irrigation withdrawals for golf courses were removed from U.S. Geological Survey reported total irrigated acreage and total irrigation withdrawals, if known.

Table 2. Approximate field irrigation-application efficiencies.

[LEPA, low energy precision application; adapted from Howell, 2003]

Irrigation method	Field efficiency (in percent)		
	Attainable	Range	Average
Surface			
Graded furrow	75	50–80	65
with tail-water reuse	85	60–90	75
Level furrow	85	65–95	80
Graded border	80	50–80	65
Level basins	90	80–95	85
Sprinkler			
Periodic move	80	60–85	75
Side roll	80	60–85	75
Moving big gun	75	55–75	65
Center pivot			
Impact heads with end gun	85	75–90	80
Spray heads without end gun	95	75–95	90
LEPA without end gun	98	80–98	95
Lateral move			
Spray heads with hose feed	95	75–95	90
Spray heads with canal feed	90	70–95	85
Micro-irrigation			
Trickle	95	70–95	85
Subsurface drip	95	75–95	90
Micro spray	95	70–95	85
Water-table control			
Surface ditch	80	50–80	65
Subsurface drain lines	85	60–80	75

As with all methods of estimation, there are limitations associated with the IIWEM. With little local knowledge of the irrigation practices occurring in other parts of the county, the best available data were gathered and used for this comparison. It is understood that the inputs used in the indirect method are generalized to a State level and may not exhibit exactly what is occurring at a regional level or county-by-county scale, thus providing a possible source of error in the estimates. Another limitation with this method is that irrigation-system efficiencies are generalized by using an average efficiency for the entire State and not a more local approach, such as the county level. Irrigation-system efficiencies can change depending upon numerous factors, including age of the system, source of water, and distance the water is transported to the field, among others. Precipitation also can be a source of error when using this method. Rainfall can be localized, and the more rain gages used, the more accurate the data. The percent of effective precipitation may differ depending upon region of the country, region of the State, and time of year, among others. Another important limitation of this method is that the method assumes no crops are water-stressed in a State, and the crops are getting all the water that they need to grow.

Arizona and Utah are the two States where the CDL was used for irrigated-acreage inputs in the IIWEM, and the method reproduced total irrigation withdrawals within 3 and 5 percent, compared to what was reported in the 2005 water-use compilation (fig. 19). Importantly, in the States using the CDL as a source for irrigated acreage, the IIWEM can be used with the inputs found in figure 19 to produce reasonable estimates that agree with irrigation withdrawals reported in previous years (less than 10 percent different). In these two States, the CDL is considered a reasonable source for irrigated acreage because

Table 3. Sources of data used to estimate irrigated crop acreage and irrigation withdrawals that are compared to irrigated crop acreage and irrigation withdrawals reported by selected States to the Aggregate Water Use Data System (AWUDS) in 2005.

[NRCS, Natural Resources Conservation Service; NASS, National Agricultural Statistics Service; FRIS, Farm and Ranch Irrigation Survey; golf courses were removed from total irrigated acreage and total irrigation withdrawals, if possible, to facilitate a comparison]

Geographic area	Source of irrigated crop acreage	Source of crop consumptive-use estimates	Total conveyance loss and irrigation-system efficiencies[1]
Arizona	2009 Cropland Data Layer	2009 NRCS	0.59
California	California Department of Water Resources	2000 California Department of Water Resources	0.78
Florida	2005 NASS	1977 Southwest Florida Water Management District Regulation Division and 1982 Resource Planning Department reports	0.78
Idaho	2005 NASS	2005 U.S. Bureau of Reclamation	0.48
Montana	2005 NASS	Montana State University Extension Agency and 2005 Bureau of Reclamation	0.32
New Mexico	2002 Census of Agriculture	2005 NRCS	0.56
Oregon	2008 FRIS	2007 U.S. Bureau of Reclamation	0.59
Texas	2005 NASS and 2008 FRIS	1960 Texas Water Development Board report	0.71
Utah	2009 Cropland Data Layer	2005 NRCS	0.64
Washington	Average of 2003 and 2008 FRIS values	2005 U.S. Bureau of Reclamation	0.71
Wyoming	2005 NASS	1992 Wyoming Water Resources Center report	0.47

[1] Estimated from AWUDS data.

all planted crops are considered irrigated. In other States, with local knowledge, some crops or counties can be evaluated for irrigation and the CDL may be used to help estimate withdrawals.

The IIWEM also was applied to multiple States using irrigated acreage from various data sources. California, Florida, Idaho, Montana, New Mexico, Oregon, Texas, Washington, and Wyoming were chosen because input data for the IIWEM were available and appreciable amounts of irrigation occur in each State (fig. 19). Irrigation-withdrawal estimates in five States (Idaho, Montana, New Mexico, Oregon, and Wyoming) were within 10 percent of what was reported in the 2005 water-use compilation. This was thought to be a reasonable agreement in these cases owing to the wide range of irrigation practices occurring in these States. For this comparison, the estimates for the five States produced by the IIWEM are close to reported data in the 2005 water-use compilation despite using statewide averages for crop consumptive use, conveyance losses, and irrigation-system efficiencies. Refining the irrigation-system efficiencies and conveyance-loss inputs to the indirect method with local knowledge and more data likely would further improve the agreement.

In four States (Florida, California, Washington, and Texas) the IIWEM comparison produced results that differ significantly from what was reported in the 2005 water-use compilation. When comparing the estimates used to calculate irrigation withdrawals in Florida, the IIWEM and the 2005 compilation differed in both irrigated acreage and withdrawal estimates. The IIWEM used an irrigated-acreage estimate that was 110,000 acres larger than reported in the 2005 water-use compilation, (1,818,000 acres estimated for the IIWEM compared to 1,708,080 acres reported for the 2005 water-use compilation), and both datasets used 2005 data, 2005 NASS in the IIWEM, and 2005 values provided by Florida Department of Agriculture and Consumer Sciences for the 2005 water-use compilation. Conveyance loss and irrigation-system efficiencies were calculated by averaging conveyance-loss data reported to AWUDS in 1985, 1990, and 1995 and applying efficiencies of 90 percent to micro-irrigation (drip) systems, 80 percent to acres irrigated by sprinkler systems, and 70 percent to surface (flood) irrigation, producing a State average of 78 percent efficiency. The IIWEM produced an irrigation-withdrawal estimate 45 percent lower than Florida reported in 2005 (2,124,520 acre-ft estimated from the IIWEM compared to 3,070,654 acre-ft reported for the 2005 water-use compilation; fig. 19), even though the irrigated-acreage estimate used in the IIWEM was higher. This shows that the application rates coupled with system efficiencies and conveyance loss used in the 2005 water-use compilation could be significantly larger than what was used for the IIWEM. Also, the crop consumptive-use estimates may not be representative of the entire State of Florida and may need to be adjusted at a more local scale.

When comparing the IIWEM to reported 2005 values for California, the irrigation withdrawals were slightly different. The irrigation withdrawals estimated using the IIWEM were about 13 percent higher than the withdrawals reported for the 2005 water-use compilation (31,542,658 acre-ft were estimated with the IIWEM compared to 27,290,928 acre-ft reported for 2005). The irrigated-acreage values are very close, about 2 percent, so irrigated acreage is not considered to be a reason for the difference in irrigation withdrawals. The withdrawal rate from the 2005 data indicates just over 3.0 acre-ft per acre was applied on average throughout the entire State, whereas the IIWEM produced an average withdrawal-rate estimate of 3.4 acre-ft per acre, a difference of about 12 percent (fig. 19). The total system efficiencies used to estimate irrigation withdrawals with the IIWEM was 78 percent. This could be a contributing factor for the difference in irrigation withdrawals, because there are areas of California where a majority of irrigation is done by sprinkler and (or) micro-irrigation systems, which are more efficient than flood irrigation.

Washington's indirect comparisons also produced different results when compared to reported data from the 2005 water-use compilation. The estimate for irrigated acreage reported in the 2005 compilation and the acreage estimated using the IIWEM were very close and are not considered to be contributing sources of the difference. The withdrawals computed using the indirect method were larger than what was reported in the 2005 compilation (6,542,661 acre-ft estimated with the IIWEM compared to the 3,918,756 acre-ft reported in the 2005 compilation; fig. 19). The withdrawal-application rates subsequently are different; the IIWEM estimates an average of 3.68 acre-ft per acre, while the 2005 compilation data provides an average application rate of 2.15 acre-ft per acre. The irrigation-system efficiencies are averaged to 71 percent, which could be the source of the higher withdrawals estimated with the IIWEM. Additional knowledge of irrigation systems in Washington could help to decrease the irrigation-withdrawal estimate.

Lastly, the IIWEM differed from the 2005 water-use compilation data for Texas. The acreage estimate used in the IIWEM comparison and the acreage reported in the 2005 compilation were close (6,009,066 acres estimated using the IIWEM compared to 6,205,780 acres from the 2005 compilation) and are not considered to be major contributing sources of difference. When comparing withdrawal estimates in Texas, the results are very different (19,548,537 acre-ft estimated using the IIWEM compared to 8,737,452 acre-ft from the 2005 compilation). This produces different average-application rates; 3.25 acre-ft per acre were estimated using the IIWEM and 1.4 acre-ft per acre was reported in the 2005 water-use compilation. Crops that are grown in dry, windy climates and receive small amounts of annual rainfall, similar to the climate in west Texas, need to be irrigated. Also, the major crop grown in Texas is cotton, which is estimated to use over 2.7 acre-ft per acre (Borelli and others, 1998) of water annually, which

is almost 2 acre-ft per acre more than was reportedly applied, at a statewide level, according to the 2005 water-use compilation estimate. Thus, a statewide-application rate of 1.4 acre-ft per acre reported in the 2005 water-use compilation could be an underestimation. The indirect method used a 71 percent statewide irrigation-system and conveyance-loss efficiency, which is consistent with application rates in States with similar irrigation practices and climate.

The IIWEM compared favorably with the 2005 water-use compilation data for seven States, but was somewhat different for four other States. Using the IIWEM to compare results with reported irrigation-withdrawal data from other agencies can be a valuable tool to check how data compare at the State and county level. With local knowledge of irrigation practices in a State, coefficients could be refined for irrigation-system efficiencies and conveyance losses used in the method and could improve these estimates for each State. This method also can be applied at a more local (such as, regional or county) level to increase the accuracy of the method. Using this method, the States of Arizona, California, Idaho, Montana, New Mexico, Oregon, Utah, and Wyoming irrigated acreage and irrigation withdrawals were within 16 percent of what was estimated by the WSCs in 2005. Owing to the variety of data sources used in the IIWEM comparisons, especially data used from outside the 2005 water-use compilation, these results were able to reproduce, to an extent, the data reported in the 2005 water-use compilation and could be a good method to check data received from other agencies for upcoming water-use compilations.

Recommendations for Future USGS Irrigation Water-Use Compilations

The recommendations for future USGS water-use compilations focus on improving the methods and documentation in each WSC for the irrigation category. The irrigation category has three primary differences from other categories (such as, thermoelectric, mining, domestic) in the water-use report: (1) irrigation water-withdrawal estimates regularly depend upon the cooperation of individual private citizens (for example, farmers) to accurately report data to State agencies; (2) the spatial scale of land required for irrigation water use is vast, requiring between 1,000 to 9 million acres depending upon the State; and (3) there are a wide variety of techniques, assumptions, and data sources to consider when estimating water use for irrigation. These factors, combined with the fact that data are reported once every five years, demonstrate the need to have thorough documentation of sources and methods used to compile irrigation data. While not every recommendation presented in this report will be applicable to every WSC, application of these recommendations by most WSCs should lead to more comprehensive irrigation estimates in future USGS water-use compilations. Additionally, these recommendations may lead to more consistency in future USGS water-use compilations. More resources allocated to WSCs to collect water-use data would improve the quality of the data.

Estimating Conveyance Losses and Irrigation Efficiencies

In areas where metered data are unavailable and irrigation withdrawals are estimated, conveyance losses and irrigation-system efficiencies should be accounted for in irrigation-withdrawal estimates. Conveyance losses and irrigation efficiencies are properties that affect all States regardless of the amount of irrigation water used, if metered data are unavailable. Accounting for these two components will help to improve estimates of irrigation withdrawals. Conveyance losses can be estimated based on areas with similar regional characteristics that have known conveyance losses. The primary variables associated with conveyance losses are (1) water source (groundwater or surface water), (2) condition of irrigation canals/ditches/pipes, (3) distance transported, and (4) climatic conditions. An important indicating factor for estimating conveyance losses is determining if water applied to fields is from groundwater or surface water. Surface-water diversions often are transported longer distances through open-channel canal systems, while groundwater diversions are usually transported shorter distances through pressurized-pipe systems. The condition of open-air canal systems can vary widely from well-lined cement structures to shallow compacted dirt that has higher losses owing to infiltration or riparian vegetation along the canals (fig. 20). Unlike groundwater systems, open air surface-water systems can have additional losses through evaporation in dry or windy conditions. When these factors are considered, a reasonable estimate of conveyance losses can be determined.

Irrigation-system efficiencies are another component in estimating irrigation withdrawals. Irrigation-system efficiencies are more easily quantified with percent ranges of efficiencies associated with different irrigation systems. Center-pivot and sprinkler systems range from 55 to 98 percent (fig. 21); surface (flood) irrigation systems range from 50 to 95 percent efficient (fig. 22); and micro-irrigation (drip) systems range from 70 to 95 percent efficient (fig. 23) (Howell, 2003). Unless there is additional site-specific information, values from the 2003 “Irrigation Efficiency” report by Terry Howell can provide reasonable estimates of irrigation-system efficiency for a wide range of conditions (table 2).

Estimating Golf Course Irrigation Data

Golf course irrigation withdrawals can affect the total irrigation withdrawals, particularly for smaller States. The majority of States with reported total irrigation withdrawals of less

Figure 20. Concrete-lined canals in Maricopa County, Arizona (top photo) and unlined irrigation canal in Yuma County, Arizona (bottom photo). (Photographs by Saeid Tadayon, U.S. Geological Survey.)

Figure 21. Alfalfa irrigated by a center-pivot system in Yuma County, Arizona (top). (Photograph by Brandon Forbes, U.S. Geological Survey.) Corn irrigated by sprinkler system in eastern South Dakota (bottom). (Photograph by Kathleen Neitzert, U.S. Geological Survey.)

than 120,000 acre-ft/yr can be greatly affected by reporting golf course withdrawals. States with irrigation withdrawals over 120,000 acre-ft/yr are less affected when including golf course data. It is still recommended that all WSCs, regardless of their total irrigation withdrawals, estimate golf course withdrawals separately from crop irrigation withdrawals.

There are many methods that can be used to determine golf course irrigation withdrawals, and extrapolation from statistical sampling represents an effective technique for estimation. Through using contact information provided by golf course database Web sites such as *www.golfable.com* or *www.golfnationwide.com*, golf course management personnel can be reached for withdrawal data. With a statistically significant sample size of golf course withdrawals, as described by Luckey (1972) and Helsel and Hirsch (1995), in combination with additional information available on golf course Web sites, a withdrawal per acre, per hole, or per yard can be estimated.

If golf course acreage and withdrawals are estimated, then the data should be presented separately from the crop irrigation data. If a WSC does not estimate golf course acreage and withdrawals, then the WSC should clearly state this in their documentation to ensure that long-term trends still can be analyzed despite gaps in data. This will prevent any ambiguity in water-use trends caused by any omission of golf course data, since reporting golf course data remains optional in the USGS water-use compilation.

Maintaining a Consistent Methodology to Establish Irrigation Water-Use Trends

One of the objectives of the USGS water-use compilation is to establish long-term statewide and nationwide trends in water use. These trends are important indicators of the impacts of population, land-use change, and conservation measures on a State's water resources. Trends in irrigation water use are subject to variations in methods and data availability from one compilation to the next. Unlike other categories of water use, such as, thermoelectric power, mining, and industrial, that have highly localized water use, irrigation water use covers vast areas. This spatial challenge requires a methodology that accounts for factors such as climatic conditions, conveyance losses, and irrigation efficiencies, among others. Changes in these parameters can affect the total irrigation water-use estimate. Variations in the irrigation water-use estimate from one compilation year to the next may be owing to a change in methods, and not to actual changes in

Figure 22. Surface (flood) irrigation of an alfalfa field in Maricopa County, Arizona. (Photograph by Saeid Tadayon, U.S. Geological Survey.)

Figure 23. Subsurface-drip irrigated melon field in La Paz County, Arizona (top). (Photograph by Saeid Tadayon, U.S. Geological Survey.) Drip-irrigated mango crop in Santa Isabel, Puerto Rico (bottom). (Photograph by Jose M. Rodriguez, U.S. Geological Survey.)

water use. Changes to the methods and parameters of irrigation water-use estimates need to be documented.

Recommendations to Improve Irrigation Water-Use Documentation

While there is no standard method to determine an irrigation water-use estimate, there is a need to more sufficiently describe how the irrigation data were determined. Thorough documentation of sources and methods that each WSC used to compile irrigation data is necessary for consistency in future compilations. Detailed documentation allows for refinement of sources and methods in future water-use compilations. This also allows for the users of the irrigation data to gain more understanding of how the data were compiled by each WSC. It is important to document data sources, assumptions, and techniques used to estimate and compile irrigation data.

A suggested template illustrates a way to organize the irrigation category of the USGS documentation (fig. 24). The table organizes the values, sources, and other ancillary information for each irrigation component. With data presented in a tabular form, a reviewer can easily understand the data sources and methods used to estimate irrigation data. This table provides a universal template for presenting irrigation data independent of the sources or methods used by each WSC. There can be additional description of sources, methods, and any ancillary data below the table in paragraph format. The essential points that should be addressed by the documentation include all sources (agencies, universities, documents, etc.) used to estimate irrigated acreage or irrigation withdrawals, along with information that will allow future compilers to refer to those sources. Important questions that should be documented regarding methods used to estimate irrigation withdrawals include how irrigation water use was estimated, what sources were used, and providing any calculations used, if necessary, for water withdrawals, irrigated acreage, golf course water use, conveyance losses, and system efficiencies. If time permits, an analysis of the reported data, comparison to previously reported data, and any improvements that could be made for future compilations also should be included. This template can be easily updated for each 5-year compilation.

System for Rating Irrigation Water-Use Data

A qualitative rating system was developed to allow the option for WSCs to rate the overall quality of their irrigation water-use data. This can be applied on a statewide level, but is more insightful at smaller spatial scales, such as counties, basins, or regions. This will allow for a general comparison of data quality that can be applied throughout the United States. Based on the general descriptions of each ranking, the WSCs can match their irrigation-withdrawal data with an associated qualitative rank.

Excellent:

- Use of field verification to identify irrigated acreage and irrigation-system type
- Use of aerial photographs and (or) satellite imagery to delineate acreage
- Use of acreage reported by farmers to permitting agency
- Groundwater and surface-water withdrawals are metered or gaged and reported
- Agencies provide access to methods of reported acreage and withdrawal data

Good:

- Some use of field verification to identify irrigated acreage and irrigation-system type
- Use of aerial photographs and (or) satellite imagery to delineate acreage
- Groundwater and surface-water withdrawals are metered or gaged in areas of the State
- Use of power data to estimate irrigation withdrawals
- Use of ET methods (for example, Blaney-Criddle, Penman-Monteith, and others) to estimate withdrawals or check reported withdrawals
- Irrigation-withdrawal estimates include conveyance loss and irrigation-system efficiencies
- Use of multiple sources to compare and validate irrigated acreage and irrigation withdrawals
- Agencies provide access to methods of reported acreage and withdrawal data

Fair:

- Limited use of field verification, aerial photography, satellite imagery, or power data to estimate irrigated acreage or irrigation-system type
- Use of agricultural-census data (for example, Census of Agriculture, FRIS, Annual Agricultural Statistics Reports, and others) to estimate irrigated acreage, irrigation-system type, and (or) irrigation withdrawals
- Use of data from outside the compilation year
- Irrigation-withdrawal estimates include conveyance loss and irrigation-system efficiencies

Poor:

- No use of field verification, aerial photography, satellite imagery, or power data to estimate irrigated acreage or irrigation withdrawals
- Irrigated-acreage estimates and irrigation-system types are received directly from a third party with no validation of received data
- Irrigation-withdrawal estimates are received from agencies with no validation of received data
- No metered or gaged groundwater or surface-water withdrawals
- Withdrawal estimates do not include estimates for conveyance loss or irrigation-system efficiencies
- Information is collected from agencies with little or no documentation

State: State Name Unabbreviated
Compiler: WSCs Primary Compiler
Date Submitted: Month Year
Contact Email: Primary USGS.gov Email
Contact Phone: (XXX) XXX-XXXX
Contact Address: Address of WSC
Statewide Agricultural Water Use Estimate: Presented in Mgal/day (and thousand acre-ft/yr)

Sub-category	Value	Main source(s) of data	Worth noting/brief summary/method of estimation
Irrigated crop acreage	Crop acreage. Value just represents crop-based acreage (omit golf courses, pasture, etc.)	List of sources and describe the data provided	Briefly discuss method of estimation
Acreage irrigated by type of system	Sprinkler, microirrigation, and surface (flood) presented in acreage and percent	List of sources and describe the data provided	Briefly discuss method of estimation
Crop irrigation rates (inches/year)	List values by various crop type (for the most common crops)	List of sources and describe the data provided	Briefly discuss method of estimation
Irrigation system Efficiencies	Sprinkler, microirrigation, and surface (flood) efficiencies presented as a minimum/maximum range or state-wide average	List of sources and describe the data provided	Briefly discuss method of estimation
Water withdrawals	Crop water withdrawals presented in both thousand acre-ft/yr and Mgal/day	List of sources and describe the data provided	Briefly discuss method of estimation
Water sources	Groundwater and surface water totals presented in thousand acre-ft/yr and Mgal/day and percentage of total	List of sources and describe the data provided	Briefly discuss method of estimation
Conveyance losses	Estimate in both thousand acre-ft/year and Mgal/day	List of sources and describe the data provided	Briefly discuss method of estimation
Golf course acreage	Total irrigated golf course acreage (NA if not estimated for compilation)	List of sources and describe the data provided	Briefly discuss method of estimation
Golf course withdrawals	Golf course withdrawals presented in both thousand acre-ft/yr and Mgal/day (NA if not estimated for compilation)	List of sources and describe the data provided	Briefly discuss method of estimation
Pasture irrigated acreage	Total irrigated pasture acreage (NA if not estimated for compilation)	List of sources and describe the data provided	Briefly discuss method of estimation
Pasture irrigation withdrawals	Pasture withdrawals presented in both thousand acre-ft/yr and Mgal/day (NA if not estimated for compilation)	List of sources and describe the data provided	Briefly discuss method of estimation
Horticulture irrigated acreage	Total irrigated horticultural acreage (NA if not estimated for compilation)	List of sources and describe the data provided	Briefly discuss method of estimation
Horticulture withdrawals	Horticulture withdrawals presented in both thousand acre-ft/yr and Mgal/day (NA if not estimated for compilation)	List of sources and describe the data provided	Briefly discuss method of estimation

Figure 24. Image of a suggested template for documenting irrigation water use with example data presented in blue.

Summary and Conclusions

The U.S. Geological Survey (USGS) National Water Use Information Program (NWUIP) is the only program that reports both irrigated acreage and irrigation withdrawals every five years for the entire United States, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands. Irrigation water use accounted for 31 percent (more than 143 million acre-feet per year) of total water use in the United States in 2005 (Kenny and others, 2009). This report presents (1) key factors affecting irrigated-acreage and irrigation-withdrawal estimates, (2) sources of data used for the 2005 NWUIP to estimate irrigated acreage and irrigation withdrawals, (3) a comparison of USGS-reported irrigated acreage to other sources of acreage, (4) comparisons of estimated irrigation withdrawals to USGS-reported irrigation withdrawals, (5) suggestions for improving future compilations, and (6) a summary of the sources and methods used by each Water Science Center (WSC) to estimate irrigation data.

There are a variety of factors that may contribute to changes in irrigated-acreage and irrigation-withdrawal estimates. When estimating irrigation water use, key factors affecting every WSC are conveyance losses and irrigation-system efficiencies. Other elements contributing to total irrigation withdrawals are pasture, horticulture, golf courses, and double cropping. To develop more comprehensive estimates for total irrigation withdrawals, these elements should be included in estimates and documentation.

Irrigated-acreage and irrigation-withdrawal estimates for 2000 and 2005 for each WSC are documented in this report. WSC documentation also was reviewed to understand the sources and methods used by each WSC. The main sources of irrigated-acreage data used by WSCs for the 2005 USGS water-use compilation were the 2002 Census of Agriculture, 2003 Farm and Ranch Irrigation Survey (FRIS), National Agricultural Statistics Service (NASS), and local and State agencies. The main sources of irrigation-withdrawal data for the 2005 USGS water-use compilation were the 2003 FRIS-application rates, reference evapotranspiration equations, and information reported to permitting agencies. Comparisons were made using the 2000 and 2005 USGS-reported irrigated acreage to the Census of Agriculture and FRIS irrigated acreage, which showed an increase in the total irrigated acreage from 1997 to 2007 (Census of Agriculture) and 1998 to 2008 (FRIS), while the total irrigated acreage reported by the USGS decreased.

Irrigation withdrawals were estimated for 11 States using an indirect method and compared to data reported by those WSCs using the 2005 USGS water-use compilation. A comparison using acreage from the 2009 Cropland Data Layer (CDL), crop water requirements, and estimated irrigation-system efficiencies was completed in Arizona, California, and Utah. The average estimated withdrawals were within 5 percent of the irrigation withdrawals reported to Aggregate Water Use Data System (AWUDS) for the 2005 USGS water-use compilation. In an additional eight States, acreage from sources including NASS and others, crop consumptive use, and estimated irrigation-system efficiencies were used as a comparison to estimated irrigated acreage and irrigation withdrawals reported in 2005. The average irrigation withdrawals were within about 15 percent of the values reported in 2005.

Recommendations and documentation for improving irrigation estimates are presented in this report. Golf courses can be large users of irrigation water. Proper documentation of sources and methods or the decision not to estimate golf course acreage and irrigation withdrawals should be documented in order to maintain a consistency of estimation for future compilations. Conveyance loss and irrigation-system efficiencies are essential components of total irrigation withdrawals and should be included when estimating irrigation withdrawals. Thoroughly documenting sources and methods used to estimate irrigated acreage and irrigation withdrawals is important for creating and maintaining trends in irrigation water-use estimates.

A summary of data sources and methods used by each WSC to estimate irrigated acreage and irrigation withdrawals for the 2000 and 2005 compilations is presented in appendix 1. The summary discusses sources for irrigated acreage and irrigation withdrawals, methods used to estimate irrigation withdrawals, sources and methods used to estimate golf courses, if included, and any ancillary information available for that WSC.

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Glossary

The following terms are referenced in the text or are part of the irrigation water-use vocabulary.

application rate Rate at which water is applied to a given area. Usually expressed as units of depth per time.

biofuel crop Crops whose biomass materials can produce fuel; including corn, switchgrass, soybeans, sugarcane, etc.

consumptive use The part of water withdrawn that is evaporated, transpired, incorporated into products or crops, consumed by humans or livestock, or otherwise removed from the immediate water environment. Also referred to as water consumed.

conveyance loss 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.

crop requirement The volume of water required by the crop to maintain optimum growth.

double cropping The practice of sequentially raising and harvesting a second crop on the same field in a single growing season. Growing more than two crops in a season in multicropping.

effective precipitation The precipitation that is effective in meeting the consumptive-use needs of a crop and may not be equal to the total precipitation.

horticulture The science, skill, or occupation of cultivating plants, especially flowers, fruit, vegetables, and ornamental plants, in gardens or greenhouses.

irrigation efficiency The ratio of the average depth of irrigation water that is beneficially used to the average depth of irrigation water applied, expressed as a percent. Beneficial uses include satisfying the soil-water deficit and any leaching requirement to remove salts from the root zone.

irrigation requirement For planning purposes, the total amount of water required at the field to produce the crop, less natural sources of water such as precipitation or subsurface water.

irrigation water use Water that is applied by an irrigation system to assist crop and pasture growth, or to maintain vegetation on recreational lands such as parks and golf courses. Irrigation includes water that is applied for pre-irrigation, frost protection, chemical application, weed control, field preparation, crop cooling, harvesting, dust suppression, leaching of salts from the root zone, and conveyance losses.

micro-irrigation An irrigation system that wets only a discrete portion of the soil surface in the vicinity of the plant by means of applicators (such as orifices, emitters, porous tubing, or perforated pipe) and is operated under low pressure. The applicators may be placed on or below the surface of the ground or suspended from supports.

pasture Ground that is set aside for grass and other growing plants that are suitable food for livestock.

pre-irrigation The application of water to cropland before planting to assure adequate soil moisture for crop germination and early plant growth.

sprinkler irrigation An irrigation system in which water is applied by means of perforated pipes or nozzles operated under pressure so as to form a spray pattern.

surface irrigation Irrigation by means of flood, furrow, or gravity. Flood irrigation is the application of irrigation water in which the entire soil surface is covered by ponded water. Furrow irrigation is a partial surface-flooding method of irrigation normally used with clean-tilled crops in which water is applied in furrows or rows of sufficient capacity to contain the design irrigation stream. Gravity is an irrigation method in which water is not pumped, but flows in ditches or pipes and is distributed by gravity.

water withdrawal Water removed from the ground or diverted from a surface-water source. The amount of water withdrawn may not equal the amount of water used owing to water losses.

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Appendices 1–3

Appendix 1. Summary of Sources of Information and Methods Used by Each Water Science Center to Collect Irrigated Acreage and Irrigation Withdrawals for the 2005 USGS Water-Use Compilation

This section presents summaries of the sources of data and methodologies used to estimate the irrigated acreage and amount of irrigation withdrawals by each WSC as reported to regional water-use specialists and used in the 2005 USGS water-use circular (Kenny and others, 2009). The best available information was used in summarizing these data and methods, including personal communications with most of the WSCs. Where information from WSCs was not available, summaries were synthesized from documentation that was submitted to the regional water-use specialists. In the individual unpublished reports for each WSC, information was provided on source and methodology for collecting irrigated acres and irrigation withdrawals, whether or not golf course and horticulture irrigation were included in the irrigation category and how they were estimated. Twelve WSCs published reports covering the data and methods used for the 2005 USGS water-use compilation on irrigation as well as the other categories. The WSCs that published reports include Alabama (Hutson and others, 2009), Arkansas (Holland, 2007), Colorado (Ivahnenko, 2009 and Ivahnenko and Flynn, 2010), Florida (Marella, 2009), Georgia (Fanning and Trent, 2009), Louisiana (Sargent, 2007), Oklahoma (Tortorelli, 2009), Puerto Rico (Molina-Rivera and Gomez-Gomez, 2008), South Dakota (Carter and Neitzert, 2008), Washington (Lane, 2009), West Virginia (Atkins, 2007), and Wisconsin (Buchwald, 2009). If available, information on type of irrigation system, source of irrigation water withdrawals, and any changes in estimation methodology between the 2000 and 2005 WSC documentation also is presented.

Alabama

The Alabama WSC used the 2003 Farm and Ranch Irrigation Survey (FRIS; U.S. Department of Agriculture, 2004b) to estimate irrigated acreage along with the type of irrigation system for the 2005 USGS water-use compilation, with WSC and FRIS personnel collaborating for data exchange. Withdrawals were estimated using crop acreage from FRIS and applying an application rate based on irrigation system used and crop type. Of the crops that were irrigated, 97 percent were irrigated by sprinklers, 2 percent were irrigated with micro-irrigation systems, and less than 1 percent was irrigated by surface (flood) irrigation. In the 2005 USGS water-use compilation, it was assumed that consumptive use for irrigation purposes was 100 percent. In 2005, golf course irrigation was included in the irrigation category and was estimated using a relation between the number of holes and average irrigation per hole depending upon the classification of the golf course and its watering needs. Golf courses classified as Tier 1 were watered extensively, Tier 2 courses were watered frequently, and Tier 3 golf courses were watered only when necessary with priority given to greens and tees. It was assumed that all withdrawals for golf course irrigation were from surface-water sources. Estimates of golf course withdrawals increased greatly between the 2000 and 2005 USGS water-use compilations, in part because of improved accounting of the number of courses, with over 200 estimated in Alabama in 2005 compared to only 13 golf courses in 2000. Horticulture was included for the first time in the 2005 compilation. The number of horticultural acres was approximated using an estimate of the number of acres from the “Nursery Guide” (Alabama Department of Agriculture and Industries, 2007) and an application rate of 1.22 Mgal/d of water per acre (3.74 acre-ft/yr of water per acre), estimated by surveying multiple nurseries in Alabama.

Alaska

The Alaska WSC estimated a very small amount of water for irrigation purposes, owing to a limited growing season, which begins in May and ends in early August. The number for irrigated acreage came from the 2003 FRIS report (U.S. Department of Agriculture, 2004b) and through verbal conversations with farmers and the State of Alaska Division of Agriculture. An application rate of 0.0003 Mgal/d per acre (0.34 acre-ft/yr per acre) from the 2003 FRIS report (U.S. Department of Agriculture, 2004b) was used to estimate irrigation withdrawals. The Alaska Department of Natural Resources designates water rights to users, but permits are issued for much greater amounts of water than is used. Golf course withdrawals were estimated separately from crop irrigation but were included in the irrigation totals for the 2000 and 2005 USGS water-use compilations. An assumed application rate of 0.0008 Mgal/d per acre (0.897 acre-ft/yr per acre) was multiplied by the estimated number of golf course acreage in Alaska to estimate withdrawals for golf course use. There was no horticulture that occurred in 2000 or 2005. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 compilations.

Arizona

The Arizona WSC used primarily the "2005 Arizona Agricultural Statistics Bulletin" (U.S. Department of Agriculture, 2006) to estimate irrigated acreage for the 2005 USGS water-use compilation. When county-level data were not disclosed by Arizona Agricultural Statistics Service (AASS), the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) was used to fill in the unavailable data. The Arizona WSC began field verification of selected areas in 2004. The data from 2004 and later years field verification were used to compile irrigated acreage in these selected areas for the 2005 water-use compilation. For the 2000 USGS water-use compilation, the 2000 AASS (U.S. Department of Agriculture, 2001) was the primary source of irrigated acreage with the 1997 Census of Agriculture (U.S. Department of Agriculture, 1999b) used to supplement irrigated acres in areas that the AASS did not disclose. Total county and (or) area irrigation withdrawals were estimated based on crop acres, consumptive-water requirement rates by crop, and irrigation efficiency. Consumptive-water requirement rates for crops were determined from the modified Blaney-Criddle method as described by the U.S. Bureau of Reclamation (U.S. Bureau of Reclamation, 1992). The modified Blaney-Criddle method requires inputs of latitude, average monthly temperature, total monthly precipitation, crop type, and crop planting and harvesting dates. County and (or) area irrigation-system efficiencies were used in conjunction with irrigated crop acreage and consumptive-water requirement rates to estimate total withdrawals. The county-level and (or) area efficiencies also include conveyance loss and application losses. When metered surface-water withdrawals were available for a county, groundwater withdrawals were estimated by subtracting the metered surface water from the total irrigation withdrawals. The methods for estimating irrigation withdrawals were the same for the 2000 and 2005 USGS water-use compilations. Irrigated acreage and irrigation withdrawals for golf courses and horticulture were not included in the 2000 or 2005 USGS water-use compilations.

Arkansas

The Arkansas WSC obtained crop-acreage and irrigation-withdrawal data from the Arkansas Natural Resources Commission (ANRC) for the 2005 USGS water-use compilation. Conservation District secretaries, located in 27 counties in eastern Arkansas and 2 counties in southwest Arkansas, work together under a Memorandum of Understanding (written agreement) to collect agricultural water-use data for ANRC. The Conservation District secretaries (housed at the USDA–Natural Resources Conservation Service offices) conduct annual interviews of farmers and require them to pay a registration fee for each withdrawal site on their property; these data are conveyed to the ANRC. The USGS and ANRC work under a cooperative agreement to collect water-use data for Arkansas, and the WSC has direct access to the reported acreage and withdrawal data. Farmers estimate irrigation withdrawals based on the number of times water is applied to the field and by using an average of about 3 in. per application or from inline flowmeter readings. Farmers also report to the ANRC the types of irrigation systems used on their farms. In the 2000 USGS water-use compilation, golf course irrigation was included in the irrigation category. In 2005, however, golf course irrigation was included in the commercial category. In the 2005 USGS water-use compilation, horticulture was compiled separately and included in the totals for the irrigation category. The methodology for collecting and reporting irrigated acres and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations, with the exception of the change in which category golf course estimates are located.

California

The California WSC used estimates of irrigated acreage and irrigation withdrawals from the California Department of Water Resources (CADWR). CADWR conducts inventories of irrigated lands, by county, about once every 10 years; the data inventory used for this effort was conducted in 2002 for the 2001 growing season. The irrigated lands from these surveys were used to tabulate county irrigated acreage in the 2000 and 2005 USGS water-use compilations. Remote-sensing and ET values, by crop type, are used with the irrigated acreage to compute irrigation withdrawals and consumptive-water use. Golf courses were included in the 2000 USGS water-use compilation but were not included in the 2005 USGS water-use compilation. Horticulture was not included in the irrigation category for the 2000 or 2005 USGS water-use compilations.

Colorado

The Colorado WSC used the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) and NASS (U.S. Department of Agriculture, 2006) to estimate the irrigated acreage reported in the 2005 USGS water-use compilation. In 2000 and 2005, the Blaney-Criddle ET Model (Blaney and Criddle, 1950) was employed to estimate ET, which then was used for estimating irrigation withdrawals. In the 2005 compilation, irrigation water requirements were calculated using a program created by the Colorado Division of Water Resources (CODWR). The model estimates irrigation water requirements using alfalfa as the

reference crop and applying a crop coefficient for other crop types. Surface-water diversion data for irrigation were collected by the CODWR. There was no mention of golf course estimates in the 2000 USGS water-use compilation. Estimates of irrigation for golf courses were included in the irrigation category for the 2005 USGS water-use compilation. These values were estimated by sending surveys to the golf course superintendents inquiring about the irrigated acreage and amount of withdrawals for irrigating golf courses. For golf courses that did not respond to the survey, an online search for number of holes and acres was conducted and estimates based on irrigation rates for other golf courses in the county were developed. Horticulture was included in the irrigation category for the 2005 USGS water-use compilation. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations, with the exception of the change in golf course estimation in 2005.

Connecticut

The Connecticut WSC estimated irrigated crop acreage by using the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) and the NASS (U.S. Department of Agriculture, 2006). The State Extension Service reported that there were no crops irrigated by surface (flood) methods, 90 percent of crops were irrigated by sprinkler, and 10 percent of crops were irrigated using micro-irrigation. The following equation was applied to each county to estimate withdrawals for crop irrigation:

$$(a \times b \times 2c \times 27200d) \times 0.000001 = f \times (124e) \quad (1)$$

where

- a is irrigated acreage;
- b is number of irrigation applications required;
- c is number of inches of irrigation water needed to bring soil to field capacity per irrigation application;
- d is number of gallons of water per acre for each inch of irrigation water applied;
- e is number of days in the growing season to obtain an average seasonal rate of water application; and
- f is estimated water used for a county in million gallons per day.

Golf course acreage and withdrawals were computed for the 2005 USGS water-use compilation but were not reported separately and cannot be separated from crop data. Golf course acreage was estimated using GIS analyses with the following equation used to estimate the golf course withdrawals:

$$a \times 43{,}560 \times b \times (1/12) \times 7.48 \text{ gallons/1 cu.ft. * 13 weeks (growing season) =}$$
$$[(c)\ 1\text{yr}\ /365\ \text{days}]\ /\ 1{,}000{,}000 = \text{Mgal/d} \quad (2)$$

where

- a is total acreage of irrigated golf courses;
- b is inches of water applied per week; and
- c is gallons per year of golf course irrigation.

Horticulture was included in the irrigation category for the 2005 USGS water-use compilation; however, it is only a small portion of the total irrigation in Connecticut. The methodology for collecting and reporting data remained unchanged between the 2000 and 2005 USGS water-use compilations.

Delaware

The Maryland-Delaware-District of Columbia WSC used 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) data to estimate crop acreage and water withdrawals for irrigation for the 2005 USGS water-use compilation. Irrigation withdrawals are supposed to be reported monthly to the Delaware Department of Natural Resources and Environmental Control; however, withdrawals often are underreported and the WSC was unable to use this information. Instead, a coefficient based on climate and the year's precipitation, along with the estimated irrigated acreage, was used to estimate withdrawals. The Delaware Extension Service estimated the amount of irrigation withdrawals that were from groundwater and surface water. It is uncertain if golf course irrigation was included in the irrigation category for the 2000 or 2005 USGS water-use compilations. Acreage and withdrawals for horticulture were not estimated in 2005. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

District of Columbia

The only form of irrigation contained in the 2005 USGS water-use compilation for the District of Columbia was irrigated golf courses; there was no irrigation for agricultural purposes. There are six golf courses in the District of Columbia: three are 18 hole and three are 9 hole, for a total of 81 holes. The golf course superintendents verified whether or not irrigation was ongoing. A coefficient was derived from an 18-hole golf course in nearby Montgomery County, Maryland, which averaged about 0.04 Mgal/d (44.84 acre-ft/yr) or 0.0022 Mgal/d per hole (2.47 acre-ft/yr per hole) of surface water for irrigation. This coefficient was applied to the 81 holes to estimate the water withdrawals for golf course irrigation. The methodology for collecting and reporting golf course information remained unchanged between the 2000 and 2005 USGS water-use compilations. Horticulture was not estimated in 2000 or 2005. Golf course irrigation data were not collected prior to the 2000 USGS water-use compilation.

Florida

The Florida WSC used information provided by the five Water Management Districts (WMDs) and the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) to estimate irrigated acreage and irrigation-water withdrawals. The 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) was the main source of acreage data and was supplemented with the 2005 Florida Agricultural Statistics Service (Florida Department of Agriculture and Consumer Sciences, 2006), when 2005 data were available. Withdrawals were estimated by multiplying application rates from the WMDs by the irrigated acreage and by irrigation-system efficiencies. Golf courses were included in the irrigation category for the 2005 USGS water-use compilation. Golf course acreage was estimated by applying a coefficient of 6 acres to the number of holes in the State. A water-use coefficient then was applied to this estimate of acreage to estimate the golf course withdrawals. Horticulture, which is a large part of the irrigation water use in Florida, was estimated based on acreage provided by the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) and the 2005 Florida Agricultural Statistics Service (Florida Department of Agriculture and Consumer Sciences, 2006), when 2005 data were available. Acreage was multiplied by crop coefficients provided by each WMD based on the type of horticulture. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained mostly unchanged between the 2000 and 2005 USGS water-use compilations.

Georgia

Irrigated crop acreage and estimated irrigation withdrawals were provided to the Georgia WSC by the University of Georgia Cooperative Extension Service (CES) using information from a survey conducted by the CES in 2004. The CES provided crop acreage and withdrawals in millions of gallons per day for all irrigation methods. The WSC collated the irrigated acreage, by system type, into the USGS water-use categories. It was assumed that there was 100 percent consumptive use and 0 percent conveyance loss related to irrigation in Georgia. Golf course acreage was estimated by applying a coefficient of 5.5 acres per hole for every golf course in Georgia. Golf course withdrawals were estimated for the 2000 USGS water-use compilation by applying an annual water-use coefficient of 20 in/yr for the previously estimated irrigated acreage of every course. The 2000 estimates were used for 2005, as no updated information on golf courses was available. Golf courses are permitted by the Georgia Environmental Protection Division either under agricultural permits (still not fully required to report water use) or under municipal/industrial permits depending upon the location of the golf course. However, available reported water use for golf courses was not used in favor of the consistent statewide estimate. Horticulture was included in the CES survey; therefore it was included in the 2000 and 2005 USGS water-use compilations. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Hawaii

The Pacific Islands WSC estimated the irrigated crop acreage by using the Hawaii Agricultural Statistics Service for 2005 data. It was assumed that all crops were irrigated using micro-irrigation, with no irrigation via surface (flood) or sprinkler-irrigation methods. Conveyance losses were accounted for by assuming a 15 percent loss in all counties. The Pacific Islands WSC obtained irrigation groundwater and surface-water withdrawal information from the Hawaii State Commission on Water Resource Management (CWRM). Because the CWRM does not receive data for most of the surface-water withdrawals in Hawaii, the use of surface water was estimated by back-calculating from the minimum amount of water needed for irrigation of the four major crops and all golf courses, multiplied by the estimated number of acres of those crops and golf courses, and then subtracting the amount of withdrawal from groundwater wells. No effort was made to verify the results from back-calculating. Irrigation of golf courses was included in the 2005 compilation. A list of golf courses throughout the State was retrieved from

the Internet with acreage estimated from the list. All 18-hole golf courses were assumed to be 200 acres. Additionally, it was assumed that all golf courses were irrigated using sprinkler systems. The water requirement that was used for golf courses was 1 Mgal/d (1,121 acre-ft/yr) for every 200 acres in each county. The methodology for collecting and reporting irrigated acreage remained unchanged between the 2000 and 2005 USGS water-use compilations. The methodology for collecting and reporting irrigation withdrawals changed between the 2000 and 2005 USGS water-use compilations because the 2005 compilation included the back-calculated water-use amounts in addition to limited surface-water withdrawal information from CWRM.

Idaho

The Idaho WSC used estimated county data reported from the 2005 Idaho Agricultural Statistics Service to tabulate irrigated crop acreage. Withdrawals were estimated using these data and crop irrigation needs based on ET values from the University of Idaho Research and Extension Center in Kimberly, Idaho, and irrigation-system types. Acreage irrigated by system types was based on the 2005 county irrigated crop acreage and 2000 percentages for irrigation-system types. Crop irrigation requirements are based on ET data, which considers the crop type, geography, and weather data. ET data are used to determine the minimum volume of water that is required; total withdrawals consider the water-conveyance systems and irrigation-system types. Some counties had measured surface-water diversions, and these data were used as a correction to estimated data based on crop type, ET, and irrigation-system type. Irrigation for golf courses was estimated separately from crop irrigation. There were no new golf courses constructed between 2000 and 2005; therefore, the same acreage was used for the 2005 USGS water-use compilation as for 2000. ET data also were used to estimate irrigation withdrawals based on minimum grass irrigation needs for golf courses. Horticulture was not included in the 2005 USGS water-use compilation. The methodology for collecting and reporting irrigated acres and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Illinois

The 2002 Census of Agriculture report (U.S. Department of Agriculture, 2004a) was used by the Illinois WSC to estimate irrigated crop acreage. Irrigation withdrawals were estimated using a combination of data. For all but a few counties, a rainfall-deficit method was used, where water withdrawals were considered as a supplement to rainfall to satisfy estimated crop demands of 1.25 in. of water per week. Rainfall data were obtained from daily values provided in monthly climatic reports prepared by the National Oceanic and Atmospheric Administration–National Climatic Data Center. Total irrigation in each county was estimated as the product of the application rate (rainfall deficit) and irrigated acreage. Where available, irrigation withdrawals reported to the Illinois State Water Survey are used to supplement the rainfall-deficit based estimates. For two of the most irrigated counties, a well-tested relation with power consumption is used to estimate irrigation withdrawals. In 2005, golf courses were included in the irrigation category and were estimated separately from crop acreage and withdrawals. Golf course acreage was estimated by multiplying the total length of each golf course by a constant width. Primarily, the rainfall-deficit method was used to estimate golf course irrigation withdrawals. Where available, irrigation withdrawals reported to the Illinois State Water Survey were used to supplement the rainfall-deficit based estimates. Horticulture was estimated for the 2005 USGS water-use compilation by using estimates from the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a). The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations, except for the separate inclusion of golf course estimates in 2005.

Indiana

The Indiana WSC estimated irrigated crop acreage using the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a). In counties where the Census of Agriculture was incomplete for irrigated acreage, estimates were made based on the acreage reported in previous Census of Agriculture publications. All of the acreage in Indiana was assumed to be irrigated using the sprinkler method because the irrigated acreage by alternative methods was very small. The Indiana Department of Natural Resources–Division of Water requires annual reporting of withdrawals from wells that are capable of pumping 0.1 Mgal/d (112.1 acre-ft/yr); the WSC was able to gather this information for use in the 2005 USGS water-use compilation. In 2005, it was assumed that there was no conveyance loss associated with crop irrigation. Irrigation for golf courses was not included in the irrigation category for either the 2000 or 2005 USGS water-use compilations. Horticulture was not estimated for either the 2000 or 2005 USGS water-use compilations. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Iowa

The Iowa WSC used data provided by the Iowa Department of Natural Resources (IDNR) to estimate the number of irrigated acreage and irrigation withdrawals. The IDNR requires that any user withdrawing 25,000 gal or more from any source—well, stream, and (or) reservoir/lake—in a single day have a permit and that every user report annually the total amount of water withdrawn, including no withdrawals. The WSC assumed that the method of irrigation was sprinkler for all irrigation. Irrigated acreage and irrigation withdrawals for golf courses were included in the irrigation category of the 2000 and 2005 USGS water-use compilations. Golf course acreage and withdrawals also were estimated by the IDNR. There were no reported withdrawals or acreage irrigated for horticulture in the 2005 USGS water-use compilation. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Kansas

The Kansas WSC used information reported to the Kansas Department of Agriculture–Division of Water Resources (DWR) through that agency's annual water-use report program for the irrigation estimates for the 2005 USGS water-use compilation. According to State law, all irrigation water use requires a permit and annual reporting of water use and acres irrigated. More than 95 percent of the irrigation in Kansas is from groundwater. Additional data on withdrawals and irrigated acreage were obtained from the U.S. Bureau of Reclamation for areas receiving surface water from U.S. Bureau of Reclamation irrigation districts in 2005. Irrigated acreage within privately owned surface-water irrigation districts in southwest Kansas were partially estimated using application rates from 2000. Self-supplied golf courses also are permitted and report withdrawals and acres irrigated to DWR; this information was compiled separately from crop irrigation by the WSC for the 2005 USGS water-use compilation. Horticultural water use is reported to the DWR and was included in the crop irrigation category, but does not represent an appreciable amount of use. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Kentucky

The 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) was used by the Kentucky WSC to estimate irrigated acres for the 2005 USGS water-use compilation. The 2003 FRIS (U.S. Department of Agriculture, 2004b) was used to estimate the distribution of irrigation systems in Kentucky with 90 percent of acres irrigated by sprinkler methods, 6 percent by surface (flood) methods, and 4 percent irrigated using micro-irrigation. In order to estimate withdrawals for crop irrigation, the irrigated acreage was multiplied by 130,341 gal per year (146.11 acre-ft/yr) times 0.893, a coefficient. It was assumed, from previous documentation, that groundwater was 4 percent of the total withdrawals and surface-water withdrawals made up the remaining 96 percent. Golf courses were included in the 2000 and 2005 USGS water-use compilations if they had the capacity to pump more than 0.01 Mgal/d (11.21acre-ft/yr) but they were not separated from crop irrigation totals. Irrigated golf course acreage was estimated by applying a coefficient to the number of holes at each course. The coefficient applied to golf courses was 7.0 in 2000, based on a Florida coefficient representing the number of irrigated acres per hole. The coefficient decreased to 1.71 in 2005, based on a coefficient for West Virginia. Estimates of irrigated acreage and irrigation withdrawals for horticulture were included in the irrigation category. The methodology for collecting and reporting irrigation and golf course acreage and withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations, with the exception of the change to the coefficient of acres per hole for golf course estimation.

Louisiana

The Louisiana WSC estimated acreage and withdrawals for crop irrigation based on the "Louisiana Summary, Agricultural and Natural Resources" report generated by the Louisiana State University Agricultural Center and the Louisiana Cooperative Extension Service (Louisiana Cooperative Extension Service, 2005). The Louisiana Summary is published every year, by county, and sometimes includes information regarding irrigated and non-irrigated cropland. NASS (U.S. Department of Agriculture, 2006) data were used as a check for acreage of certain crops. The Louisiana WSC separated data for rice irrigation, which also was provided by the Louisiana Summary. Withdrawals were estimated using a variety of sources such as the U.S. Department of Agriculture, the Survey Extension Service (Louisiana Cooperative Extension Service, 2005), the Louisiana Agricultural Center, Louisiana Department of Agriculture, and FRIS (U.S. Department of Agriculture, 2004b), which all were averaged to estimate withdrawals as accurately as possible. An application rate of 0.54 Mgal per acre per year (1.66 acre-ft per acre per

year) was used to estimate withdrawals for rice, and an average of 0.18 Mgal per acre per year (0.56 acre-ft per acre per year) was used to estimate withdrawals for general crops. Available golf course and horticultural-withdrawal information provided by the Capitol Area Ground Water Commission was included in the irrigation category but was not separated from the total estimates for crops. Surveys were mailed to nurseries and the reported numbers were added to irrigation totals for that county. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Maine

The Maine WSC used a combination of data from NASS (U.S. Department of Agriculture, 2006), 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a), and National Oceanic and Atmospheric Administration (NOAA) climate records to estimate irrigated acreage for the 2005 USGS water-use compilation. NOAA climate data were used to determine where the irrigation deficits from rainfall exist in order to estimate irrigation needs in those areas. In 2003, irrigation water users that withdrew more than 0.02 Mgal/d (22.42 acre-ft/yr) from streams and groundwater sources were required to report water usage annually to the Maine Department of Agriculture, but there were inconsistencies in reporting and these data were not used for the 2005 USGS water-use compilation. In 2005, golf course estimates were included in the irrigation category and were included separately. In 2000, the Maine Department of Environmental Protection conducted a survey of golf courses; however, the survey was incomplete and statewide assumptions had to be made based on the returned surveys. The acreage was estimated based on how many holes each course had, with an 18-hole golf course assumed to be 124 acres and a 9-hole golf course assumed to be 54 acres. A coefficient, using the turf-irrigation rate from the University of Maine crop specialists, was applied to estimate the withdrawals. Horticulture was included in the 2005 USGS water-use compilation, but other than irrigation for turf farms, it was minimal. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Maryland

The Maryland-Delaware-District of Columbia WSC used data from the State of Maryland, which requires water-appropriation permit holders that pump more than 0.01 Mgal/d (11.21 acre-ft/yr) to report their irrigation withdrawals and irrigated acreage on a monthly basis to the Maryland Department of the Environment (MDE). The data were available to the WSC to help estimate irrigation withdrawals for the 2005 USGS water-use compilation. Irrigation method was determined from the 2003 FRIS (U.S. Department of Agriculture, 2004b) and NASS (U.S. Department of Agriculture, 2005). The 2005 data from the MDE were checked for trends and compared to the previous 4 years of data; in cases of large discrepancies in the 2005 data, 2004 data were used instead. In 2005, golf courses were included in the irrigation category. Golf course data were gathered from the courses that pumped more than 0.01 Mgal/d (11.21 acre-ft/yr) and were therefore required to report data on a monthly basis to the MDE. Horticulture information was not collected for the 2005 USGS water-use compilation. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Massachusetts

The Massachusetts-Rhode Island WSC separated irrigated acreage and irrigation withdrawals into cranberries and crops other than cranberries. The 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) was used to estimate irrigated crop acreage with the subtraction of the reported cranberry-bog acreage. It was assumed that 4 in. per month was required for crop irrigation, which came from numbers used by the New Hampshire-Vermont WSC. The average precipitation for the growing season was estimated and subtracted from the 4 in. per month estimated water requirement. Cranberry acreage was obtained from the Massachusetts Department of Environmental Protection (MADEP), based on the number of farms that withdrew water. The MADEP metered withdrawals for cranberries and provided the estimate to the WSC. Golf course irrigation and withdrawals were included in the irrigation category of the 2000 and 2005 USGS water-use compilations. Some golf course acreage and withdrawals were obtained from the MADEP and a coefficient of 0.015 Mgal/d (16.82 acre-ft/yr) per irrigated acre was estimated; the remaining golf courses were estimated by applying the calculated coefficient to the acreage from an online list. Irrigated acreage and irrigation withdrawals for horticulture were not included in the 2000 or 2005 USGS water-use compilations. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Michigan

The 1997 Census of Agriculture (U.S. Department of Agriculture, 1999a) and the 1998 FRIS (U.S. Department of Agriculture, 1999b) were used by the Michigan WSC to estimate irrigated crop acreage for 2000. The 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) and the 2003 FRIS (U.S. Department of Agriculture, 2004b) were used to estimate irrigated crop acreage by the Michigan WSC for the 2005 USGS water-use compilation. To estimate withdrawals, the acreage was input into a model, "Estimated Water Use for Agricultural Irrigation in Michigan 1997–1999" (Anderson and others, written commun., 2000), created by the Michigan Department of Agriculture and the Michigan Department of Environmental Quality. Irrigation-system types were estimated using statewide averages from NASS. It was assumed that sprinkler irrigation was almost 96 percent of total irrigation. Golf courses were included in the irrigation category of the 2000 and 2005 USGS water-use compilations. Golf courses were metered or estimated by the owners and reported to the Michigan Water Use Reporting Program. There was no mention of horticultural acreage or withdrawals being included in the 2000 or 2005 USGS water-use compilations. The methodology for collecting and reporting crop and golf course acreage and withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations. Methods will change for 2010 because agricultural irrigators are now being required to report withdrawals to the State so these likely will not need to be estimated as in the past.

Minnesota

The Minnesota WSC used information reported to the Minnesota Department of Natural Resources (DNR) through that agency's annual water-use report program for its irrigation estimates for the 2005 USGS water-use compilations. Water users with the ability to pump more than 1 Mgal per year (3.07 acre-ft/yr) are required to obtain a water-appropriations permit and report acreage and withdrawals annually to the DNR. The permit owners also were required to report the method of irrigation to the DNR. Golf courses also are permitted and this use was compiled separately from crop irrigation within the irrigation category. Golf course withdrawals are estimated using either a flowmeter reading or the number of hours a pump ran times the average pumping rate. Water use for horticulture was included with the crop irrigation category for the 2005 USGS water-use compilation. Most horticulture in Minnesota included nurseries and sod farms. The methodology for collecting and reporting crop and golf course irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Mississippi

The Mississippi WSC obtains estimates of irrigation withdrawals for the Mississippi River alluvial aquifer, which underlies an agricultural area locally referred to as the Delta, from a network of 150 wells located throughout the area. This network of wells is monitored by the Yazoo-Mississippi-Delta Joint Water Management District. Pumping rates for individual wells within this network are obtained by use of a non-intrusive flowmeter. Length of running time for each well is determined by reading the electrical meter boxes each month during the pumping season. These two datasets are used to calculate a total volume of water pumped for each well. Crop types for each well are identified and verified. The application rate for each crop type within the network is believed to be representative of all irrigated land in the Delta with that crop type. The Mississippi Department of Agriculture uses remote sensing to determine all crop types grown each year throughout the Delta. Application rates computed for each of these crop types then are applied to the total acreage for each crop type, and a total volume of water withdrawn is calculated. Estimates for the remainder of the State are obtained from the Mississippi State University Agriculture Extension Service. Their data come from several sources, such as county agents, small informal studies made by agents and growers, and some small field studies. Groundwater is the main source of water for irrigation in Mississippi. All wells greater than 6 in. are required to be permitted in Mississippi. There are few wells smaller than 6 in. used for irrigation. Irrigation for golf courses was not included in the irrigation category for either the 2000 or 2005 USGS water-use compilations. Horticulture was not included in the 2005 USGS water-use compilation. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Missouri

The Missouri WSC used the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) to estimate some of the irrigated acreage, and the remaining data were supplemented by the University of Missouri Agriculture Extension for the 2005 USGS water-use compilation. The WSC examined the trends from the 1997–2002 Census of Agriculture reports and, based on the trends, used either the same number that was used in the 2000 USGS water-use compilation or the number used

in the 2002 Census of Agriculture. Withdrawals were estimated using crop coefficients based on the type of crop and irrigation method and applying those values to the acreage estimates. The coefficient for sprinkler-irrigated systems was 0.7 Mgal/d (784.7 acre-ft/yr) per 1,000 acres, for micro-irrigation systems was 0.01 Mgal/d (11.21 acre-ft/yr) per 1,000 acres, and for surface irrigation was 2.0 Mgal/d (2,242 acre-ft/yr) per 1,000 acres. The Missouri Department of Natural Resources (DNR) had data available for the ratio of groundwater to surface-water withdrawn for a majority of irrigation uses. The remaining irrigation use that was not estimated by the DNR was assumed to be from groundwater withdrawals. Golf courses were included in the irrigation category but were not separated from crop irrigation. The WSC received only limited golf course estimates from private courses. Horticulture estimates were included in the total irrigation estimates in the 2005 USGS water-use compilation. The methodology for crop and golf course irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Montana

The Montana WSC used the 2005 Montana Agricultural Statistics Service to obtain total irrigated crop acreage. Acres irrigated by groundwater sources were based on the 1982 Census of Agriculture (U.S. Department of Agriculture, 1984) and updated using water-rights information from the Montana Department of Natural Resources and Conservation (DNRC) for acres developed after 1985. Acreage irrigated by surface-water sources was calculated as the total irrigated crop acres minus those irrigated by groundwater. Irrigated pasture acreage by surface water were estimated as the average from the two previous Census of Agriculture reports. Irrigation withdrawals were estimated based on crop water requirements and system efficiencies. It was assumed that all irrigation from groundwater sources was done by sprinklers. Consumptive uses for crops and pasture were estimated using crop and grass water needs from the 1974 Irrigation Guide for Montana (U.S. Soil Conservation Service, 1974). Original values for irrigation efficiencies from the U.S. Soil Conservation Service (1978) were updated in 2005 to reflect the large increase in sprinkler irrigation in Montana. An unpublished 1995 NRCS field survey and newer information from the DNRC indicated that about 40 percent of all acreage in Montana was irrigated by sprinklers. The overall irrigation efficiency for the State was 0.25 because of the low conveyance efficiencies from river to farm acreage irrigated by flood systems. Irrigation for neither golf courses nor horticulture was included in the irrigation category for Montana in the 2000 or 2005 USGS water-use compilations. The methodology for estimating irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Nebraska

The Nebraska WSC used a combination of calculated and reported data for the irrigation category of the 2005 USGS water-use compilation. The irrigated acreage by crop type were assembled from the National Agricultural Statistics Service (U.S. Department of Agriculture, 2006) and 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a). Crop acres were separated into four groups based on the crop water requirement: high water requirement, low water requirement, small grains, and hay. Crop water requirements obtained from the High Plains Climate Center at the University of Nebraska-Lincoln were used to determine monthly crop water requirements for each of the four groups during their respective growing seasons and within each climatic region of Nebraska. These water requirements were adjusted using monthly precipitation data from the National Climatic Data Center for each of the eight climatic divisions to determine the net irrigation requirement for each crop group. Reported site-specific data from the Republican River Compact Area (RRCA) model region were used instead of the calculated irrigation requirements in some counties. Estimates of the source of irrigation water (surface water or groundwater) and the method of application (surface (flood), sprinkler, or drip) were made on a county basis using available information from the Nebraska Department of Natural Resources (DNR), DNR field offices, RRCA data, or previous compilations. Irrigation for golf courses and horticulture was not included in the irrigation category for either the 2000 or 2005 USGS water-use compilations. The methodology for determining irrigated acreage and irrigation withdrawals was similar for the 2000 and 2005 USGS water-use compilations.

Nevada

The Nevada WSC used multiple sources to estimate irrigated acreage, including NASS (U.S. Department of Agriculture, 2005), the Nevada Department of Water Resources (NDWR), and LANDSAT photographs of Nevada. The 2005 NASS estimated irrigated acres of hay, wheat, and barley. Irrigated acreage for specialty crops was estimated using the 2005 NASS "Annual Statistics Bulletin" (U.S. Department of Agriculture, 2005). These estimates were supplemented with information from the NDWR and satellite images. Groundwater withdrawals were reported to the NDWR, and surface-water withdrawals were estimated by subtracting the irrigation supplied by groundwater from the total irrigation withdrawals estimated using the irrigated acres from NASS and NDWR-application rates. Irrigation for golf courses and horticulture was not included in the

irrigation category for either the 2000 or 2005 USGS water-use compilations. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

New Hampshire

The New Hampshire-Vermont WSC used the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) to estimate irrigated crop acreage in New Hampshire. The State registered-users' database provided data on withdrawals for crop irrigation for large water users. For the 2005 USGS water-use compilation, these data were supplemented using the Fennessey and Vogel ET method (Fennessey and Vogel, 1996), which uses average air temperature, longitude, and elevation and was estimated for every month in the growing season, which was May–September. Most of the crops are irrigated using micro-irrigation methods. It was assumed that effective precipitation was 70 percent of the total precipitation. A monthly net irrigation requirement was computed using the calculated ET minus the effective precipitation. This number then was multiplied by the irrigated acreage to estimate irrigation withdrawals for a month. The monthly estimated withdrawals then were summed for every month in the growing season and divided by 365 to get units of million gallons per day. Golf courses were included in the irrigation category. Golf course acreage was estimated using an average of 20 acres per 9 holes at a golf course, which came from the "Water Use Verification in the Merrimack River Basin" study (New Hampshire Department of Environmental Services, written commun., 2001). It was assumed that surface-water withdrawals were 90 percent of the total irrigation withdrawals, with groundwater making up the other 10 percent. Withdrawals for irrigating golf courses were estimated using a coefficient of 0.005 Mgal/d (5.61 acre-ft/yr) per 1,000 yards in 2005 and 0.007 Mgal/d (7.85 acre-ft/yr) per 1,000 yards in 2000, which was applied to the estimated golf course acres. Horticultural irrigation was not included in the 2000 or 2005 USGS water-use compilations. For the 2000 USGS water-use compilation, the irrigation season was assumed to be June–August and irrigation was estimated as the difference between the assumed 4 in. of rain needed per month (1 in. weekly) during the growing season and actual monthly precipitation.

New Jersey

The New Jersey WSC used multiple sources to estimate irrigated crop acreage including the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a), 2003 FRIS (U.S. Department of Agriculture, 2004b) and information from the New Jersey Department of Agriculture. Farmers with the capacity to pump 70 gal/min or more were required to report their withdrawals to the State. Farmers also were required to report the type of irrigation system being used. Farmers estimate their withdrawals using pump capacity and running time or electric-power usage, although some operations have meters. The WSC estimated consumptive-use values based on previously reported estimates from Rutgers University and the New Jersey Cooperative Extension service reports and advice. The consumptive-use coefficient for cranberries that was used for the 2000 and 2005 USGS water-use compilations was 0.25; for crops other than cranberries a coefficient of 0.9 was used. Golf courses were estimated separately in the irrigation category of the 2000 and 2005 USGS water-use compilations. Irrigated acreage for golf courses was estimated using GIS coverage. An average of 109.91 acres for an 18-hole golf course and 90.19 acres for a 9-hole golf course was used to fill in the acreage not estimated from GIS. Golf course irrigation is reported as metered monthly values to the State. Withdrawals for golf courses were estimated using a coefficient based on grass type, irrigation type, number of holes, and age of the course, and a consumptive-use coefficient of 0.9. Horticultural water use was included in the irrigation category and intensive use was reported. The methodology for crop and golf course irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

New Mexico

The New Mexico WSC used irrigation information provided by the New Mexico Office of the State Engineer (NMOSE) for the 2005 USGS water-use compilation. Irrigated acreage data were compiled from data obtained from the U.S. Bureau of Reclamation, Farm Service Agency, NASS, irrigation districts, conservancy districts, and county extension agents. Data also were obtained from hydrographic surveys, adjudications and court decrees, licenses and permits for water rights, 2005 aerial photography, and the New Mexico Interstate Stream Commission. Other withdrawals were estimated using calculated crop water requirements that included conveyance loss, system efficiencies, and crop consumptive use. Streamflow records were used to adjust for shortages where necessary. Self-supplied golf course water use was compiled by NMOSE but was considered commercial use. Some horticultural water use was included in the irrigation category, except for greenhouses, which are considered commercial operations in New Mexico. The methods for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

New York

The 2003 FRIS (U.S. Department of Agriculture, 2004b) was used by the New York WSC to estimate irrigated acreage. FRIS includes estimates of irrigated acreage by system type, which was used by the WSC. There was no surface (flood) irrigation in New York, only sprinkler irrigation (which was about 69 percent of the total) and micro-irrigation (making up the remaining 31 percent). Irrigation withdrawals were estimated by using the following application rates from FRIS: 0.065 Mgal per acre (0.2 acre-ft per acre) for sprinkler irrigation and 0.13 Mgal per acre (0.4 acre-ft per acre) for micro-irrigation. These application rates were multiplied by the irrigated acreage to estimate irrigation withdrawals. Based on the 2000 USGS water-use compilation, it was assumed that a State average of 73 percent of irrigation withdrawals were from surface water and the other 27 percent was from groundwater, except for Nassau County and Suffolk County, where it was assumed to be 100 percent groundwater. Golf course acreage was estimated separately and included in the irrigation category of the 2005 USGS water-use compilation. Irrigated golf course acreage was estimated by applying a coefficient of 20 acres irrigated for each 9-hole golf course and 40 irrigated acres for each 18-hole golf course. Irrigation withdrawals for golf courses were estimated by applying a coefficient of 0.022 Mgal/d (24.66 acre-ft/yr) for each 9-hole golf course and 0.045 Mgal/d (50.45 acre-ft/yr) for each 18-hole golf course. The same percentages of groundwater and surface-water sources used for crop irrigation were used for golf courses. Golf course data were not estimated for the 2000 USGS water-use compilation. There was quite a bit of horticulture taking place in New York, although it was not estimated in the 2000 or 2005 USGS water-use compilations. The methods for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

North Carolina

The North Carolina WSC used the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) and 2005 crop data from the North Carolina Agricultural Statistics Service (North Carolina Agricultural Statistics Service, 2006) to estimate irrigation water use for 2005. The total harvested acreage as well as irrigated acreage in each county was obtained for the following major crops: all hay, tobacco, corn (for grain), corn for silage, cotton, vegetables, soybeans, wheat, peanuts, sweet potatoes, berries, land in orchards, nursery container, and nursery field. For these crops, the percentage of total acreage that was irrigated in 2002 was determined for each county. Subsequently, the total harvested acreage in each county during 2005 was obtained for all hay, tobacco, corn (for grain), corn for silage, cotton, vegetables, soybeans, wheat, peanuts, and sweet potatoes. For these 10 crops, the same ratio of irrigated acreage to total harvested acreage in 2002 was applied to the total number of harvested acreage in each county in 2005. For the other crops with no 2005 data available, the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004b) values for irrigated acreage were used. For nursery crops, acreage data were obtained from the List of Certified Nurseries and Plant Collectors in North Carolina. Nursery-crop data were subdivided into field-grown and container-grown crops, and acreage was compiled for each county using this delineation. All nursery acreage was assumed to be irrigated. Application rates of 40 in. per acre per year were used for container-grown nursery crops and 8 in. per acre per year for all other crops. These application rates were multiplied by the acreage based on the crop type in order to estimate withdrawals. Golf course acreage and withdrawals were estimated and included in the irrigation category. A typical "regulation" 18-hole golf course was assumed to have 75 irrigated acres, an "executive" 18-hole golf course was assumed to have 56 irrigated acres, and par-3 courses were assumed to have 36 irrigated acres. The State of North Carolina was divided into three different regions, and the estimated irrigation requirements for golf courses in each of those regions were multiplied by the golf course acreage in each region. Extensive horticultural water use was included in the irrigation category of the 2005 USGS water-use compilation. The same percentage of groundwater or surface water used in previous compilations was used for each county in 2005. Some of the methodology changed from the 2000 to the 2005 USGS water-use compilation because of differences in available crop data, revisions in procedures used to develop estimates for golf course irrigation, and because the 2000 irrigation category was estimated by the Florida WSC.

North Dakota

The North Dakota WSC used the North Dakota State Water Commission as one of the primary sources for obtaining irrigation data. The North Dakota State Water Commission collects information on irrigated acreage and irrigation withdrawals as part of its water-permit allocation program. Additionally, data on irrigated acreage are collected for annual reports by the North Dakota Agricultural Statistics Service located on the North Dakota State University campus in Fargo, N.D. These data, along with irrigation data compiled by the Department of Agriculture at North Dakota State University, help contribute to the data compiled by the North Dakota State Water Commission. In some instances, additional irrigation data are obtained from individual users or irrigation districts when large discrepancies in withdrawals or irrigated acreage occur from year to year. Data also may be obtained from and (or) verified by county agricultural agents who have access to individual farms in their counties.

The North Dakota State Water Commission issues permits for users with the ability to pump more than 4.88 Mgal per year (15 acre-ft/year). Farmers are required to report the source of irrigation water and the type of irrigation systems used. Golf courses were estimated and included in the total irrigation category of the 2005 USGS water-use compilation but cannot be separated out from the total irrigated acreage and irrigation withdrawals. Horticulture was included in the irrigation category if the operation received a permit from the North Dakota State Water Commission. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Ohio

The Ohio WSC estimated irrigated acreage by using the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) data. In the 1997 Census of Agriculture (U.S. Department of Agriculture, 1999a, 1999b), it was reported that 99 percent of the irrigated acreage was irrigated using sprinkler methods, and only about 1 percent was irrigated using micro-irrigation. In 2005 it was assumed that all irrigation was done by sprinklers. The Ohio Department of Natural Resources (ODNR) requires facilities with the capacity to pump at least 0.1 Mgal/d (112.1 acre-ft/yr) to report monthly and annual water withdrawals. The ODNR registration form is an annual form used to collect water-withdrawal and return-flow data from irrigation facilities including farms, nurseries, and golf courses (return-flow data reporting is optional). Consumptive use was estimated by subtracting ODNR return-flow data from the reported withdrawals. Golf courses and horticulture were included in the irrigation category and were reported separately. An acres-per-hole coefficient was applied to the number of holes to estimate the golf course acreage. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained largely unchanged between the 2000 and 2005 USGS water-use compilations. The primary difference between the 2000 and 2005 irrigation data was re-examining golf course acreage irrigated through golf course inventories, the number of holes, and the length of the fairways.

Oklahoma

The Oklahoma WSC obtained irrigated-acreage estimates, by crop type, from the Oklahoma Water Resources Board (OWRB). The OWRB receives reported, site-specific data from farmers. Using the OWRB data, it was estimated by Oklahoma WSC personnel that 81 percent of irrigated acreage was irrigated using sprinklers, 18 percent was irrigated using surface (flood) irrigation, and less than 1 percent was irrigated by micro-irrigation. The OWRB also supplied the WSC with irrigation-withdrawal data. From that data, it was determined that 73 percent of agricultural-irrigation water was supplied from groundwater and the other 27 percent was from surface water. The WSC estimated consumptive use by applying NRCS tables, which estimated ET using the Blaney-Criddle equation (Blaney and Criddle, 1950) for the irrigated acreage. Conveyance loss was estimated to be 5 percent of surface-water withdrawals. Golf courses were included in the public supply and commercial categories, not in the irrigation category of the compilation. There was very little horticultural water use in Oklahoma in 2005, so it was not estimated. The methodology for collecting and estimating irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Oregon

The Oregon WSC used the Oregon Agricultural Statistics Service (OASS; Oregon Agricultural Statistics Service, 2006) to estimate irrigated acreage. The 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) and 2003 FRIS (U.S. Department of Agriculture, 2004b) were consulted for data on certain irrigated crops and irrigated pasture. Crop water use was estimated using ET data and crop water requirements. Irrigation withdrawals were estimated by analyzing data on irrigated acreage, crop water needs, consumptive use, irrigation systems, irrigation efficiencies, and total water use. Application efficiencies for various irrigation types were taken from a 1977 report published through Oregon State University. Efficiencies ranged from 45 percent for surface (flood) irrigation up to 90 percent for micro-irrigation. Consumptive use was estimated by multiplying the irrigated crop acreage to the estimated crop water needs. The consumptive use then was divided by a system efficiency to calculate total irrigation withdrawals. Irrigation for golf courses was not included in the irrigation category for either the 2000 or 2005 USGS water-use compilations. Horticulture from nurseries and turf farms was included in the irrigated acreage and withdrawal estimates in the irrigation category for the 2000 and 2005 USGS water-use compilations. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Pennsylvania

The Pennsylvania WSC utilized select data from the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) and 2003 FRIS (U.S. Department of Agriculture, 2004b) for the 2005 USGS water-use compilation. Approximately 1 percent of harvested cropland in Pennsylvania is irrigated (42,315 acres irrigated, and 4,078,361 acres harvested). Of irrigated acreage, about 49 percent was irrigated by sprinkler methods, 21 percent was irrigated by micro-irrigation, 29 percent used a combination of sprinkler and micro-irrigation, and less than 1 percent used surface (flood) irrigation. FRIS data indicated commonwealth-wide average-application rates for nine select crops ranging from 0.1 ft per acre for silage and green chop to 0.7 ft per acre for berries, and 0.4 ft per acre as a combined average for all irrigated crops. Application rates were applied to the representative select-crop irrigated acreage, county-by-county. The majority of counties (64 of 67) had additional irrigated acreage not identified with select crops; the combined average-application rate (0.4 ft per acre) was applied to irrigated acreage not identified with a select crop. Select crop and other crop irrigation were totaled for each county to estimate withdrawals. FRIS estimated that one-third of the irrigated land in Pennsylvania came from groundwater and two-thirds was irrigated by surface water. Golf courses were included in the irrigation category for the 2005 USGS water-use compilation. Golf course acreage was estimated by applying a coefficient of 3.5 acres per hole to the number of holes. Analysis of site-specific data resulted in an application rate of 0.008 Mgal/d (8.97 acre-ft/yr). This application rate was multiplied by the irrigated golf course acreage to estimate withdrawals. Golf course irrigation was not included in the 2000 USGS water-use compilation. The WSC followed the Commonwealth practice of assigning golf course irrigation to commercial water use, because the data did not allow reliable separation of irrigation and club-house or pool water use, and the commercial category was optional for the 2000 USGS water-use compilation. The 2005 USGS water-use compilation represents the first specific inclusion of golf course irrigation, in addition to agricultural irrigation, used by the WSC. Horticultural water use was not included in the 2000 or 2005 USGS water-use compilations.

Puerto Rico

The Caribbean WSC estimated irrigated acreage for Puerto Rico by using aerial photographs from the U.S. Army Corps of Engineers and the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a). The methods of irrigation were obtained from the 2002 Census of Agriculture, field visits, and data provided by the Puerto Rico Land Authority. Surface-water withdrawals were estimated by the Puerto Rico Electric and Power Authority (PREPA), which owns the irrigation districts, and the data were reported to the Caribbean WSC. Groundwater withdrawals were estimated using electricity-consumption data from the Puerto Rico Land Authority to estimate a discharge used for crop irrigation. An irrigation-application rate for groundwater sources was estimated by dividing the total cultivated acreage that was delineated from 2004 aerial photographs taken by the U.S. Army Corps of Engineers. Golf courses were included in the 2000 USGS water-use compilation but not in the 2005 USGS water-use compilation. In 2000, golf course acreage was estimated using aerial photographs of greens and tees. Golf course withdrawals were estimated by applying an irrigation coefficient based on acreage, location, irrigation methods, and estimated average precipitation. There was no estimation of horticulture for the 2005 USGS water-use compilation.

Rhode Island

The 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) was used to estimate irrigated crop acreage in the Massachusetts-Rhode Island WSC. Weather data were consulted to determine the months in which crops needed irrigation. A crop water requirement of 4 in. per month was applied to the acreage to estimate withdrawals during those months. Golf courses were included in the irrigation category for the 2000 and 2005 USGS water-use compilations, and the acreage was estimated based on the number of yards at a course. Withdrawals for irrigating golf courses were estimated using a coefficient of 0.0117 Mgal/d per 1,000 yards (13.12 acre-ft/yr). Horticultural acres and withdrawals were not estimated for the 2000 or 2005 USGS water-use compilations. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

South Carolina

The South Carolina WSC received irrigated-acreage estimates from the South Carolina Department of Health and Environmental Control, which requires any farmer that has pumped at least 3 Mgal per month (9.2 acre-ft/month) to register and report all data. The permitted users are required to have meters on irrigation wells. Golf courses that irrigated had to follow the same reporting requirements as farmers who irrigated. A coefficient of 4.5 acres per hole was estimated as 4.5 acres in size, and this coefficient was used to estimate the number of acres. Horticultural irrigation was not estimated for the 2000 or 2005 USGS

water-use compilations. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

South Dakota

The South Dakota WSC used data reported by water-permit holders to the South Dakota Department of Environmental and Natural Resources (SDDENR). Those irrigators that use a pump are required to submit an annual-irrigation questionnaire each fall providing information on withdrawal rate, irrigated acreage, irrigation occurred, and crops grown for that irrigation season. All irrigation is done using the sprinkler method. Irrigation for golf courses and horticulture was not included in the irrigation category for either the 2000 or 2005 USGS water-use compilations. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Tennessee

The 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) and the 2003 FRIS (U.S. Department of Agriculture, 2004b) reports were used to estimate irrigated acreage for the Tennessee WSC. A crop-application coefficient based on the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) was applied to the irrigated acreage to estimate a withdrawal for irrigation. Golf courses were estimated and included in the irrigation category for the 2000 and 2005 USGS water-use compilations. The Tennessee Department of Environment and Conservation collected data on all golf course acreage and withdrawals and provided that information to the WSC. There was no mention of horticultural irrigation estimates in either the 2000 or 2005 USGS water-use compilations. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Texas

The Texas WSC received estimates from the Texas Water Development Board (TWDB), which used different methodologies for estimating irrigation in 2000 and 2005. The estimate for 2000 was based on the Natural Resource Conservation Service (NRCS) 2000 survey of irrigation, which was the final year this survey was performed causing the TWDB to adopt a new method for estimating irrigation water use annually. For the 2005 USGS water-use compilation, estimates for irrigated acreage came from the Farm Service Agency (FSA). A crop water-need estimate based on ET was applied to irrigated acreage data acquired from the FSA, and the data then were sent to the respective Groundwater Conservation Districts for comment. For those counties with surface-water irrigation, the initial estimate was adjusted based on diversion data from Texas Commission on Environmental Quality (TCEQ) and the Texas Watermasters. The “Irrigation by system type report” from 2000 was used to determine the percent of irrigation-system types throughout the State. Golf course water use was not supplied by public water systems and horticultural water use are not accounted for in the TWDB annual estimates of irrigation; therefore, they were not estimated in the irrigation category for the 2000 or 2005 USGS water-use compilations.

Utah

The Utah WSC estimated crop acreage from a land-use survey of each river basin along with field verification of one or two basins by the Utah Division of Water Resources (UDWR). The UDWR does field verification of one or two basins annually, rotating which basins are field verified each year. Employees inspect a field for the crop type growing, the crop acreage, irrigation method being used, and the source of irrigation water. Groundwater withdrawals were estimated using USGS well ratings, pumpage inventories, and electrical records, which are published annually. Surface-water withdrawals were estimated using information from the UDWR, which had a GIS-based model that approximated potential amounts of water diverted from canals by different irrigation methods. Model inputs included irrigated acreage, crop coefficients, amount of precipitation and evaporation, irrigation shortages, and canal efficiencies. Crop consumptive use was estimated using central weather stations and applying the modified Blaney-Criddle method (Blaney and Criddle, 1950) in conjunction with weather data obtained from the PRISM Climate Group. Golf course and horticultural water use were not estimated for the irrigation category for the 2000 or 2005 USGS water-use compilations. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Vermont

The 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) was used to estimate irrigated crop acreage directly for Vermont by the New Hampshire-Vermont WSC. For the 2005 compilation, the Fennessey and Vogel method

(Fennessey and Vogel, 1996), an ET model that includes data on temperature, longitude, and elevation, was the first step in estimating irrigation withdrawals. Micro-irrigation was assumed to be the primary method of crop irrigation. For the 2000 USGS water-use compilation, the irrigation season was assumed to be June–August; irrigation was estimated as the difference between the assumed 4 in. of rain needed per month (1 in. weekly) during the growing season and actual monthly precipitation. The irrigation season was assumed to be May–September in 2005. It was assumed that effective precipitation was 70 percent of the total precipitation in the growing season. The monthly net-irrigation requirement was calculated by subtracting net precipitation from the estimated crop ET. The irrigation requirement then was multiplied by the irrigated acreage in order to estimate irrigation withdrawals. It was assumed that surface-water withdrawals were 90 percent of the total withdrawals and groundwater withdrawals made up the remaining 10 percent. Golf courses were included in the irrigation category for the 2005 USGS water-use compilation. Irrigated golf course acreage was estimated using an average of 20 acres irrigated per nine holes. Withdrawals for golf courses were estimated using crop coefficients of 0.005 Mgal/d (5.61 acre-ft/yr) per 1,000 yards in 2005 and 0.007 Mgal/d (7.85 acre-ft/yr) per 1,000 yards in 2000. These coefficients were empirically derived from a water-use database provided by the State of New Hampshire. Since the irrigated crop acreage in the 2005 USGS water-use compilation was taken from the 2002 Census of Agriculture, horticultural acreage and withdrawals were included in the irrigation totals.

Virginia

The Virginia WSC used a combination of 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) and some site-specific data reported to the Virginia Department of Environmental Quality to estimate irrigation withdrawals for the 2005 USGS water-use compilation. The same percentage of irrigation types from 2000 was applied to the 2005 USGS water-use compilation, which was mostly sprinkler irrigation. In Virginia, water users who withdraw an average of more than 0.03 Mgal/d (33.63 acre-ft/yr) are required to report site-specific withdrawals to the State. The WSC obtained this information for the 2005 USGS water-use compilation but believed it was underestimated. Application rates from the 2000 report were used again in the 2005 USGS water-use compilation. Estimates for irrigated golf course acreage and withdrawals were included in the irrigation section and were delineated separately. Golf courses with the capacity to pump an average of at least 0.01 Mgal/d (11.21 acre-ft/yr) are required to report withdrawals to the Virginia Department of Environmental Quality. For golf facilities with reported withdrawal data, information on course yardage and number of holes was used with the reported withdrawals to develop regressions, which then were used to estimate withdrawals for non-reporting courses. (When both number of holes and yardage were available for a golf facility, the mean estimated withdrawal from the two regressions was used as the estimated withdrawal for that facility.) Golf course acreage was estimated using an average of 97.8 acres per course. There was some horticultural irrigation occurring in eastern Virginia, and it was included in the 2005 USGS water-use compilation.

U.S. Virgin Islands

In the Caribbean WSC, the U.S. Virgin Islands had no crop, golf course, or horticultural irrigation taking place so it was not estimated in the 2000 or 2005 USGS water-use compilations.

Washington

The Washington WSC used information from the 2003 FRIS report (U.S. Department of Agriculture, 2004b) along with data from the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a) to estimate irrigated acreage at the county level. The county-level application rates from the 2000 USGS water-use compilation then were coupled with the 2005 county acreage to produce initial and total irrigation water use. This estimate then was compared to the data from the 2002 Census of Agriculture and NASS, and county estimates were adjusted until the totals agreed. County-level surface-water values were initially estimated using percentages of groundwater and surface-water use from the 2000 USGS water-use compilation, which was the State total compared to data from the 2003 FRIS, and individual county withdrawals were adjusted until the estimated total agreed with the FRIS total. County-level groundwater values then were calculated as the difference between the county total-irrigation value and the county surface-water value. Conveyance losses were not included in the withdrawal estimates, owing to lack of data. Golf course locations and acreage were obtained from 2000 data for the 2005 USGS water-use compilation. The number of holes was multiplied by a factor of 4.5 acres per hole in order to estimate irrigated acreage. Application rates for golf courses were obtained from the crop irrigation category of the 2005 USGS water-use compilation. The groundwater and surface-water sources were based on data from the public supply category. Conveyance losses and application rates were not calculated for golf course irrigation category owing to a lack of data and nearness of sources to the individual courses. Horticulture in Washington comprises a very small percentage of the total irrigated acreage and was not separated from crop irrigation.

West Virginia

The West Virginia WSC estimated irrigated acreage to be 20 percent of the total agricultural acreage reported in the 2002 Census of Agriculture (U.S. Department of Agriculture, 2004a). Crops in West Virginia are irrigated with a combination of sprinkler and micro-irrigation methods. Users with the capacity to pump over 750,000 gal per month (2.3 acre-ft/month) are required to report withdrawals to the State. For users pumping less than 750,000 gal per month, an application rate of 55,395 gal per acre per year was applied to the irrigated acreage numbers. It was assumed that irrigation water was supplied by 50-percent groundwater and 50-percent surface water. Golf courses were major users of irrigation water and were included in the irrigation estimate in the 2005 USGS water-use compilation. Golf course acreage was estimated by multiplying the number of holes by 1.71 acres. An average coefficient of 5.37 gal/d was applied to the acreage in order to estimate golf course irrigation withdrawals. Horticulture was included in the irrigation category of the 2005 USGS water-use compilation. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Wisconsin

The Wisconsin WSC used county-level data from the 1997 and 2002 Censuses of Agriculture (U.S. Department of Agriculture, 1999, 2004a) to report irrigated acreage for the 2000 and 2005 USGS water-use compilations. The estimates for crop-irrigation withdrawals in 2000 were based on adjusting 1995 water-use estimates with new totals of irrigated crop acreage and wells identified for irrigation from high-capacity well approval data from the Wisconsin Department of Natural Resources (DNR). However, in 2005, a statewide coefficient-based method where the irrigated acreage was multiplied by 0.001 Mgal/d per acre was adopted to estimate total crop irrigation withdrawals for each county. Surface-water diversion-permit data from Wisconsin DNR were used to create surface-water withdrawal estimates. These estimates then were subtracted from the total estimated irrigation withdrawals in order to estimate groundwater withdrawals. Golf course acreage and withdrawals were included in the 2000 and 2005 USGS water-use compilations. In 2000 and 2005, an average number of 30 acres for an 18-hole course was assumed. All golf courses were presumed to have some irrigation requirement. About one-half of Wisconsin's golf courses were identified as having irrigation wells. In 2000, groundwater withdrawals were estimated by either applying 90 percent of the DNR-approved normal-daily pumpage rate for the well over a 3-month period, or assuming an irrigation coefficient of 10 Mgal per golf season, which was provided by a turfgrass specialist. Zero surface-water withdrawal was assumed for golf courses in 2000. In 2005, it was presumed that all golf courses identified as having a well received 100 percent of their water supply from groundwater sources. Groundwater withdrawals were calculated from either reported water-use rates prior to 1990 or an irrigation coefficient of 10 Mgal per golf season. For the remaining courses with no well-records identified, it was uncertain whether they irrigated, and if they did, whether the irrigation water was public or self-supplied or if the source was groundwater or surface water. Therefore, the estimated water use for an 18-hole golf course was reduced by one-half to 5 Mgal per golf season, and the water source was allocated 85 percent groundwater and 15 percent surface water. In the 2005 compilation, a new subcategory of irrigation called "Other Irrigation" was included. The "Other Irrigation" category included groundwater withdrawals for places other than agricultural fields growing primary crops (for example, corn) or golf courses. Examples include groundwater withdrawals for landscaping, nurseries, greenhouses, athletic fields, and specialty commodities (such as sod, flowers, and specialty edibles). Irrigated acreage was not determined. Withdrawals were based either on reported water-use rates (prior to 1990) to the Wisconsin DNR or on a median withdrawal value of wells with the same water-use purpose reported by the State of Wisconsin DNR.

Wyoming

The Wyoming WSC used the harvested-acreage values from the 2005 Wyoming Agricultural Statistics Service (WASS) for irrigated crop acreage and acreage of each major crop harvested by county. The WSC used the acreage harvested instead of the acreage planted in order to estimate irrigated acreage. Withdrawals were estimated using data from the WASS. Consumptive use was estimated by multiplying ET by the corresponding crop coefficient. The crop coefficient was calculated by estimating the ratio between crop ET and the reference-crop ET. The consumptive-irrigation requirement was calculated using the consumptive-use requirement minus the effective precipitation. The WSC referenced a report written by the U.S. Bureau of Reclamation called "Estimating Agricultural Crop Water Requirements in 1983" (U.S. Bureau of Reclamation, 1983) in order to estimate the irrigation-system efficiencies, using an average conveyance loss of 30 percent. Irrigation for golf courses and horticulture was not included in the irrigation category for either the 2000 or 2005 USGS water-use compilations. The methodology for collecting and reporting irrigated acreage and irrigation withdrawals remained unchanged between the 2000 and 2005 USGS water-use compilations.

Appendix 2. Additional Tables for Reference

Table 2–1. Total irrigated acreage reported by the 1997, 2002, and 2007 Censuses of Agriculture; 1998, 2003, and 2008 Farm and Ranch Irrigation Surveys; and 2000 and 2005 U.S. Geological Survey National Water Use Information Program.

[FRIS, Farm and Ranch Irrigation Survey; USGS, U.S. Geological Survey; data are in thousand acres and are associated with figures 13–17 in the report; golf courses were removed from total irrigated acreage, if possible, to facilitate a comparison]

State	1997 Census of Agriculture	1998 FRIS	2000 USGS NWUIP	2002 Census of Agriculture	2003 FRIS	2005 USGS NWUIP	2007 Census of Agriculture	2008 FRIS
Alabama	79.65	46.81	70.01	108.78	52.72	109.08	112.82	75.02
Alaska	2.67	2.62	2.50	2.74	2.25	1.96	3.73	1.59
Arizona	1,075.34	873.59	975.74	931.74	836.59	949.24	876.16	861.50
Arkansas	3,785.34	4,043.38	4,508.17	4,149.77	3,944.87	4,868.93	4,460.68	4,493.44
California	8,886.69	8,139.83	10,038.90	8,709.35	8,471.94	8,951.73	8,016.16	7,329.25
Colorado	3,374.23	2,942.23	3,375.23	2,590.65	2,562.33	3,001.20	2,867.96	2,865.84
Connecticut	7.69	1.91	7.35	10.14	2.21	12.48	9.90	2.34
Delaware	75.02	77.38	79.72	97.17	69.09	95.00	104.56	104.62
Florida	1,873.82	1,613.72	1,941.68	1,815.17	1,497.65	1,708.08	1,552.12	1,222.80
Georgia	773.07	647.75	1,504.70	870.81	710.89	1,475.32	1,017.77	1,007.76
Hawaii	76.97	96.54	121.50	69.19	78.54	118.92	58.64	99.58
Idaho	3,543.81	3,188.41	3,742.13	3,288.52	3,126.86	3,520.89	3,299.89	3,319.83
Illinois	351.68	290.83	365.15	390.84	374.92	435.14	474.45	457.08
Indiana	255.92	217.20	250.08	313.13	276.29	313.13	397.11	404.40
Iowa	133.15	67.85	78.09	142.11	134.16	116.25	189.52	162.84
Kansas	2,695.82	2,650.49	3,294.92	2,678.28	2,543.95	3,107.51	2,762.75	2,570.00
Kentucky	60.03	25.45	66.60	36.75	20.69	38.10	58.73	32.38
Louisiana	960.83	920.82	940.21	938.84	838.72	1,055.28	954.35	932.71
Maine	22.23	18.32	34.35	19.70	18.17	29.23	20.99	18.15
Maryland	68.66	55.15	54.47	80.83	53.73	74.32	92.81	85.55
Massachusetts	26.82	16.37	25.17	23.72	16.15	21.36	23.13	17.42
Michigan	407.07	367.99	374.99	456.28	432.67	426.98	500.43	531.93
Minnesota	403.29	322.35	547.64	454.85	434.50	441.94	506.36	504.33
Mississippi	1,110.15	1,109.08	1,421.24	1,175.53	1,169.79	1,526.69	1,368.66	1,451.65
Missouri	921.11	832.59	1,325.38	1,032.97	1,020.73	1,276.81	1,199.98	1,232.35
Montana	2,101.55	1,740.87	2,172.33	1,976.11	2,131.96	2,272.34	2,013.17	1,947.16
Nebraska	7,065.56	5,692.22	7,820.30	7,625.17	7,516.17	8,350.61	8,558.56	8,365.55
Nevada	763.74	694.93	647.10	746.65	639.31	575.00	691.03	685.26
New Hampshire	2.84	.72	2.68	2.29	.82	2.29	2.48	.72
New Jersey	94.38	63.51	108.08	96.89	46.68	96.87	95.28	59.41
New Mexico	851.74	720.32	997.89	844.80	769.79	867.71	830.05	835.64
New York	73.79	29.18	80.55	74.66	48.55	76.01	68.01	20.16
North Carolina	156.32	134.47	143.90	264.06	101.06	239.56	232.08	149.00
North Dakota	183.00	164.74	236.52	202.82	207.77	259.17	236.14	248.07
Ohio	35.07	12.04	33.95	40.69	14.48	40.66	37.96	18.55
Oklahoma	509.11	451.79	507.09	517.55	508.84	472.44	534.77	461.24

Table 2–1. Total irrigated acreage reported by the 1997, 2002, and 2007 Censuses of Agriculture; 1998, 2003, and 2008 Farm and Ranch Irrigation Surveys; and 2000 and 2005 U.S. Geological Survey National Water Use Information Program.—Continued

[FRIS, Farm and Ranch Irrigation Survey; USGS, U.S. Geological Survey; data are in thousand acres and are associated with figures 13–17 in the report; golf courses were removed from total irrigated acreage, if possible, to facilitate a comparison]

Oregon	1,963.48	1,534.96	2,169.95	1,907.63	1,731.66	1,967.96	1,845.19	1,758.60
Pennsylvania	40.09	17.92	36.04	42.52	19.63	42.28	37.79	17.36
Rhode Island	3.33	.41	2.91	3.96	.65	5.73	4.31	.68
South Carolina	88.90	61.02	142.47	95.64	52.05	163.90	132.44	104.09
South Dakota	367.20	297.21	354.32	401.08	390.41	421.83	373.84	360.07
Tennessee	47.01	22.74	40.28	61.22	34.43	59.64	81.41	72.86
Texas	5,764.30	5,237.58	6,487.94	5,074.64	4,947.75	6,205.78	5,010.42	5,356.88
Utah	1,218.47	1,076.35	1,407.82	1,091.01	1,082.21	1,206.60	1,134.14	1,068.93
Vermont	2.85	.58	2.57	2.34	.83	2.34	2.30	.49
Virginia	86.39	65.73	73.21	98.91	33.64	97.36	82.19	44.82
Washington	1,787.12	1,554.81	1,550.72	1,823.16	1,806.78	1,821.88	1,735.92	1,675.90
West Virginia	3.54	1.21	3.19	1.98	.80	3.31	2.19	.91
Wisconsin	358.47	351.02	354.52	385.90	391.76	385.95	377.29	396.12
Wyoming	1,749.91	1,533.47	1,158.49	1,541.69	1,415.04	1,001.52	1,550.72	1,497.12

Table 2–2. Irrigated acreage and irrigation withdrawals reported by selected States compared to estimated irrigated acreage and estimated irrigation withdrawals using the Indirect Irrigation Withdrawal Estimation Method.

[Data are associated with figure 19 in the report; acreage is in thousand acres and withdrawals are in thousand acre-feet]

State	2005 reported acres	2005 reported withdrawals	Estimated acreage	Estimated withdrawals
Arizona	949.24	5,386.67	998.66	5,557.64
California	9,050.31	27,290.93	9,244.60	31,542.66
Florida	1,708.08	3,070.65	1,818.00	2,124.52
Idaho	3,520.89	18,510.87	3,509.70	17,133.22
Montana	2,272.34	10,842.14	2,428.50	10,173.14
New Mexico	867.71	3,155.50	951.02	3,215.05
Oregon	1,967.96	6,402.01	1,765.80	7,074.07
Texas	6,205.78	8,737.45	6,009.07	19,548.54
Utah	1,206.60	4,476.41	1,448.27	4,249.96
Washington	1,821.88	3,918.76	1,777.33	6,542.66
Wyoming	1,001.52	4,474.98	1,121.10	4,664.81

Table 2–3. Summary of information presented in State summaries and available National Agricultural Statistics Service data for each State.

[NASS, National Agricultural Statistics Service; golf courses, pasture, and horticulture indicates whether or not these elements were included in the estimates for irrigated acreage and (or) irrigation withdrawals. It does not necessarily indicate whether they were reported separately from crop irrigation. More detail can be found in the State summaries in appendix 1. Annual NASS data indicate whether or not the U.S. Department of Agriculture–NASS reports data on a State level annually. This may or may not include irrigated acreage, planted acreage, or harvested acreage]

State	Golf courses	Pasture	Horticulture	Annual NASS data
Alabama	Yes	Not specified	Yes	Yes
Alaska	Yes	Not specified	No	Yes
Arizona	No	Not specified	No	Yes
Arkansas	Public supply category	Yes	Yes	Yes
California	No	Not specified	No	Yes
Colorado	Yes	Yes	Yes	Yes
Connecticut	Yes	Not specified	Yes	Yes
Delaware	Not specified	Not specified	No	Yes
District of Columbia	Yes	No	No	No
Florida	Yes	Not specified	Yes	Yes
Georgia	Yes	Not specified	Yes	Yes
Hawaii	Yes	Not specified	Not specified	Yes
Idaho	Yes	Not specified	No	Yes
Illinois	Yes	Not specified	Yes	Yes
Indiana	No	Not specified	No	Yes
Iowa	Yes	Not specified	Not specified	Yes
Kansas	Yes	Not specified	Yes	Yes
Kentucky	Yes	Not specified	Yes	Yes
Louisiana	Yes	Not specified	Yes	Yes
Maine	Yes	Not specified	Yes	Yes
Maryland	Yes	Not specified	No	Yes
Massachusetts	Yes	Not specified	No	Yes
Michigan	Yes	Not specified	No	Yes
Minnesota	Yes	Not specified	Yes	Yes
Mississippi	No	Not specified	No	Yes
Missouri	Yes	Not specified	Yes	Yes
Montana	No	Yes	No	Yes
Nebraska	No	Not specified	No	Yes
Nevada	No	Not specified	No	Yes
New Hampshire	Yes	Not specified	No	Yes
New Jersey	Yes	Not specified	Yes	Yes
New Mexico	Commercial category	Not specified	Irrigation and commercial	Yes
New York	Yes	Not specified	No	Yes
North Carolina	Yes	Not specified	Yes	Yes
North Dakota	Yes	Not specified	Yes	Yes

Table 2–3. Summary of information presented in State summaries and available National Agricultural Statistics Service data for each State. —Continued

[NASS, National Agricultural Statistics Service; golf courses, pasture, and horticulture indicates whether or not these elements were included in the estimates for irrigated acreage and (or) irrigation withdrawals. It does not necessarily indicate whether they were reported separately from crop irrigation. More detail can be found in the State summaries in appendix 1. Annual NASS data indicate whether or not the U.S. Department of Agriculture–NASS reports data on a State level annually. This may or may not include irrigated acreage, planted acreage, or harvested acreage]

State	Golf courses	Pasture	Horticulture	Annual NASS data
Ohio	Yes	Not specified	Yes	Yes
Oklahoma	Public supply and commercial categories	Not specified	No	Yes
Oregon	No	Yes	Yes	Yes
Pennsylvania	Yes	Not specified	No	Yes
Puerto Rico	Yes	Not specified	No	Yes
Rhode Island	Yes	Not specified	No	Yes
South Carolina	Yes	Not specified	No	Yes
South Dakota	No	Not specified	No	Yes
Tennessee	Yes	Not specified	No	Yes
Texas	No	Not specified	No	Yes
Utah	No	Not specified	No	Yes
Vermont	Yes	Not specified	Yes	Yes
Virginia	Yes	Not specified	Yes	Yes
U.S. Virgin Islands	No	No	No	No
Washington	Yes	Not specified	Yes	Yes
West Virginia	Yes	Not specified	Yes	Yes
Wisconsin	Yes	Not specified	Yes	Yes
Wyoming	No	Not specified	No	Yes

Appendix 3. A Case Study Conducted in Arizona in 2009 to Verify Irrigation Water Withdrawals Using the IIWEM

Irrigation withdrawals are estimated annually for many basins in Arizona by the USGS Arizona WSC as part of the water-use program using an IIWEM (Tadayon, 2005). The methods described by Hutson (2007), used to estimate irrigation withdrawals with ancillary irrigation data, were tailored to the conditions observed in Arizona and have been used there to estimate irrigation withdrawals since 2007. The Arizona irrigation water-withdrawal estimates are based on a combination of field-verified crop acreage, an ET-estimation method using the modified Blaney-Criddle method, published information, and field experience. Each field in the region is visited at least once during the growing season to document crop type, irrigation-system type, water source, and irrigation-system efficiencies. Fields may be visited up to three times during the growing season to document multicropping and potential changes in irrigation practices, which can occur during the year. After all crop and irrigation information has been documented, the yearly crop water requirements are calculated using the modified Blaney-Criddle ET method (U.S Bureau of Reclamation, 1992), which uses available rainfall and temperature data to calculate yearly crop water consumptive use.

Irrigation withdrawals then are estimated for each crop, in each region, using the following relation:

$$W = (A \times C) / L \quad (1)$$

where

W is irrigation withdrawals, in acre-feet, for a particular crop;
A is planted acreage of the crop in the specified groundwater basin, in acres;
C is the consumptive-water requirement for the crop estimated using the modified Blaney-Criddle method, in feet; and
L is all potential water loss that occurred while irrigating (for example, conveyance loss, irrigation-system efficiency, overwatering, irrigation-system age and condition, and others), in decimal fraction (Tadayon, 2005).

Published values are available for irrigation-system efficiency (Howell, 2003; table 2).

An important variable in equation 1 that has both an effect on estimated irrigation withdrawals and contributes to potential uncertainty is L, the total losses occurring, which includes both the efficiency of the irrigation system and conveyance losses. L represents the ability of the particular irrigation water-conveyance system, coupled with the efficiency of the irrigation system, to transport water from the withdrawal or diversion point and deliver it to the roots of the plants. When a farmer irrigates, they usually will divert and (or) withdraw water until the required amount of water is delivered to each plant in the field, regardless of the losses occurred to achieve this. This leads to excess water being diverted, which decreases total irrigation efficiency compared to crop water demand alone. When using the IIWEM, the decimal fraction L needs to account for all the potential losses occurred to adequately supply the entire crop with irrigation. Irrigation practices, the distance the water is transported, the crops being irrigated, and availability of water along with the condition of the irrigation system and irrigation-system type all need to be evaluated when using this method to estimate the total withdrawals in an irrigated region. Choosing an irrigation efficiency that quantifies all water-loss sources is important in accurately estimating irrigation withdrawals.

Comparison of the IIWEM to Metered Data in Selected Regions in Arizona

Arizona has little or no metered irrigation-withdrawal data to compare with estimates generated using the IIWEM, used in various regions in Arizona since 2004. However, in 2009, metered and gaged withdrawal and diversion data in Graham, Greenlee, and Cochise Counties in eastern Arizona became available to compare with estimated withdrawals using the IIWEM. The Gila Water Commissioner (GWC) reports data for all withdrawals and diversions in Graham and Greenlee Counties, where all groundwater is required to be metered and surface-water diversions are gaged within the irrigation district, and where 30,000 acres were being irrigated. The total withdrawal data were made available to USGS by GWC in 2010, with total groundwater and surface-water withdrawals and diversions reported separately for the 2009 growing season (Allred, 2010). Also, in another region in Arizona, the withdrawal data for three center pivots of 375 total acres located in Cochise County were made available to conduct the IIWEM comparison in 2009. Each of the three center-pivot irrigation systems had their own well, and each well had a flowmeter installed to measure withdrawals.

The 30,000 irrigated acres in Graham and Greenlee Counties are primarily cotton producing areas, which are mainly irrigated by flooding fields with a blend of surface water and groundwater. More than 95 percent of the total irrigated acreage was being irrigated using surface (flood), and more than 70 percent of the irrigated acreage was cotton, 15 percent was alfalfa, and the rest was a mix of wheat, sorghum, and corn. Cotton and alfalfa have a higher yearly water demand when

compared to other field crops grown in the counties and need a longer time to mature. The modified Blaney-Criddle method estimates that cotton can consume 31 in. of water in a 190-day growing season, and alfalfa can consume up to 43 in. of water in a 365-day growing season, considering the 2009 growing-season temperature and rainfall recorded in the area (Brouwer and Heibloem, 1986).

When withdrawals were estimated in Graham and Greenlee Counties in 2009 using the IIWEM, irrigation-system efficiencies and conveyance-loss coefficients were chosen using the conditions observed during the field visits conducted in the region. Each field in Graham and Greenlee Counties was irrigated and was visited at least once during the growing season; irrigation data were documented for each field. An overall irrigation-system and conveyance-loss efficiency of 50 percent was assigned given the condition of the irrigation canals, the availability of surface water, the distance that water is conveyed from the source, and the presence of salts forcing some irrigators to over-irrigate to leach salts away from the root zone. Using the IIWEM, the crop types being irrigated, the consumptive-water requirement rates for each crop, and the 50-percent irrigation-system and conveyance-loss coefficient, lead to an estimated 155,175 acre-ft of water used in the 2009 growing season, while GWC reported metered withdrawals of 150,845 acre-ft (Allred, 2010). In an area where surface (flood) irrigation dominates, like many areas in the West, the IIWEM was within 3 percent of the total metered withdrawals for the 30,000 irrigated acres in Graham and Greenlee Counties.

Additionally, three center pivots, irrigating a total of 375 acres in Cochise County, also were estimated using the IIWEM and compared to metered withdrawals in 2009. The three center pivots—each being irrigated by their own well—had flowmeters installed, which provided the Arizona WSC staff with yearly withdrawal data in hundreds of gallons. The center pivots are 125 acres each, and all were irrigating alfalfa for the duration of the 2009 growing season. The modified Blaney-Criddle method predicted that alfalfa needed about 41 in. of water throughout the year, given the local weather conditions. The irrigation-system efficiency was assumed to be 80 percent owing to the condition of the center-pivot irrigation systems observed during the growing season. The water withdrawals estimated using the IIWEM produced 1,613 acre-ft of water applied to the three fields in 2009; the three well flowmeters measured 1,611 acre-ft. The IIWEM-predicted withdrawal was estimated within 1 percent of the total metered withdrawals for these three center pivots in the Douglas Basin in 2009.

Comparison of estimated and metered irrigation withdrawals conducted in 2009 indicates that the IIWEM can provide reasonable estimates of irrigation withdrawals when metered or gaged data are not available. Using accurate estimates of efficiency and conveyance-loss coefficients, along with irrigated crop acreage and crop water requirement (both by crop type), the IIWEM may provide a valuable comparison of the reasonableness of reported irrigation withdrawals or can be used to estimate withdrawals when metered, gaged, or reported withdrawal data are not available. The comparisons in this study show that estimates for irrigation withdrawals may be applied at a field, region, or county level using appropriate irrigation data and may produce reasonable results.

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