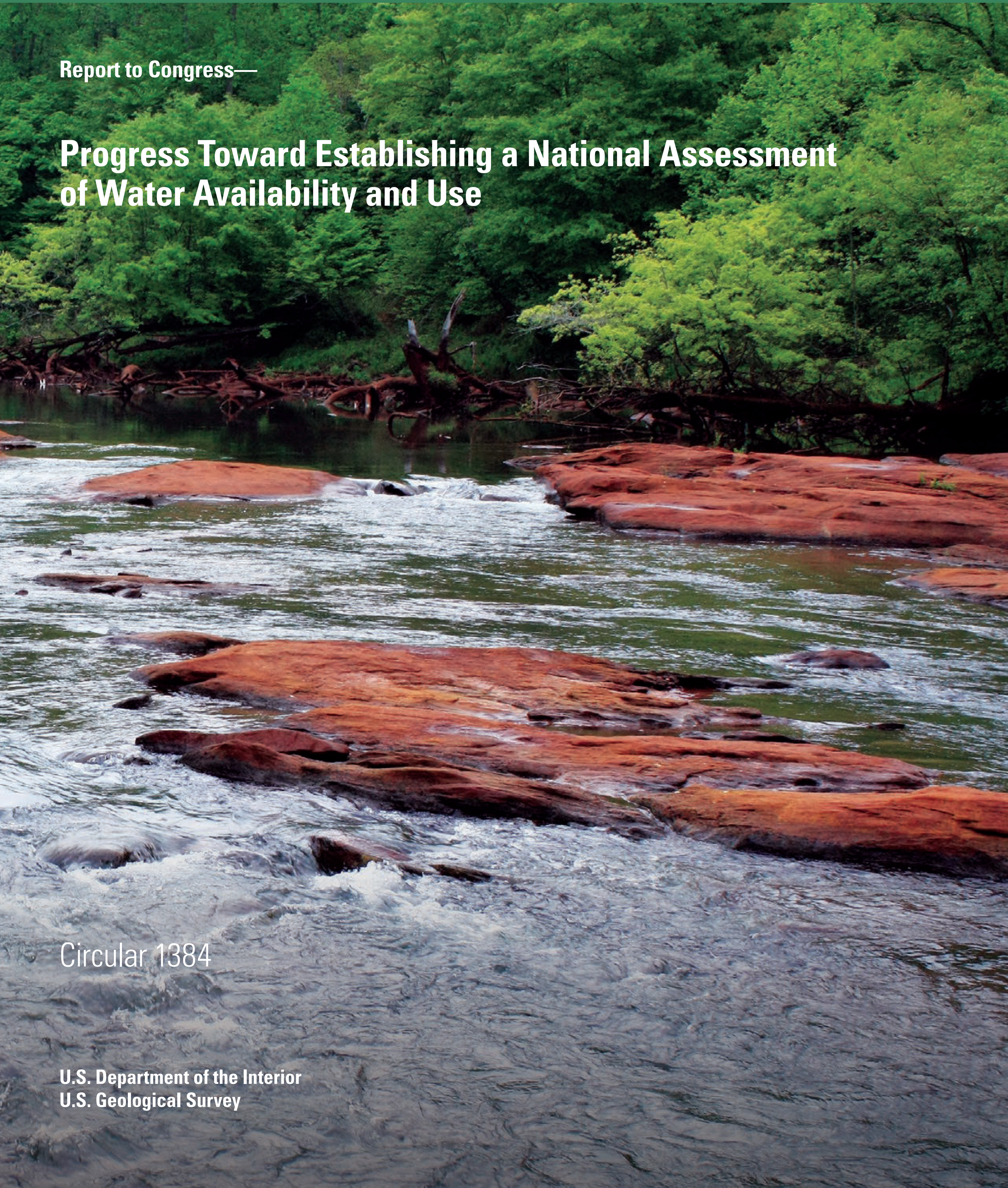

Report to Congress—

Progress Toward Establishing a National Assessment of Water Availability and Use

Circular 1384

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

Cover. Big Lazer Creek, Talbot County, Georgia. (Photo by Alan Cressler, U.S. Geological Survey)

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Progress Toward Establishing a National Assessment of Water Availability and Use

By William M. Alley, Eric J. Evenson, Nancy L. Barber, Breton W. Bruce, Kevin F. Dennehy, Mary C. Freeman, Ward O. Freeman, Jeffrey M. Fischer, William B. Hughes, Jonathan G. Kennen, Julie E. Kiang, Kelly O. Maloney, MaryLynn Musgrove, Barbara Ralston, Steven Tessler, and James P. Verdin

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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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About This Report

Many reports have recognized the need for a National Water Census (Water Census) for the United States, and have called upon the U.S. Geological Survey (USGS) to undertake this challenge. The United States Congress, in Subtitle F of the Omnibus Public Land Management Act of 2009 (Public Law (P.L.) 111-11), established a "blueprint" for a national assessment of water availability and use that outlines the information needed from a Water Census. This report, "Progress Toward Establishing a National Assessment of Water Availability and Use," describes the initial steps taken by the USGS to institute a Water Census and the progress the USGS has made toward establishing such a Census. It explains, for both Congress and the public, the steps the USGS will take to fulfill the requirements of Subtitle F of P.L. 111-11, and describes plans for the future of the Water Census.

This report presents the history and background of and the need for a Water Census. It describes the initial steps taken toward accomplishing the Water Census, which is designed to systematically provide information that will allow resource managers to assess the water availability of the Nation. The report explains how the Water Census is being organized around the unifying theme of a water budget, and explains why water budgets are critical for assessing water availability for the Nation. The report describes the importance of understanding, assessing, and delivering information about the uncertainty of water-availability information, as well as the collaboration and coordination with other agencies and organizations that is essential for the Water Census to succeed. The report explains the planned regional framework for presenting water-availability data through a set of geographic focus area studies and the planned national framework for providing uniform information on water-budget components across the country through topical area studies. The report also explains how the USGS will incorporate water-quality information into the water-availability analysis. Finally, the report describes the information management and delivery activities that are necessary for the goals of the Water Census to be achieved.

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Executive Summary

The Omnibus Public Land Management Act of 2009 (Public Law 111-11) was passed into law on March 30, 2009. Subtitle F, also known as the SECURE Water Act, calls for the establishment of a “national water availability and use assessment program” within the U.S. Geological Survey (USGS). A major driver for this recommendation was that national water availability and use have not been comprehensively assessed since 1978.

This report fulfills a requirement to report to Congress on progress in implementing the national water availability and use assessment program, also referred to as the National Water Census. The SECURE Water Act authorized $20 million for each of fiscal years (FY) 2009 through 2023 for assessment of national water availability and use. The first appropriation for this effort was $4 million in FY 2011, followed by an appropriation of $6 million in FY 2012.

The National Water Census synthesizes and reports information at the regional and national scales, with an emphasis on compiling and reporting the information in a way that is useful to states and others responsible for water management and natural-resource issues. The USGS works with Federal and non-Federal agencies, universities, and other organizations to ensure that the information can be aggregated with other types of water-availability and socioeconomic information, such as data on food and energy production. To maximize the utility of the information, the USGS coordinates the design and development of the effort through the Federal Advisory Committee on Water Information.

A National Water Census is a complex undertaking, particularly because there are major gaps in the information needed to conduct such an assessment. To maximize progress, the USGS engaged stakeholders in a discussion of priorities and leveraged existing studies and program activities to enhance efforts toward the development of a National Water Census.

Photo by Tim Merrick, U.S. Geological Survey

1.0 Introduction

Water is a key ingredient for healthy communities, economies, and natural environments. The Nation faces an increasingly large set of water-resource challenges as water shortages and water-use conflicts become more commonplace. As competition for water grows—for irrigation of crops, for use by cities and communities, for use in energy production, and for the environment—the need for information and tools to aid water-resource managers also grows, yet no comprehensive assessment or census of information currently exists that summarizes the availability of the Nation's freshwater, with respect to both quantity and quality, for human and environmental needs.

Subtitle F of the Omnibus Public Land Management Act of 2009 (Public Law (P.L.) 111-11), which was passed into law on March 30, 2009, helps address this need. Also known as the SECURE Water Act, it contains substantive mandates for both the U.S. Geological Survey (USGS) and the U.S. Bureau of Reclamation (USBR).

Section 9508 of the SECURE Water Act calls for the establishment of a "national water availability and use assessment program" within the USGS to:

- provide a more accurate assessment of the status of the water resources of the United States;
- assist in the determination of the quantity of water that is available for beneficial uses;
- assist in the determination of the quality of the water resources of the United States;
- identify long-term trends in water availability;
- use each long-term trend to provide a more accurate assessment of the change in the availability of water in the United States; and
- develop the basis for an improved ability to forecast the availability of water for future economic, energy-production, and environmental uses.

The national water availability and use assessment program called for by the SECURE Water Act also is referred to as a National Water Census (or simply the Water Census). It is one of six major science directions identified by the USGS in 2007 in its Science Plan for the next decade (U.S. Geological Survey, 2007).

The Water Census is part of an overarching Department of the Interior initiative known as WaterSMART (Sustain and Manage America's Resources for Tomorrow). Through WaterSMART, the Department is working to achieve a sustainable water strategy to help meet the Nation's water needs, and the Water Census will help inform that strategy (U.S. Department of the Interior, 2012).

Included in the SECURE Water Act is a requirement to report to Congress on progress made in implementing the national water availability and use assessment program (see Box A). This report fulfills that requirement as of December 31, 2012.

Strategically, the planning of the Water Census is encouraged to look towards developing an on-going, effective tool on a par with the social and economic censuses that supports national decision making.

National Research Council (2009)—Toward a Sustainable and Secure Water Future

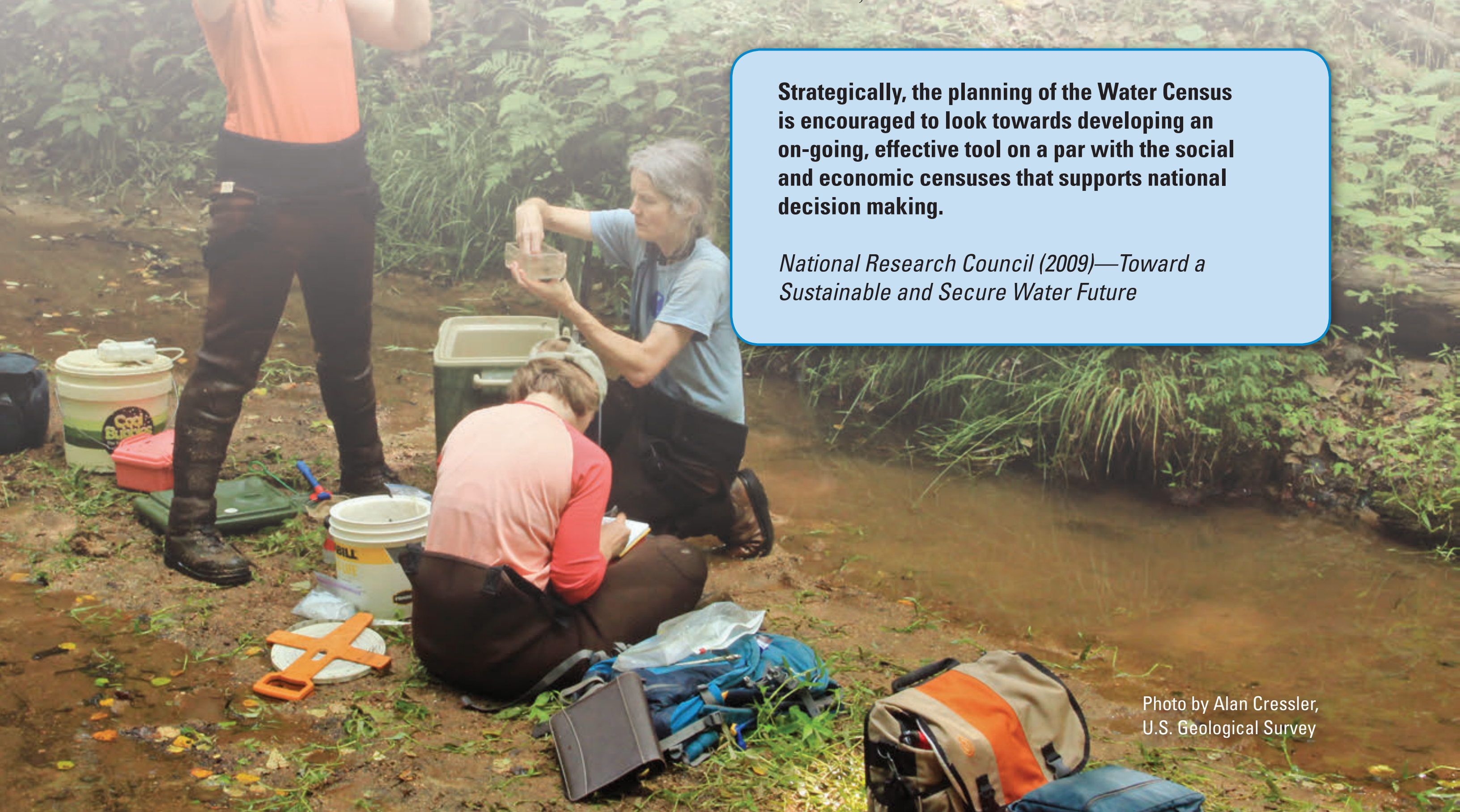


Photo by Alan Cressler, U.S. Geological Survey

Box A. Report Requested in SECURE Water Act (P.L. 111-11)

Not later than December 31, 2012, and every 5 years thereafter, the Secretary shall submit to the appropriate committees of Congress a report that provides a detailed assessment of—

(1) the current availability of water resources in the United States, including—
- (A) historic trends and annual updates of river basin inflows and outflows;
- (B) surface water storage;
- (C) groundwater reserves; and
- (D) estimates of undeveloped potential resources (including saline and brackish water and wastewater);

(2) significant trends affecting water availability, including each documented or projected impact to the availability of water as a result of global climate change;

(3) the withdrawal and use of surface water and groundwater by various sectors, including—
- (A) the agricultural sector;
- (B) municipalities;
- (C) the industrial sector;
- (D) thermoelectric power generators; and
- (E) hydroelectric power generators;

(4) significant trends relating to each water use sector, including significant changes in water use due to the development of new energy supplies;

(5) significant water use conflicts or shortages that have occurred or are occurring; and

(6) each factor that has caused, or is causing, a conflict or shortage described in paragraph (5).

2.0 National Water Census

National water availability and use have not been comprehensively assessed in more than 30 years (U.S. General Accounting Office, 2003). A rudimentary national assessment published by the U.S. Water Resources Council in 1968 was followed by a more comprehensive Second National Water Assessment in 1978 (U.S. Water Resources Council, 1968, 1978). Efforts were made to update components of the Second National Water Assessment to reflect conditions for the year 1995 as part of the National Assessment of the Potential Consequences of Climate Variability and Change (Frederick and Schwarz, 1999). Recently, the National Science and Technology Council, Committee on Environment and Natural Resources Sustainability, through the Subcommittee on Water Availability and Quality (SWAQ), has issued several reports calling attention to the need for an up-to-date, comprehensive assessment of the Nation's water availability (National Science and Technology Council, 2004, 2007).

> **National water availability and use has not been comprehensively assessed in more than 30 years.**
>
> *U.S. General Accounting Office (2003)*

Initial concepts for a Water Census were developed in 2002 when, as part of the report on the Fiscal Year 2002 Appropriations for Interior and Related Agencies, the House Committee on Appropriations directed the USGS to "prepare a report describing the scope and magnitude of the efforts needed to provide periodic assessments of the status and trends in the availability and use of freshwater resources." To prepare that report, the USGS solicited input from many individuals and organizations involved in issues of water availability and use (U.S. Geological Survey, 2002). We asked what types of decisions and policy issues would benefit from the availability of improved water facts today and in the future, what variables or indicators would be useful, what spatial and temporal scales would be appropriate, how to build on existing efforts, and where collaborative opportunities could most effectively be expanded.

Several clear messages emerged from the responses. Many individuals emphasized the potential for improved methodologies and standards for consistency of nationwide data, the importance of ecological flows as a component of water use and availability, and the connections between water quantity and water quality. National organizations noted the need for consistent indicators of water availability across the Nation. Individuals representing state and local governments emphasized that many states have done extensive planning to quantify water availability now and in the future, and that the availability of water is inherently a local issue in most respects. The design of the Water Census builds upon these comments and recommendations.

At the request of Congress, a pilot assessment was initiated in 2005 to quantify the source, movement, and dynamics of water resources in the U.S. portion of the Great Lakes Basin. New methods of hydrologic analysis and improved strategies for delivering water-related information were developed and tested in the process of assessing the availability of water in the region (Reeves, 2011). A second small pilot study focused on groundwater depletion in Arizona's Southwest Alluvial Basins (Tillman and others, 2011).

In a broad sense, water availability is viewed in terms of both human and environmental/ecological uses. The Water Census will synthesize and report information at the regional and national scales, with an emphasis on compiling and reporting this information in a way that is useful to states and others responsible for water management and natural-resource issues. The focus is on the scientific aspects of water availability, and the program reports on the physical, chemical, and biological characteristics that are important as indicators of water availability. The USGS works with Federal and non-Federal agencies, universities, and other organizations to ensure that the information can be aggregated with other types of water-availability and socioeconomic information. To maximize the utility of the information, the USGS coordinates the design and development of the effort through the Federal Advisory Committee on Water Information (ACWI).

A national assessment of water availability and use is a complex undertaking. At the time of the previous national assessments, water availability was viewed in comparatively simple terms. These early assessments focused largely on basic statistics about the quantities of water available for various human uses. Since then, competition for water resources has increased greatly and considerably more importance is attached to the availability of water for environmental and ecosystem needs, in addition to human use. Likewise, concerns have grown about groundwater depletion, streamflow alteration, climate change and variability, and water-quality impairment. Moreover, awareness of the connectivity of surface water and groundwater and the linkages between water availability and use of other natural resources has greatly increased.

The Water Census program provides broad coverage across jurisdictional boundaries and in a consistent manner from year to year. The information it provides is designed to be useful to policymakers addressing a wide range of natural-resource issues. The limitations of the data and information also must be recognized, however. Although the data are useful for national water assessments and general statewide and regional overviews, they cannot be used to address specific, localized issues.

As the primary Federal agency responsible for scientific evaluation of the natural resources of the United States, including its water and biological resources, the USGS has a key role in the national assessment of water availability and use. The agency employs a diverse cadre of scientists and technicians who evaluate the status and trends of freshwater quality and quantity for human and environmental needs at the local, state, regional, and national levels. The USGS has an existing infrastructure that allows it to conduct a regular inventory of natural resources and water use, including water quantity, water quality, and environmental water needs, in partnership with local, state, and regional water and environmental agencies. The USGS also has the biological capabilities needed to relate the presence of individual species, groups of species, and ecosystem function to the quantity, quality, and timing of water movement, as well as to the environmental habitat requirements of those organisms.

2.1 Water Budgets as a Unifying Theme

Much of the information that makes up a national assessment of water availability and use is essentially the components of water budgets for watersheds and aquifers. Water budgets account for the inputs to, outputs from, and changes in the amount of water in the various components of the water cycle. They are the hydrologic equivalent of the deposits to, withdrawals from, and changes in the balance in a checking account and provide the hydrologic foundation for analysis of water availability. Basic components of water budgets are precipitation, evapotranspiration, surface-water and groundwater flow into and out of the watershed, change in surface-water and groundwater storage, change in snow and ice storage, and human withdrawals and interbasin transfers (fig. 1). As with a monetary budget or checking account, knowing where, when, and how much water (or money) is "flowing" into or out of a water budget (or checking account) can illuminate how much is left for other uses (water availability) and reveal where stresses to the budget (the unpaid bills or water shortages) exist or are developing.

Water budgets account for the inputs to, outputs from, and changes in the amount of water in the various components of the water cycle. They are the hydrologic equivalent of the deposits to, withdrawals from, and changes in the balance in a checking account and provide the hydrologic foundation for analysis of water availability.

Unfortunately, information about most water-budget components is not available in a consistent form across the Nation. Therefore, a major undertaking of the Water Census is to provide estimates of selected water-budget components at consistent spatial and temporal scales. The Water Census will provide information about the following water-budget components through a series of topical area studies, which address surface water, groundwater, evapotranspiration, and water use. These topical area studies will provide quantitative information about the amount of water that resides in, or is moving through, each of these water-budget components. This information will be developed through direct field measurements obtained from data-collection networks and through the use of models that extend measured data into spatial areas and temporal periods for which measurements are not available. An additional topical area study will advance the science of ecological water, which quantitatively examines the relations between water

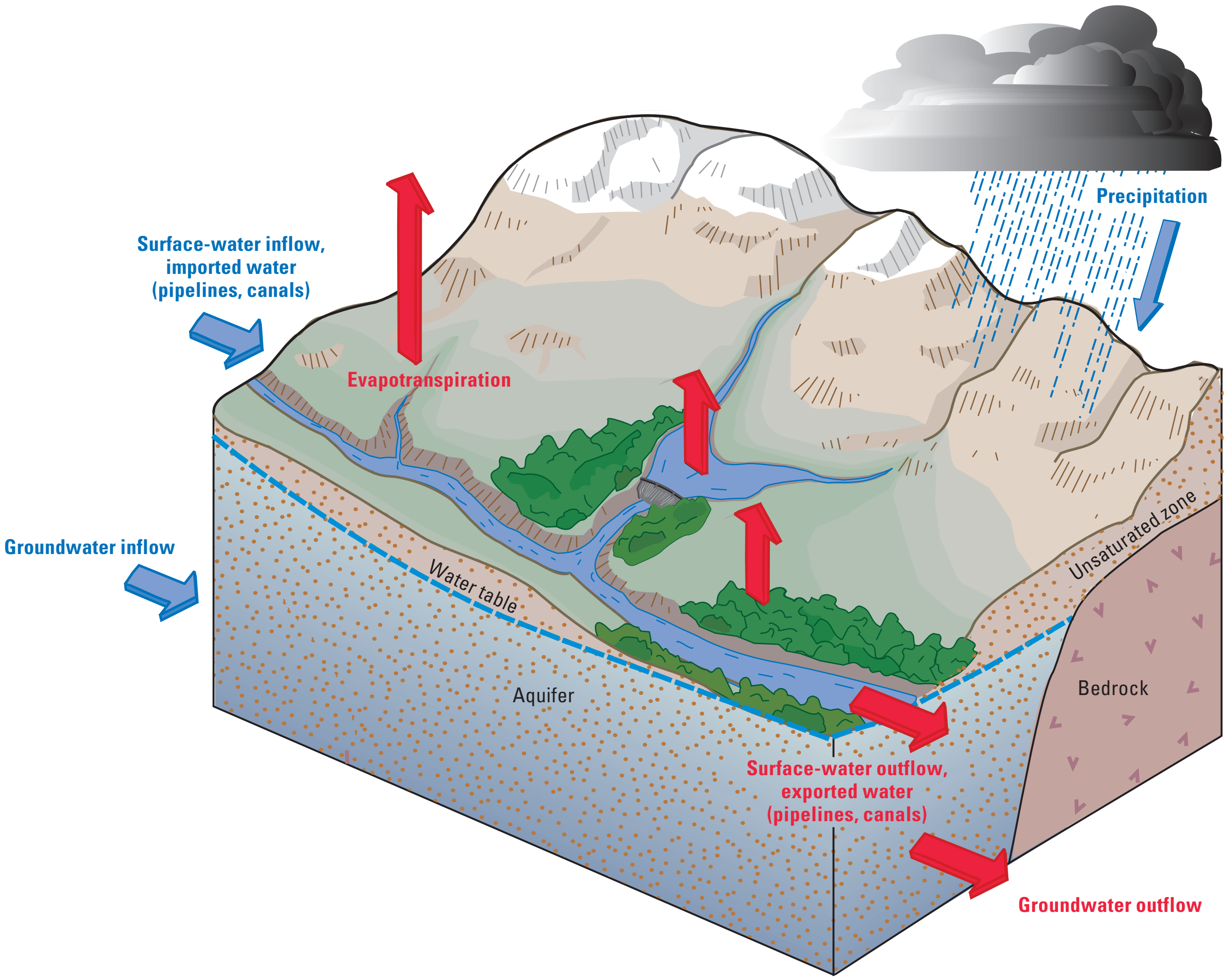
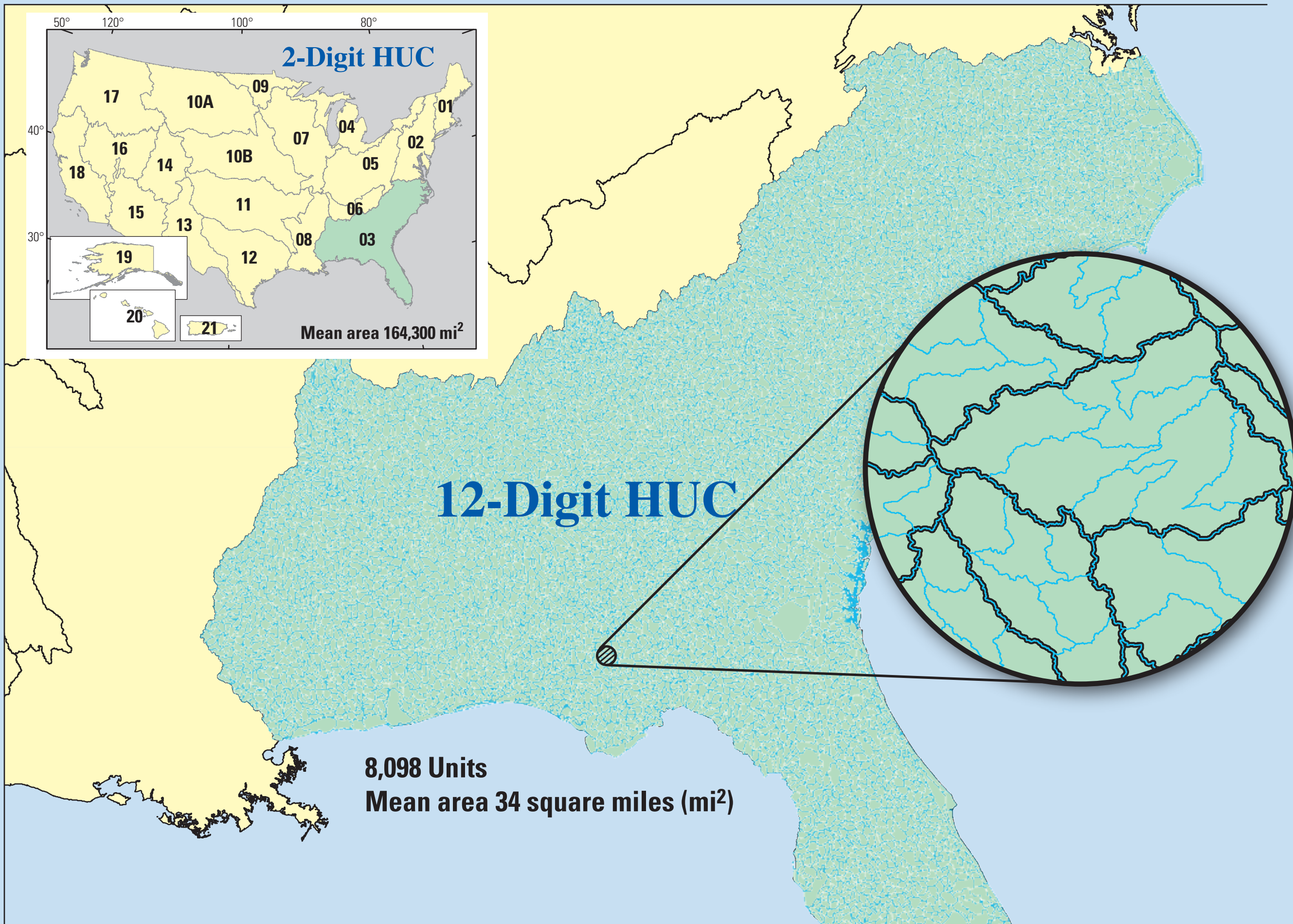


Figure 1. Components of a simple water budget for part of a watershed. (From Healy and others, 2007)

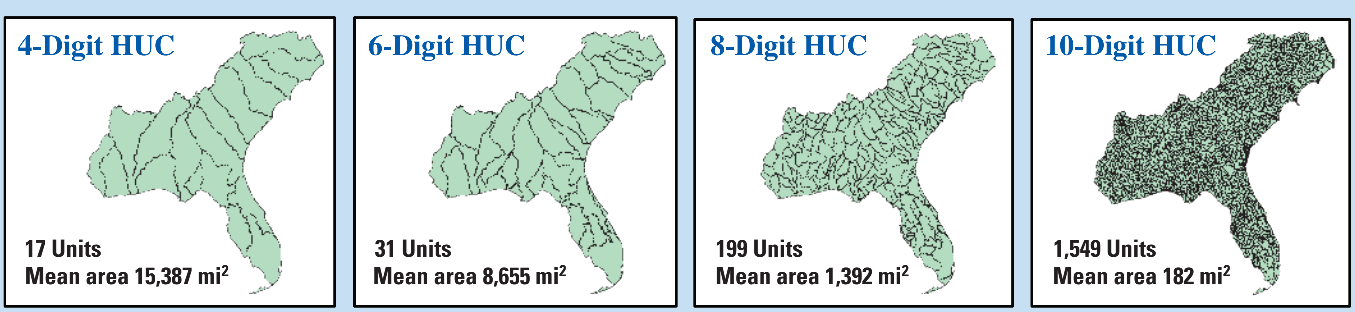
availability and healthy ecosystems. In addition to providing a basis for national indicators of water flow and storage for the Water Census, these studies will support analyses of water availability by local and regional agencies and will contribute to research quantifying the national and global water cycle. Some water-budget components, such as evapotranspiration, have proven difficult to estimate accurately with existing measurement techniques. Therefore, the program supports development of improved methods for quantifying this and other selected water-budget components. In the future, if sufficient resources are available, the Water Census may expand the study of topical areas beyond the five indicated above.

The size of the watershed area for which a water budget is calculated determines, in part, the water-resource questions that can be addressed. Calculating a water budget for a watershed area that is too large can mask water-availability problems that become apparent at a smaller scale. In contrast, calculating a water budget for a small watershed may not provide the regional or national context that the user desires. A long-term objective of the Water Census is to provide measured or estimated information for all water-budget components at the 12-digit hydrologic unit code (HUC-12) scale (see Box B)—that is, for drainage basins (watersheds) across the Nation with an average size of 37 square miles. This information can then be aggregated for larger watersheds. Although the HUC-12 scale is established as a long-term goal for the Water Census, many types of data currently (2012) can be determined only at coarser scales. This point is discussed farther on in this report.

Box B. Hydrologic Units



The United States is divided and subdivided into successively smaller watersheds. (A watershed is an area of land from which all of the water drains to the same place.) These watersheds are represented as hydrologic units, which are classified into six levels. Each hydrologic unit is identified by a unique hydrologic unit code (HUC) consisting of 2 to 12 digits based on the six levels of classification—the smaller the watershed, the more digits in the code to capture the "nesting" within larger watersheds. This coding system provides an orderly way to classify watersheds for the purpose of water-availability analysis.



Density of hydrologic unit codes (HUCs) at different levels illustrated by using the 2-digit HUC Region 03 (South Atlantic-Gulf).

Groundwater presents a particular challenge with respect to developing a complete water budget for a watershed. Aquifer systems are complex, three-dimensional geologic features. They can cover large areas, commonly do not conform to surface-water divides, and may obtain most of their recharge from locations that are far from those where the groundwater is pumped from a well or flows to a surface-water body. Because of these and other complexities, groundwater systems are incorporated into the Water Census in two ways. A major element of the Water Census focuses on regional analyses of groundwater availability in 30 to 40 principal aquifers that collectively account for more than 90 percent of the Nation's total groundwater withdrawals. In addition, to the extent possible, estimates of groundwater recharge, storage, and discharge at the watershed scale will be made by using a combination of information from the large-scale studies, data from observation-well networks, analysis of streamflow records, and other available information.

The temporal scale of a water budget, the time period for which the water budget is calculated, is also of primary importance. The long-term objective of the Water Census is to provide information about water-budget components on a monthly basis in order to capture seasonal variations. Data for some components, such as water use, currently are available largely on an annual or less frequent basis. The USGS is working with states and other agencies to increase the frequency of data collection and to develop methods for disaggregating historical annual data to monthly estimates. In addition to monthly data for water-budget analysis, data at other time steps, such as continuous or daily streamflow records for ecological flow analysis, will be included in other aspects of the Water Census.

2.2 Characterizing Uncertainty

All water-resource decisions are made in the face of uncertainty. Uncertainty is an inherent factor in hydrologic data collection, estimation techniques, and simulation (modeling). Errors associated with measurement techniques arise from the inability to accurately measure specific aspects of the hydrologic system, such as streamflow, the water level in a well, or soil properties that control evapotranspiration and runoff. Uncertainty arises from the inability of our data-collection networks to fully characterize the natural spatial and temporal variability associated with hydrology, geology, climate, and land use. Uncertainty also is present in hydrologic models because it is impossible to reproduce a natural hydrologic system in a model with complete accuracy.

To the extent possible, the USGS will strive to quantify or estimate the uncertainty associated with Water Census information products. The USGS also will address uncertainty in the highest priority water data and information by improving spatial and temporal coverage for key hydrologic variables, improving estimation techniques through advanced incorporation of key data layers into statistical and physical models, and providing quantitative (or qualitative, where quantitative estimates are unavailable) guidance about data and model uncertainties to information-product users.

2.3 Coordination and Collaboration

The USGS is developing plans for the Water Census in coordination and collaboration with Federal and non-Federal agencies, universities, and other organizations. Collaboration across agency boundaries ensures that information produced by the USGS can be aggregated with data on other types of physical, social, economic, and environmental factors that affect water availability. Data that are germane to issues of water availability include population statistics, land use, water costs and pricing, climate data, and instream-flow requirements for aquatic species and habitats. These data are compiled by state and local agencies, by universities and water-resource organizations, and by several Federal agencies, including the Department of Agriculture (USDA), the

Box C. Coordination of the Water Census with the Bureau of Reclamation

Both the USGS and the U.S. Bureau of Reclamation (USBR) have substantive responsibilities under the Department of the Interior WaterSMART initiative. The primary USGS WaterSMART activity is the Water Census. WaterSMART activities in the USBR include the River Basin Supply and Demand Studies; the WaterSMART Grants Program, which concentrates on water conservation and sustainability grants; and the Title XVI Program, which concentrates on water recycling and reuse projects. WaterSMART activities require close coordination between the two agencies. There is a natural synergy between the USBR River Basin Supply and Demand Studies and the USGS Geographic Focus Area Studies, which are described farther on in this report. To achieve this coordination, the USGS and USBR have established routine biweekly communications to stay apprised of activities of shared interest. In addition, the USGS and USBR have been active participants in the planning and execution of the studies that have joint interest. This joint interest is directly apparent in the Colorado River Basin studies—the USGS Geographic Focus Area Study of the Colorado River Basin was designed to fulfill a data need identified during the execution of the USBR River Basin Supply and Demand Study of the Colorado River.

Department of Energy, the National Oceanic and Atmospheric Administration (NOAA), the U.S. Army Corps of Engineers, the USBR, and the U.S. Environmental Protection Agency.

The USGS receives guidance on the Water Census through the Advisory Committee on Water Information (ACWI). ACWI members represent 35 organizations from all levels of government (Federal, state, Tribal, and local), public interest groups, academia, private industry, and non-profit and professional organizations. ACWI is chaired by the Assistant Secretary of the Interior for Water and Science and is staffed and supported by the USGS under a charter established pursuant to the Federal Advisory Committee Act by Office of Management and Budget Memorandum 92-01. ACWI currently (2012) has several subgroups examining water-quality monitoring, data methods and comparability, spatial water data, hydrology, streamgaging, cooperative water programs, and science issues. The USGS has worked with the Sustainable Water Resources Roundtable in ACWI to convene a multi-organization ad hoc committee of stakeholders in water availability to make recommendations on the priorities, design, and methods of presentation of the Water Census.

2.4 Progress Toward Goals

The SECURE Water Act authorized $20 million per year for the Water Census for FY 2009 through 2023. The first appropriation for this effort was $4 million in FY 2011, followed by an appropriation of $6 million in FY 2012, for a total of $10 million of the $80 million authorized during this period. This funding provided for the startup of three Geographic Focus Area Studies described in the next section, as well as initial efforts to build capability and address gaps in our ability to conduct a complete Water Census. The USGS also leveraged existing studies and activities from ongoing USGS programs to enhance efforts toward a Water Census. The USGS engaged stakeholders to establish priorities for work in surface water, groundwater, evapotranspiration, water use, and ecological water science—all key areas for the Water Census. The studies of surface water and groundwater are fundamental to addressing items (1) and (2) in the periodic reports requested by the SECURE Water Act (see Box A), whereas evapotranspiration estimates, water use, and ecological water science are fundamental to items (3) to (6). Below, we first discuss the Geographic Focus Area Studies and then describe the five topical areas.

Photo by Alan Cressler, U.S. Geological Survey

3.0 Geographic Focus Area Studies

Competition for water resources has reached a level of national attention and concern in a number of areas throughout the United States. The competing interests may arise from multiple human needs (demands for potable water, irrigation, energy, industrial processes, etc.), from competition between human and aquatic ecosystem needs, or both. These types of competition are noted in the SECURE Water Act as areas of "significant water use conflicts or shortages that have occurred or are occurring" (see Box A). The Water Census includes studies focused on these areas. These Geographic Focus Area Studies serve several purposes. They (1) contribute to ongoing assessments of water availability in large watersheds with potential water-use conflicts, (2) provide opportunities to test and improve approaches to water-availability assessment, and (3) inform and "ground truth" the Water Census with local information. Watershed stakeholders in each Geographic Focus Area are seeking a comprehensive technical assessment of water availability using the best available tools. The Apalachicola-Chattahoochee-Flint, Colorado, and Delaware River Basins were selected for the initial Geographic Focus Area Studies.

3.1 Apalachicola-Chattahoochee-Flint River Basin

The Apalachicola-Chattahoochee-Flint (ACF) River Basin (fig. 2) covers 19,800 square miles in Georgia, southeastern Alabama, and northwestern Florida. The basin includes the drainages of the Chattahoochee River and the Flint River, which join to form the Apalachicola River. The Apalachicola River flows into the Gulf of Mexico at Apalachicola Bay.

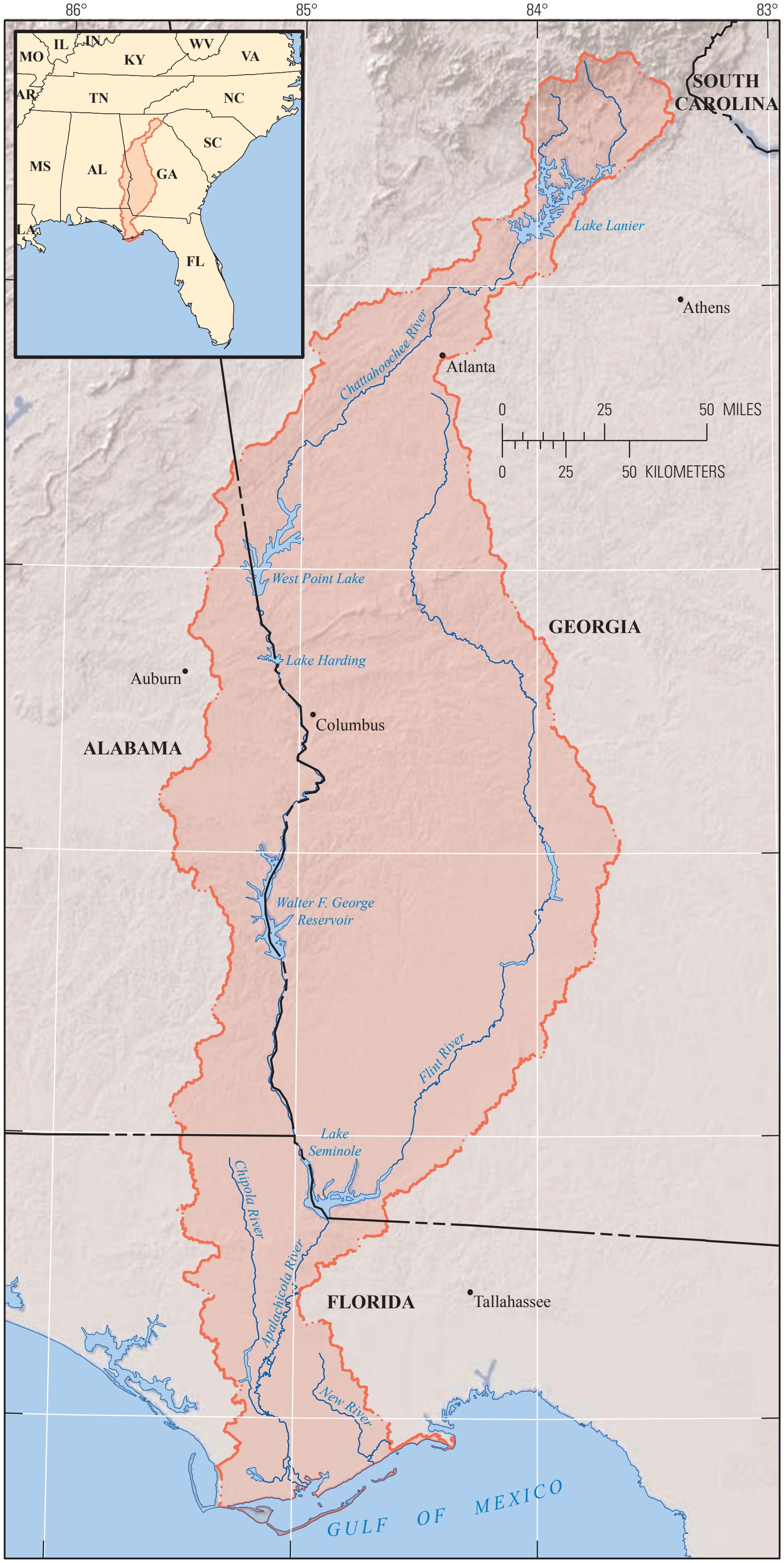
Conflict over water resources in the ACF River Basin (fig. 2) among Alabama, Florida, and Georgia has resulted from increases in water use for public supply, industry, power generation, and agriculture as the region has grown and developed over the past 50 years. Conflicts over water are not limited to interstate issues; during drought conditions, competition among all water users can become pronounced.

A primary example of this conflict is the legal action regarding the numerous uses of Lake Lanier near Atlanta, Georgia. These uses include water supply, power generation, maintenance of water quality, supply for downstream reservoirs, and maintenance of minimum flows to support aquatic species. The debate over water availability has focused on the management of water in reservoirs that are operated by the U.S. Army Corps of Engineers. These reservoirs typically have sufficient storage capacity for human uses and to maintain streamflows. Information needed for reservoir management to maintain flows in the ACF mainstem rivers is largely available. However, information on the many water-availability influences that are distributed across the basin—specifically, water withdrawals and wastewater returns, groundwater pumping for irrigation, interbasin transfers, storage in unmanaged reservoirs, and effects of increases in impervious surface and climate variability—have received less detailed study. These less examined factors are the primary target of the ACF Geographic Focus Area Study and will provide much needed data to the various Federal, state, and local groups involved in interstate water-supply negotiations and the overall management of the ACF River Basin.

"Our ability to understand and respond to problems and issues in every Alabama watershed including those with interstate implications such as the ACF Basin depends on accurate information. A fundamental tool such as the USGS Water Census that provides us with a uniform baseline of hydrologic information of both current water conditions and historical trends is invaluable in developing a technical consensus among government agencies, non-government organizations (NGOs), and stakeholders. Information from the Water Census can serve as a foundation for resolving more contentious aspects of how best to plan and prepare for the future of these watersheds."

J. Brian Atkins, Director, Alabama Office of Water Resources

The Geographic Focus Area Study of the ACF River Basin has three major components that build on ongoing USGS data collection and modeling capabilities: (1) estimating water use, (2) simulating surface-water and groundwater flow, and (3) establishing ecological flow relations. The water-use component is developing a site-specific database of water use for the ACF River Basin, developing improved methods for estimating agricultural withdrawals, and compiling available water-use projections. Calculations of net water use will be improved by obtaining information on interbasin transfers, determining irrigation and septic-tank return flows, and estimating consumptive use by thermoelectric power plants. The hydrologic simulation component will consist of a surface-water model of the entire ACF River Basin and a groundwater model of the lower ACF River Basin. These models will be linked where agricultural pumpage of groundwater is greatest to improve the simulation of groundwater/surface-water interactions. The study included coordinated monitoring of streamflow (discharge measurement locations shown in figure 3), groundwater levels, and water-quality measurements of surface water during drought conditions in July 2011 to support the hydrologic simulation component. As part of the ecological water science component (see section 4.5), ecological models will be used to predict changes in fish and mussel species occupancy due to variations in flow conditions associated with climate change, land-use change, and changes in water withdrawals or discharges. Together, these databases and models can be used to inform and improve decision making regarding the effects of future growth and water use on the availability of water for diverse uses.



Base modified from U.S. Geological Survey
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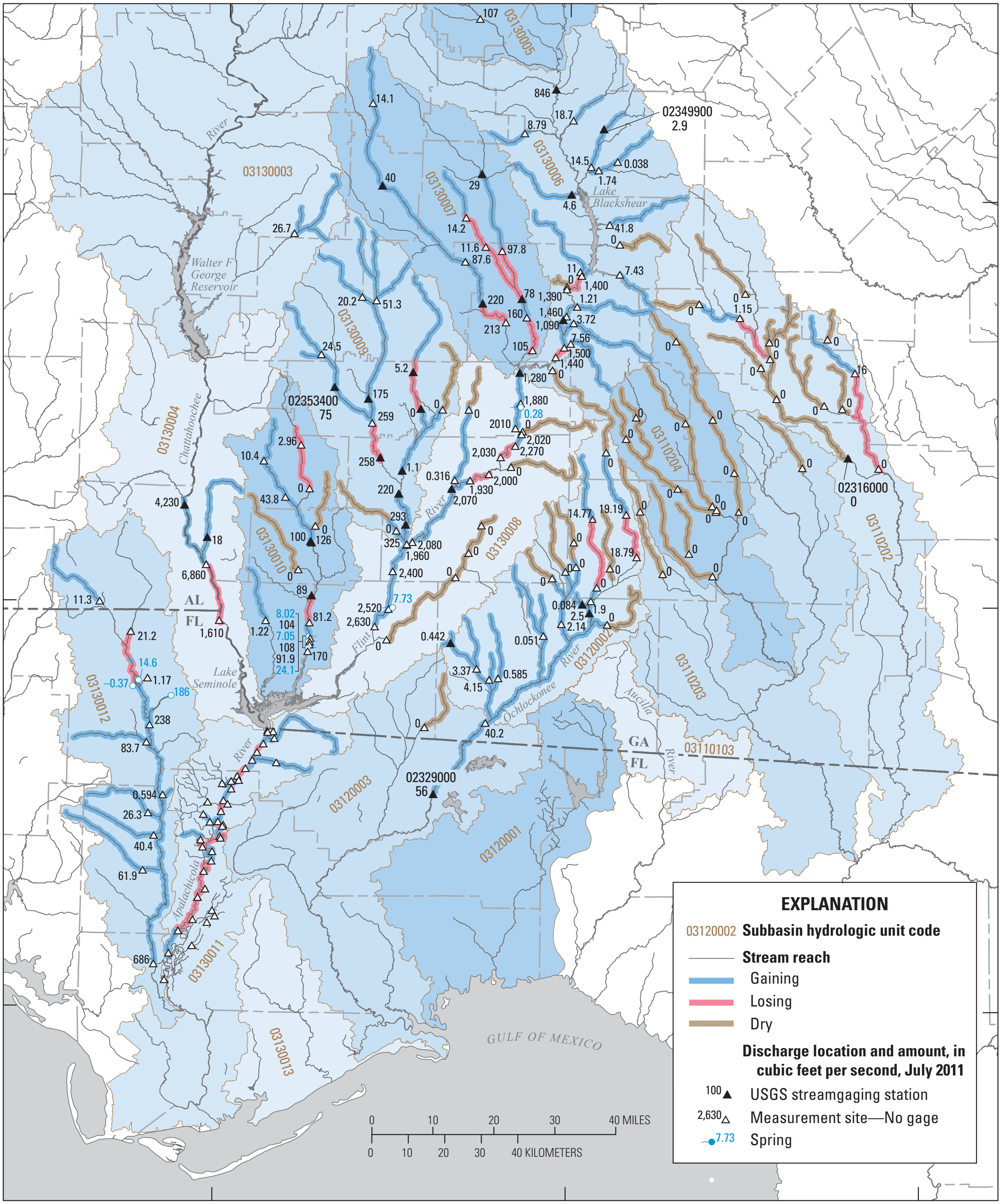
Figure 2. Location of Apalachicola-Chattahoochee-Flint (ACF) River Basin.



Base modifed from U.S. Geological Survey
1:100,000-scale digital data

Figure 3. Location of discharge measurements made in the lower Apalachicola–Chattahoochee–Flint River Basin and western and central parts of the Aucilla–Suwanee–Ochlockonee River Basin, Georgia and Florida, showing gaining, losing, and dry stream reaches during July 2011. (Modified from Gordon and others, 2012)

3.2 Colorado River Basin

The Colorado River Basin (fig. 4) covers about 246,000 square miles, including parts of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming, before the river flows into Mexico. The river supplies water to more than 30 million people, irrigates nearly 4 million acres of cropland in the U.S. and Mexico, and supplies hydropower plants that generate more than 10 billion kilowatt-hours annually. The river provides both recreational opportunities and an array of environmental benefits, supports a wide diversity of fish and wildlife and their habitats, and preserves flow and water-dependent ecological systems. Increasing population, decreasing streamflows, and the uncertain effects of a changing climate indicate the need for an improved understanding of water use and water availability in the Colorado River Basin.

The USGS coordinates the Colorado River Basin Focus Area Study with the USBR WaterSMART Basin Study Program. The purpose of the USBR study is to define the extent of water supply and demand imbalances in the Colorado River Basin through 2060 (fig. 5). The USBR study also will develop and analyze strategies to resolve those imbalances under a range of conditions that could occur during the next 50 years.

The USGS study complements the USBR study by focusing on the components of the water budget that are the least well understood. Through stakeholder consultation, the USGS has identified the following major components of the basin water budget for investigation: (1) estimation of current water use–particularly consumptive water use–and historical trends in water use; (2) regional and field-scale assessments of evapotranspiration and the dynamic variation in snowpack water content; and (3) estimation of groundwater discharge to streams and rivers. More accurate quantification of these components of the basin water budget will provide water managers with increased knowledge of water sources and movement and enhance their ability to make informed resource-management decisions to maximize water availability for human and ecological needs (see section 4.5). The water-use component of the study will expand the collection of water-use data to include information on some uses not currently estimated (for example, self-supplied commercial use). Existing water-use data also will be re-aggregated from a county distribution to an 8-digit hydrologic unit code (HUC-8) distribution to facilitate water-management applications.

Evapotranspiration and variations in the water content of the mountain snowpack (including volume and timing of snow-water releases) are important components of the water budget in the Colorado River Basin. These budget components are difficult to measure, especially over such a large area. This study will couple several recently developed remote-sensing techniques with both new and existing ground-based measurements to extrapolate evapotranspiration across the entire Colorado River Basin (see section 4.3). Recently developed snow-water models also will be applied and calibrated. Evapotranspiration data and water content of the mountain snowpack will aid in identifying water supply and consumptive use in irrigated agricultural areas—one of the largest water-use categories in the Colorado River Basin.

The groundwater contribution to streams in the Colorado River Basin is one of the least well understood components of the regional water budget. Preliminary studies by the USGS indicate that between 20 and 60 percent of the surface-water flow in the upper basin is derived from groundwater discharge. Future development of groundwater in the basin could have significant effects on surface-water flows. Identification of stream reaches that receive large amounts of groundwater discharge will be a major effort in the upper Colorado River Basin during the study. Information about the geologic controls on groundwater flow will be refined and stream reaches likely to receive significant groundwater discharge will be identified. Natural and anthropogenic chemical tracers will be measured to confirm that groundwater discharge is occurring and to estimate its relative contribution. This effort will culminate in a map indicating the location and amount of the groundwater contribution to the surface-water flow system.

Preliminary USGS studies estimate that 20 to 60 percent of surface-water flow in the upper Colorado River Basin is derived from groundwater discharge.

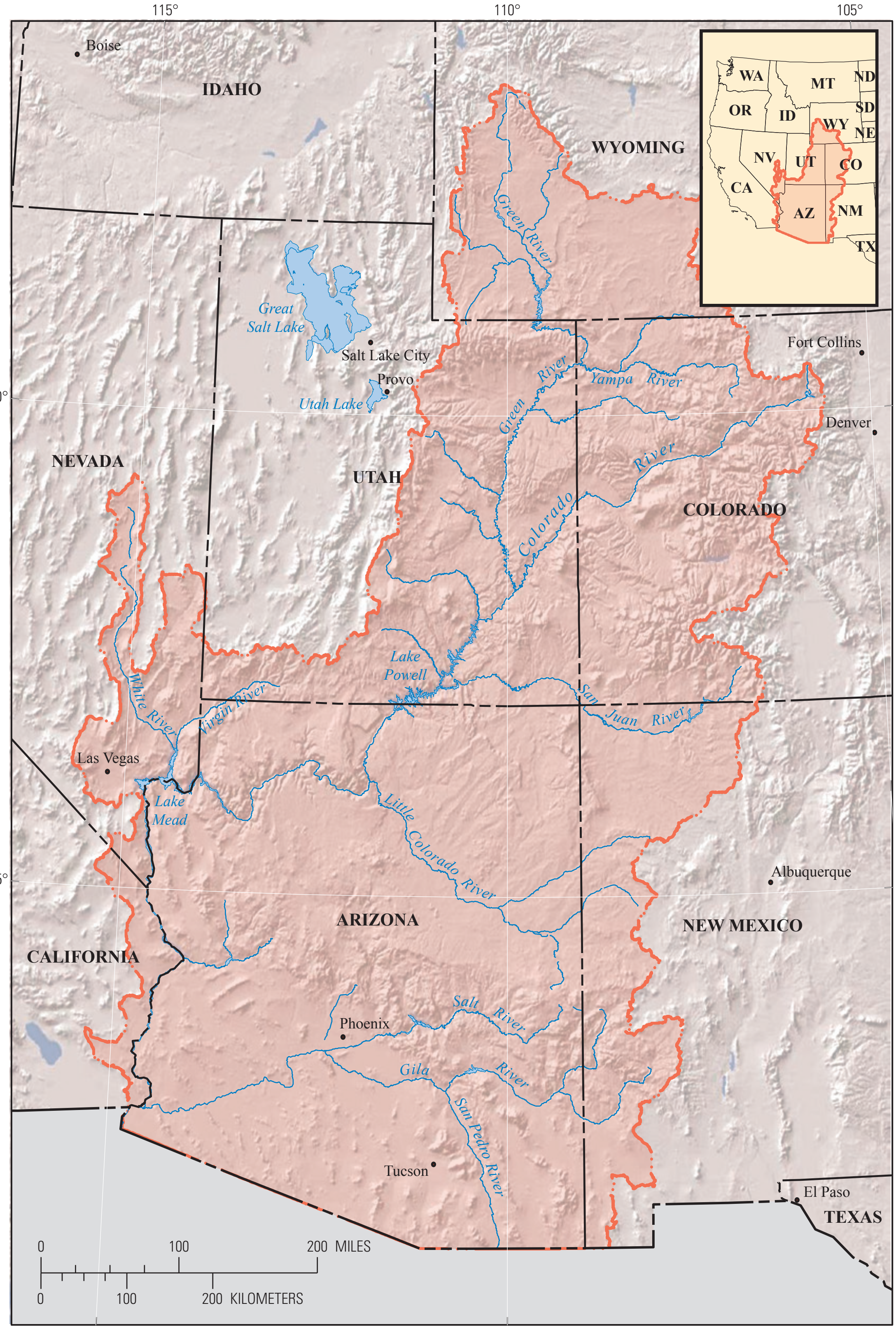
3.3 Delaware River Basin

The Delaware River Basin (fig. 6) covers 13,500 square miles in parts of four states—New York, New Jersey, Pennsylvania, and Delaware. The population within the basin is approximately 7.3 million.

The basin has the largest interbasin withdrawal of water east of the Mississippi River and provides water to more than 15 million people. Two Supreme Court decrees and coordination by an interstate river basin commission are just part of the history of allocating water resources in the basin. Concerns about the effects of new natural-gas development and the freshwater requirements for a recently discovered endangered mussel species have added new complexities to water management in the upper part of the basin.

With input from more than 60 stakeholder groups, including Federal, state, and local governments, NGOs, academia, and others, the following issues were identified as priorities in the Delaware River Basin:

- acquisition, management, and integration of improved water-use and water-supply data;



Base modified from U.S. Geological Survey
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Figure 4. Location of Colorado River Basin.

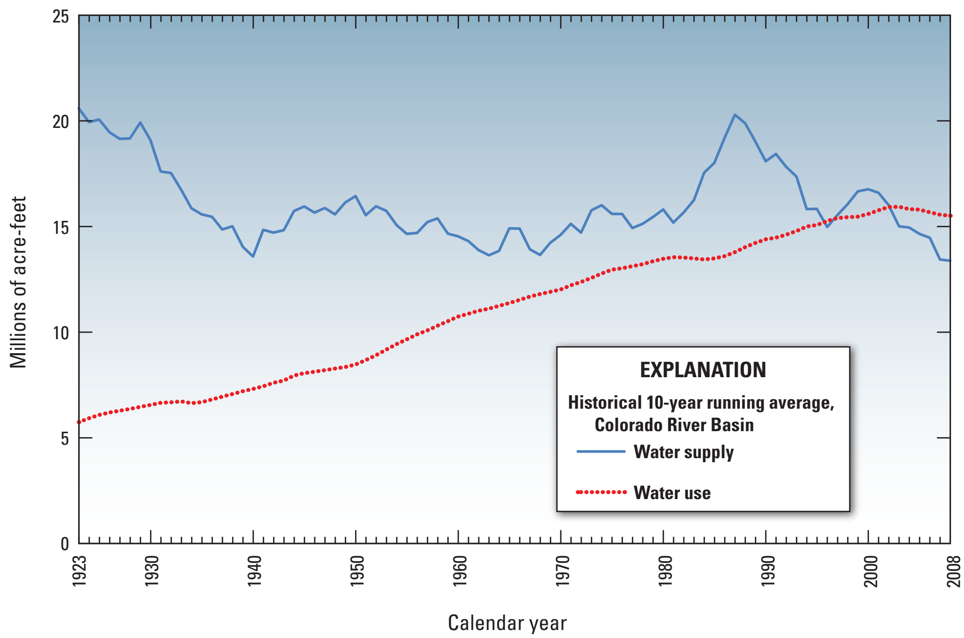


Figure 5. Water supply and water use in the Colorado River Basin, 1923–2008. (From U.S. Bureau of Reclamation, 2011)

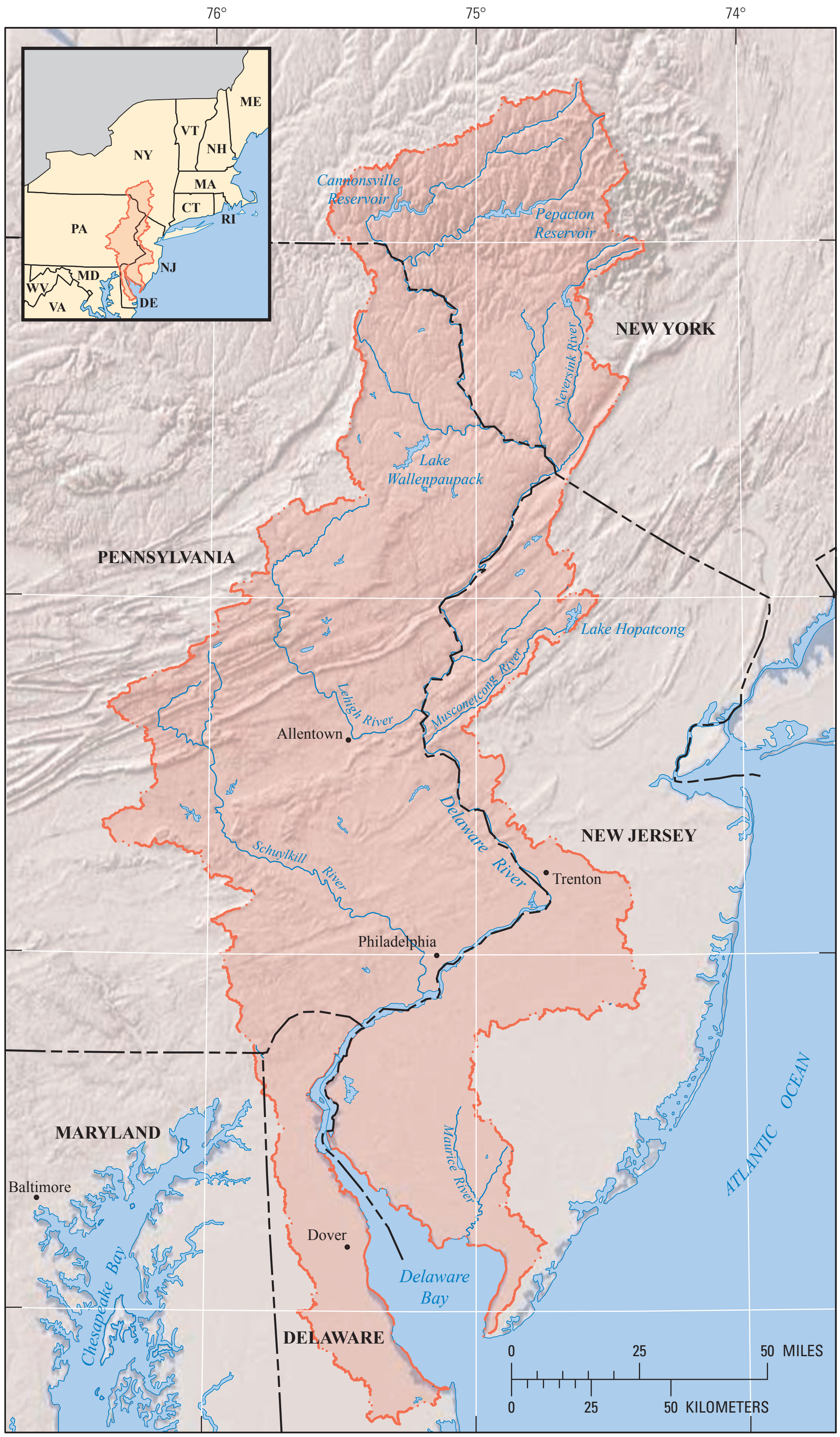
- development of ecological water science that includes enhancement of the existing Decision Support System for parts of the Delaware River, definition of relations between streamflow processes and aquatic-assemblage responses in tributaries, and development of a streamflow-estimation tool for ungaged sites (Archfield and others, 2010); and
- development of a hydrologic watershed model to evaluate the effects of water stressors, such as growth of population centers, land-use change, and climate variability and change, on water resources in the basin.

Products of this study will include (1) a database of water-withdrawal, water-use, and return-flow information for watersheds that will be accessible to water-resource managers in the basin; (2) a Web-based tool developed by using index streamgages to estimate baseline daily streamflow at ungaged streams in the basin from 1960 to 2010; (3) an evaluation of water needs for aquatic ecological systems within the basin, including an updated decision support system for sections of the river, and development of flow/aquatic-assemblage response relations for tributaries; and (4) a hydrologic model of the nontidal portions of the watershed tributaries with an easy-to-use interface that will allow water-resource managers to evaluate potential effects of future population, land-use, or water-demand scenarios.

The Delaware River Basin Commission (DRBC) has developed a "Strategy for Sustainable Water Resources–2060." The information, databases, and products developed as part of this study will contribute substantially to the information needs of the DRBC strategy. Additional information on the characteristics of the basin can be found at the DRBC Web site at *http://www.state.nj.us/drbc/*.

"The Water Census is a great example of leveraging resources for both the benefit of regional water management and the national water use and availability initiative. The Delaware River Basin Commission is getting invaluable assistance in the form of customized work products that advance our long-term Strategy for Sustainable Water Resources–2060, and the USGS is getting very specific integrated water resource management feedback from a data rich basin that will inform and ground truth the Water Census–to ensure that it is a value added to water managers across the nation."

Robert Tudor, Deputy Executive Director, Delaware River Basin Commission



Base modified from U.S. Geological Survey
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Figure 6. Location of Delaware River Basin.

4.0 Topical Areas

Five topical areas key to the Water Census are discussed below. For each topical area, we explain the information needs and past and ongoing efforts to fill them. Then, we describe the information that the Water Census will add to this existing body of work. We also discuss the use of the Geographic Focus Area Studies to provide opportunities to test and improve approaches to water-availability assessment.

4.1 Surface Water

The SECURE Water Act calls for annual updates of river-basin flows and analysis of historical trends. The USGS National Streamflow Information Program (NSIP) provides a strong and essential foundation for this type of streamflow information. The USGS operates approximately 7,800 streamgages to provide information on floods, droughts, and current water availability across the U.S. This network of streamgages provides real-time information and historical context for water-resources planning and assessment. For studies of trends in streamflow and water availability, long historical records are critical.

Because the streamgage network cannot provide direct observations of streamflow at every location of interest, information about streamflow at ungaged locations is needed. To meet this need, the USGS has conducted statistical analyses of streamgage records and has developed hydrologic models for specific basins. For example, WaterWatch (*http://waterwatch.usgs.gov*) is a national application that provides estimates of runoff (in flow per unit area) for HUC-8 watersheds in the continental U.S. These estimates are calculated by using runoff measurements made at nearby gages and are available at monthly and annual time steps (see figure 7). Estimates of streamflow statistics describing peak flows or low flows are often needed at specific ungaged locations. The USGS StreamStats (*http://streamstats.usgs.gov*) Web application has been implemented for many states to provide estimates of these statistics. These estimates are derived by using mathematical regression techniques that have been developed for use with streamflow statistics. The "point-and-click" StreamStats interface allows users to choose a location of interest and calculate streamflow statistics "on the fly."

The Water Census aims to improve upon the information that is currently available for ungaged locations by providing estimates of daily streamflow for subwatersheds nationally through a "point-and-click" Web application. Estimates will

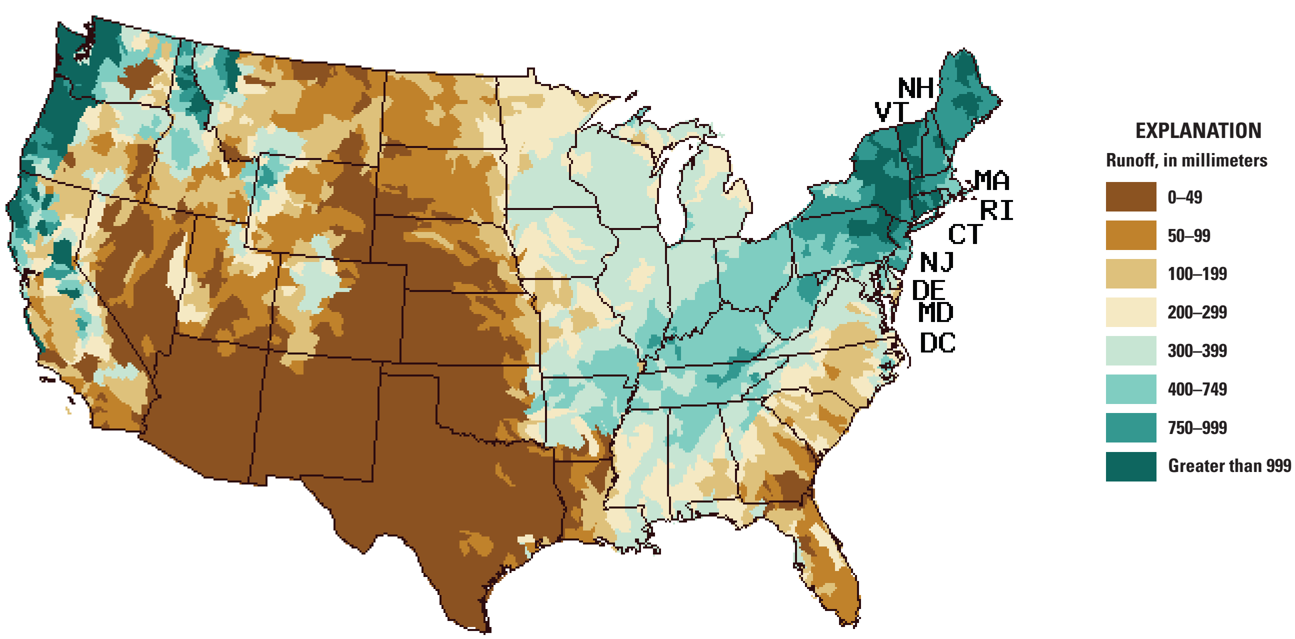


Figure 7. Screen capture of estimated annual runoff for the period October 1, 2010, through September 30, 2011, for each of the 8-digit hydrologic unit code cataloging units in the United States. (From *http://waterwatch.usgs.gov/*; no data shown for Alaska, Hawaii, or Puerto Rico)

be provided for the most recent 30-year historical period. Although uncertainty will be greater for estimated time series than for time series measured at a streamgage, these estimates can provide information needed by water managers to make decisions and by ecologists to evaluate ecological water requirements.

Many existing modeling techniques could be employed to develop these streamflow estimates. To make the most efficient use of limited resources, a national plan is being developed by comparing the accuracy, ease of implementation, and value-added capabilities of several different streamflow-estimation models. Because model performance varies with location, different models may perform better or worse in different parts of the country.

A second major activity is to evaluate trends in streamflow over time. Changes in surface-water hydrology can result from a wide variety of causes, including changes in water-management strategies, land-use changes, and climate variability or change. Changes in hydrology can impact water availability for public supply, industry, power generation, or agricultural use, and can affect water quality and aquatic ecosystems. Characterizing trends in streamflow and developing a greater understanding of the causes of trends are therefore critical to understanding future water availability.

Climate variability and change is the least well understood driver of streamflow change. The USGS has conducted a number of studies to characterize trends in streamflow at gages that are relatively free of direct human influences. Most studies are based on gages included in the HydroClimatic Data Network (HCDN) (Slack and Landwehr, 1992). Gages in the HCDN were recently updated and the dataset now includes information from 743 streamgages (Lins, 2012). Continued maintenance of a national network of such gages is necessary to allow scientists to detect and understand streamflow change.

Analyses of streamflow records have revealed temporal changes in some aspects of flow. For example, many regions that are snow-dominated in winter have shown a shift toward earlier spring runoff peaks associated with snowmelt. Studies analyzing annual flow or peak flows have been less conclusive.

Because streamflow is naturally highly variable, analyzing trends in streamflow records is difficult. Moreover, changes in many different characteristics of flow may be important to water managers or to local ecology. For example, changes in seasonality of flow or day-to-day variability in flow may be just as important as shifts in annual mean streamflow. Still other flow characteristics may be important for other, specific purposes or concerns. Future studies will need to consider these factors and their effects on water management and water availability.

4.2 Groundwater

A national assessment of water availability requires an assessment of the Nation's groundwater reserves. The Water Census will leverage a long history of groundwater studies and accelerate ongoing regional studies to achieve this goal. These groundwater assessments provide consistent and integrated information that enables the resource to be viewed and understood on aquifer-wide scales that cross political boundaries.

The USGS began a program of regional groundwater availability studies in 2004 (Dennehy, 2005) to provide the public and water managers with a better understanding of the status of and trends in the Nation's groundwater availability. These studies cover a variety of hydrogeologic terrains and include aquifer systems that account for much of the Nation's groundwater use. Additionally, the USGS has outlined an approach for developing an understanding of future groundwater availability aggregated from these regional-scale studies and has summarized current knowledge of groundwater availability at the national scale (Reilly and others, 2008).

One of the first regional studies completed was that for California's Central Valley (see Box D). As part of this assessment, the USGS developed a three-dimensional hydrologic modeling tool that can be used to simulate water-management scenarios, providing managers with an improved ability to plan water supplies that accounts for anticipated conversion of farmland to urban use as well as potential future effects of climate variability and change. Several additional studies have been completed or are underway across the United States (see figure 8).

Current plans call for studies of 30 to 40 regional aquifer systems that, once completed, will collectively lead to a national assessment of groundwater availability. The Water Census funding in FY 2011 provided an opportunity to accelerate this program with assessment of the glacial aquifer system that extends across all or parts of 25 northern states from Maine to Washington and Alaska. The glacial deposits are the source of the largest withdrawals for public and domestic supply in the United States, and an estimated 22.5 million people rely on the glacial aquifer system for their drinking water.

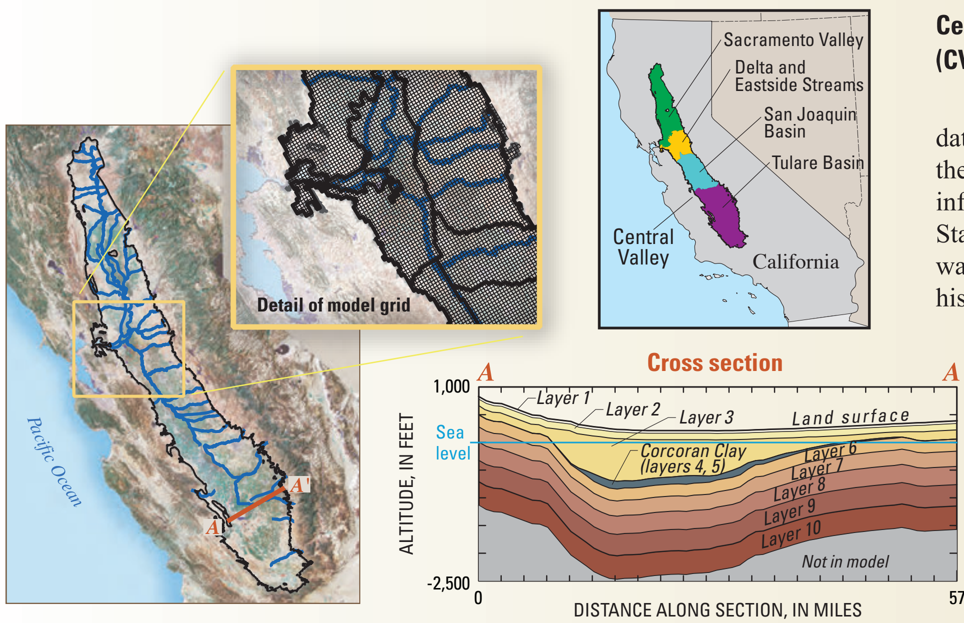
"Our present and future water management challenges must be based on sound science and the best data available. It is an old, but true, adage that you can't manage what you don't measure. Often, we lack sufficient data on existing water uses and supplies to make informed decisions. Better water resources management and decisionmaking requires more and better data, and especially more real-time data, as well as an indication of the level of confidence in the data."

Tony Willardson, Executive Director, Western States Water Council

Box D. Groundwater Availability Study of the California Central Valley (From Faunt, 2009)

Figure D1. Central Valley agriculture along the California Aqueduct.

California's continued population increase has heightened competition for water within the Central Valley. As water resources become more valuable, a number of issues have gained prominence, including how to conserve agricultural land; the conjunctive use of surface and groundwater supplies; changing land-surface elevation in response to groundwater pumping; aquifer storage and recovery; the effect of land-use changes on water supplies; and climate change. USGS scientists developed a regional three-dimensional hydrologic modeling tool to help resource agencies understand and address many issues affecting the joint use of surface- and groundwater supplies in the Central Valley.



Central Valley Hydrologic Model (CVHM)

The CVHM was built by using data and modeling techniques from the U.S. Geological Survey and information from other Federal, State, and local studies. The CVHM was constrained by simulated and historically observed groundwater levels, streamflows, and subsidence. The detail and breadth of this hydrologic modeling tool provides a better understanding of valley-wide hydrologic processes and a way to forecast system responses to future development and climate variability and change.

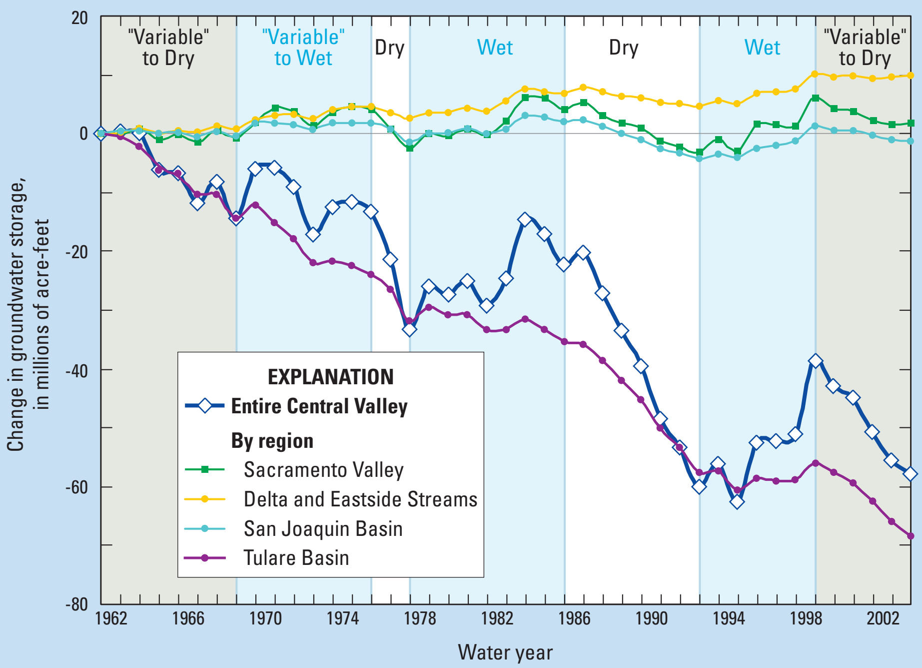
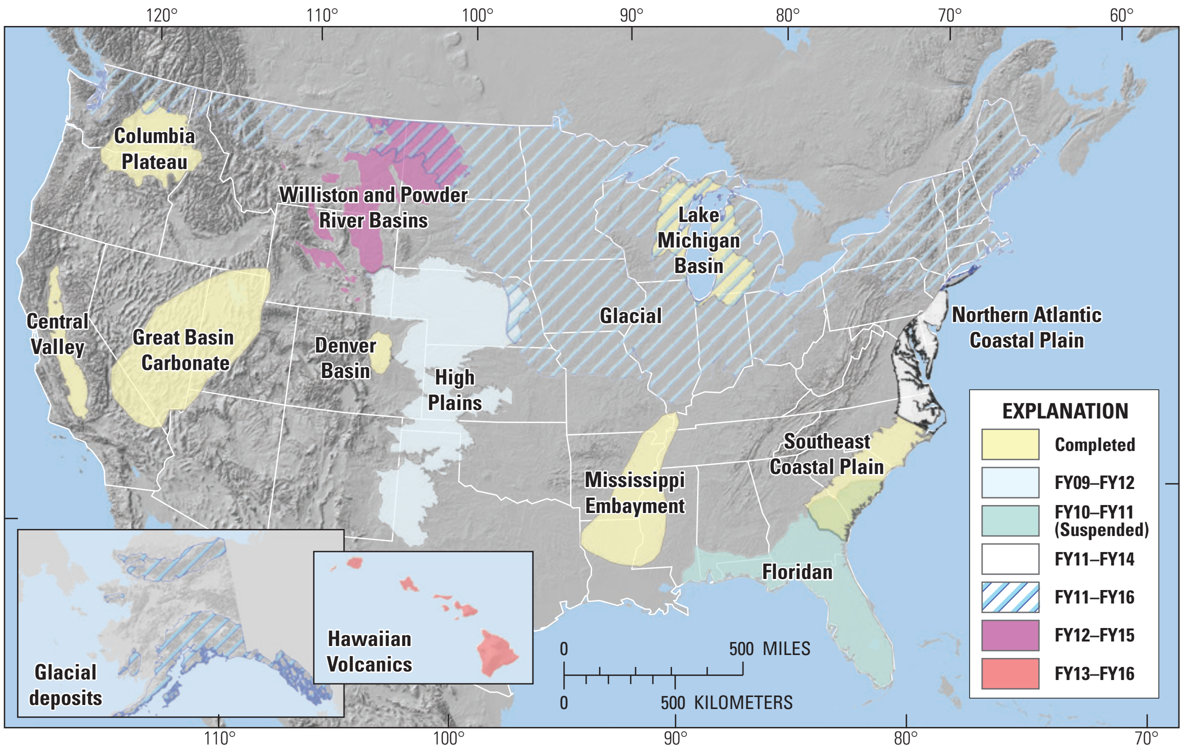


Figure D2. Simulated cumulative annual change in aquifer-system storage from water year 1962 through 2003 for the Central Valley, California. During wet and dry periods, the aquifer storage responds as expected; however, the Central Valley Hydrologic Modeling tool enables definition of the spatial and temporal implications of changing climatic conditions and the resulting storage response. The cumulative change in storage reached a maximum loss of 62.7 million acre-feet in the mid 1990s.



Base modified from U.S. Geological Survey
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Figure 8. U.S. Geological Survey Groundwater Resources Program regional-scale groundwater study areas. (Modified from *http://water.usgs.gov/ogw/gwrp/activities/regional.html*; explanation indicates the fiscal years during which the studies are plannned to occur)

4.3 Evapotranspiration

Evapotranspiration (ET) is the upward flux of water from the land surface to the atmosphere, a combination of evaporation from the soil and transpiration by plants. An essential component of water-budget determinations for water availability, ET is also a fundamental variable of water use, especially for irrigation, and has important implications for administration of water rights and river-basin compacts. Historically, reliable estimation of ET has required site-specific field measurements made by using specialized instruments. However, because these sites represent conditions only in their immediate vicinity, quantifying ET over broad areas such as irrigation districts, river basins, or states is a difficult task. In the past 15 years, substantial progress has been made in meeting this challenge by using satellite imagery to make estimates of ET across the landscape. State agencies and consultants have embraced this approach, and a variety of methods have come into common use, though all rely on the same underlying physical principles. The USGS also has adopted this practice, and is applying its satellite remote-sensing resources and expertise to quantify ET for the Water Census.

The Geographic Focus Area Study of the Colorado River Basin provides the context for testing ET remote-sensing methods for eventual application across the western United States and the country as a whole. In order to construct water budgets to determine water availability, ET is being estimated across the entire landscape by using 1-kilometer-resolution National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) land-surface temperature imagery from the archive at the USGS Earth Resources Observation Science (EROS) Data Center. Although such images are collected daily, energy-budget calculations are made on 8-day composites that greatly reduce problems of cloud cover. These results, in turn, are accumulated into monthly, seasonal, and annual summaries at the spatial scale of 8-digit HUCs. In FY 2012, this task is being accomplished for data covering the period from 2000 to 2011. Results are being compared with site-specific data from stations in the Colorado River Basin to provide uncertainty estimates for the MODIS satellite approach. Initial results for estimated annual ET in the Colorado River Basin in 2010 are shown in figure 9.

Water-use reporting requires estimates of ET at the scale of agricultural fields. USGS Landsat thermal infrared imagery, with a resolution of 60 to 120 meters, is being used for this purpose in the Colorado River Basin. The Cropland Data Layer from the USDA National Agricultural Statistics Service is used as a reference to identify the relevant subset of the landscape for which estimates are required. In FY 2012, this task is being conducted for a single calendar year over all the croplands in the basin, with as much cloud-free imagery as possible. (Landsat image acquisitions occur only every 16 days. Joint use of Landsat and MODIS images is being tested to fill temporal gaps.) Monthly, seasonal, and annual totals are being compiled for 8-digit HUC areas and measurements from ET stations are being used to verify results. The successful launch of Landsat 8 in February 2013 will benefit the Water Census by ensuring an uninterrupted flow of essential field-scale thermal infrared imagery.

An established ET remote-sensing community with a history of estimating crop water use with Landsat imagery already exists in the western United States. Universities, consultants, state agencies, and the USBR all have contributed to the development and application of techniques of this kind. The Western States Water Council gave voice to the concern of this community for inclusion of a thermal infrared imager on Landsat 8. The USGS acknowledges the experience and expertise of this community, and at the same time recognizes the potential for duplication of effort and disputes over differing methods and results. In anticipation of both possibilities and of eventual contributions to the Water Census by non-USGS organizations, the USGS has entered into a partnership with Utah State University to develop specifications and guidelines for estimating crop ET in the West by using remote sensing. The vision is for a prescribed framework for inputs, techniques, and proven model performance, within which a state, Tribe, consultant, university, or Federal agency could employ the model of its choosing, and publish crop water-use figures that would be recognized and accepted by the broad community of western water stakeholders. In this way, important economies would be realized while simultaneously meeting Water Census standards for accuracy and precision. FY 2012 marked the beginning of this 3-year effort, which will involve detailed technical evaluations and stakeholder interactions.

The quantification of water use for supplemental irrigation in the eastern United States is also being addressed with ET remote sensing. The Geographic Focus Area Studies of the Delaware and Apalachicola-Chattahoochee-Flint (ACF) River Basins provide a context for testing an approach in which satellite imagery is used.

ET remote-sensing methods are also being tested in the Central Valley of California, where ongoing USGS research on water productivity is being leveraged and the need for improved quantification of fallowed-land extent is being addressed (Thenkabail and Wu, 2012). In the first case, both yields and water use are being mapped, field by field, to reveal variations in the amount of “crop per drop,” a valuable refinement to water-use reporting. In the second case, the objective is to better characterize the impacts of water shortages on irrigated agricultural land, a significant information gap identified by the California Department of Water Resources and other stakeholders participating in the National Integrated Drought Information System (NIDIS) California pilot study led by NOAA.

Although initial applications in the three Geographic Focus Area Studies are targeting monthly summaries of ET at the HUC-8 level, these efforts are designed so that they can ultimately be “scaled up” to daily summaries at the finer HUC-12 scale.

4.4 Water Use

The SECURE Water Act places considerable emphasis on assessment of the use of surface water and groundwater for understanding the demand side of water availability; however, information on the Nation’s water use is relatively limited. Better information is needed on withdrawal, conveyance, consumptive use, and return flow by sector of use as well as on the factors that influence these components of water use. Such information will allow water managers and planners to make more effective decisions for the future. Water-use data are vital to water-availability studies such as those that simulate watershed and groundwater processes. Regular assessments of water use provide trend information, which is critical to decision making for future water needs. As an indication of its importance, activities are underway to improve the quality and availability of water-use information in all three Geographic Focus Areas.

Every 5 years since 1950, the USGS has produced a report on the “Estimated Use of Water in the United States.” These reports are a substantial undertaking, requiring coordination and assemblage of information from multiple Federal sources, as well as from all 50 states. The 2010 report is planned to be released in calendar year 2014. The most comprehensive of these reports, for 1995, provided estimates of withdrawals, public-supply deliveries, wastewater returns, and consumptive use for 11 sectors of water use: public supply, domestic, commercial, irrigation, livestock, animal specialties, industrial, mining, thermoelectric power, hydroelectric power, and wastewater treatment. The scope of the report was reduced for 2000 and 2005, with the 2005 report covering public supply, domestic, irrigation, livestock, aquaculture (replacing animal specialties), industrial, mining, and thermoelectric power use. Public-supply deliveries were estimated only for domestic use, no estimates were prepared for commercial and hydroelectric water use or for wastewater returns, and, most critically, consumptive use was not estimated. In addition, in the 1985, 1990, and 1995 reports, water use was estimated for counties and for watersheds (at the HUC-8 level); in the 2000 and 2005 reports, only county water use was estimated.

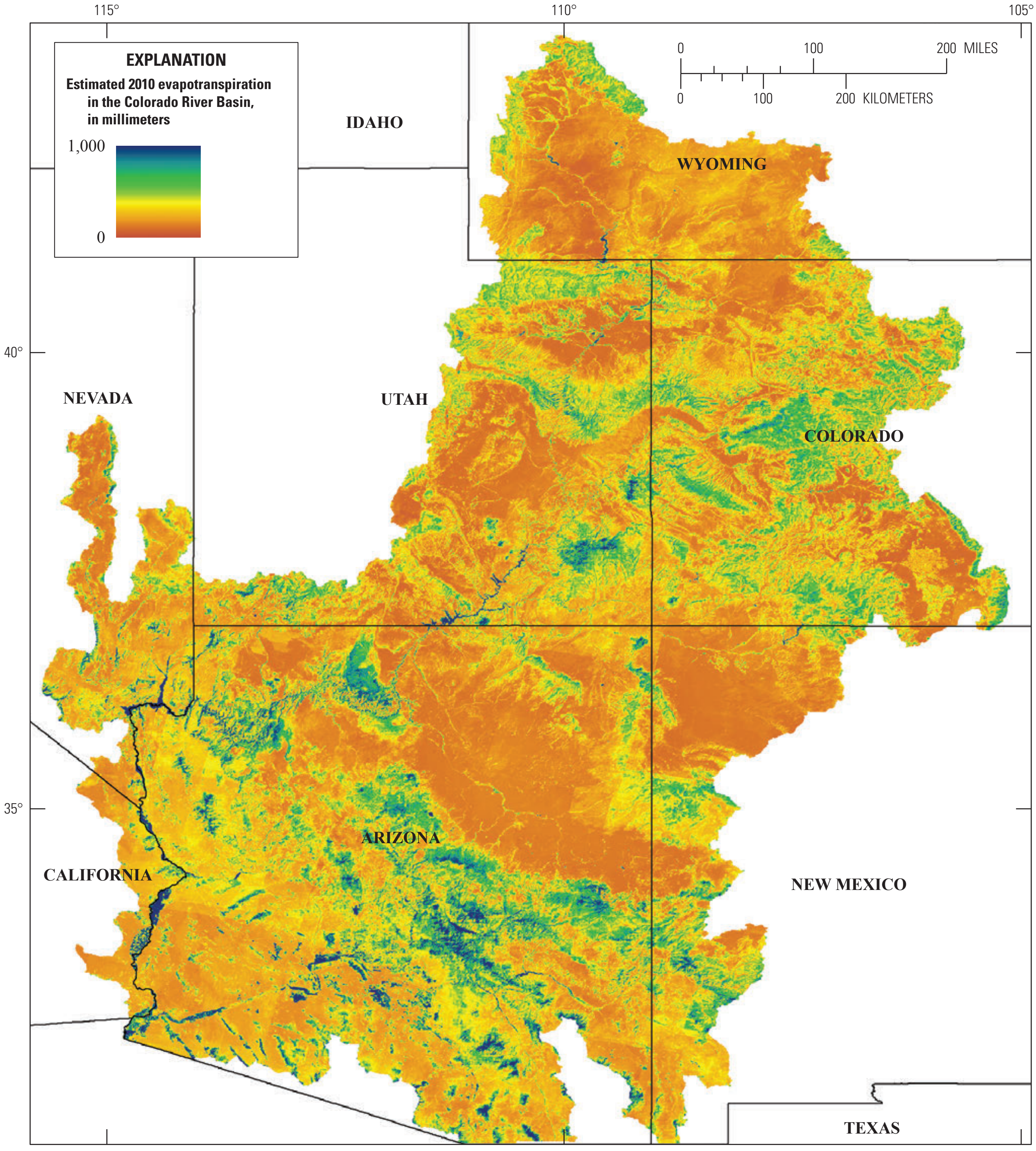


Figure 9. Estimated total annual evapotranspiration in the Colorado River Basin for 2010 determined by using Moderate Resolution Imaging Spectroradiometer (MODIS) land-surface temperature imagery and the Simplified Surface Energy Balance (SSEB) method. (From Senay and others, 2011)

The omitted components reduce the usefulness of this periodic assessment of the Nation's water use. As part of the Water Census, the USGS plans to return to the full assessment as represented by the 1995 report.

Efforts also are underway to improve estimation methods for the two largest sectors of the Nation's water use: thermoelectric power and irrigation. Thermoelectric power represented 49 percent of U.S. withdrawals in 2005 (Kenny and others, 2009), although substantial amounts of the water withdrawn are returned to a surface-water body and are readily available for other uses. The geographic distribution of five different categories of water withdrawals are shown in figure 10. Thermoelectric withdrawals are predominant in the eastern and coastal states, whereas irrigation withdrawals are predominant in the arid western states. The USGS is developing improved estimation techniques for power plants utilizing data reported to the U.S. Energy Information Administration (EIA). The two agencies are working together to improve the quality and usefulness of the reported data. In the USGS study, power plants are divided into several classes on the basis of the level of data available for them, and estimation methods will incorporate information on plant characteristics, power generation, and fuel use to estimate a range of reasonable water demand. The results will help quality assure information on thermoelectric power water demands from various sources. The thermoelectric power study also will develop techniques for estimating consumptive use for power plants by using heat-budget data. A retrospective study of estimates for the period from 1975 to 1985 is examining factors that affect thermoelectric power water demand, such as cooling-system type, fuel type, and weather conditions, to better understand future changes in demand. An additional planned study will attempt to quantify consumptive use outside the power-plant property, specifically the evaporation caused by the increase in temperature of the water used for cooling after it is returned to a stream or reservoir.

Water withdrawals for irrigation made up 31 percent of withdrawals in 2005. The geographic distribution of irrigation withdrawals is shown in figure 11. Compared to thermoelectric power water use, the proportion of the water withdrawn for irrigation that is consumed through ET or incorporated into the crop is larger, leaving less available for immediate reuse. The USGS has initiated several studies to analyze and improve estimation methods for irrigation water use. An analysis of the data and methods used for the 2000 and 2005 national estimates of irrigation water use (Dickens and others, 2011) compared data sources for irrigated crop acreage and water use and the methods used. Recommendations were made for improving future USGS estimates of irrigation water use. USGS irrigated-acreage estimates were compared to acreage reported by the USDA for similar years to assess the differences in magnitude and trends. The study also calculated

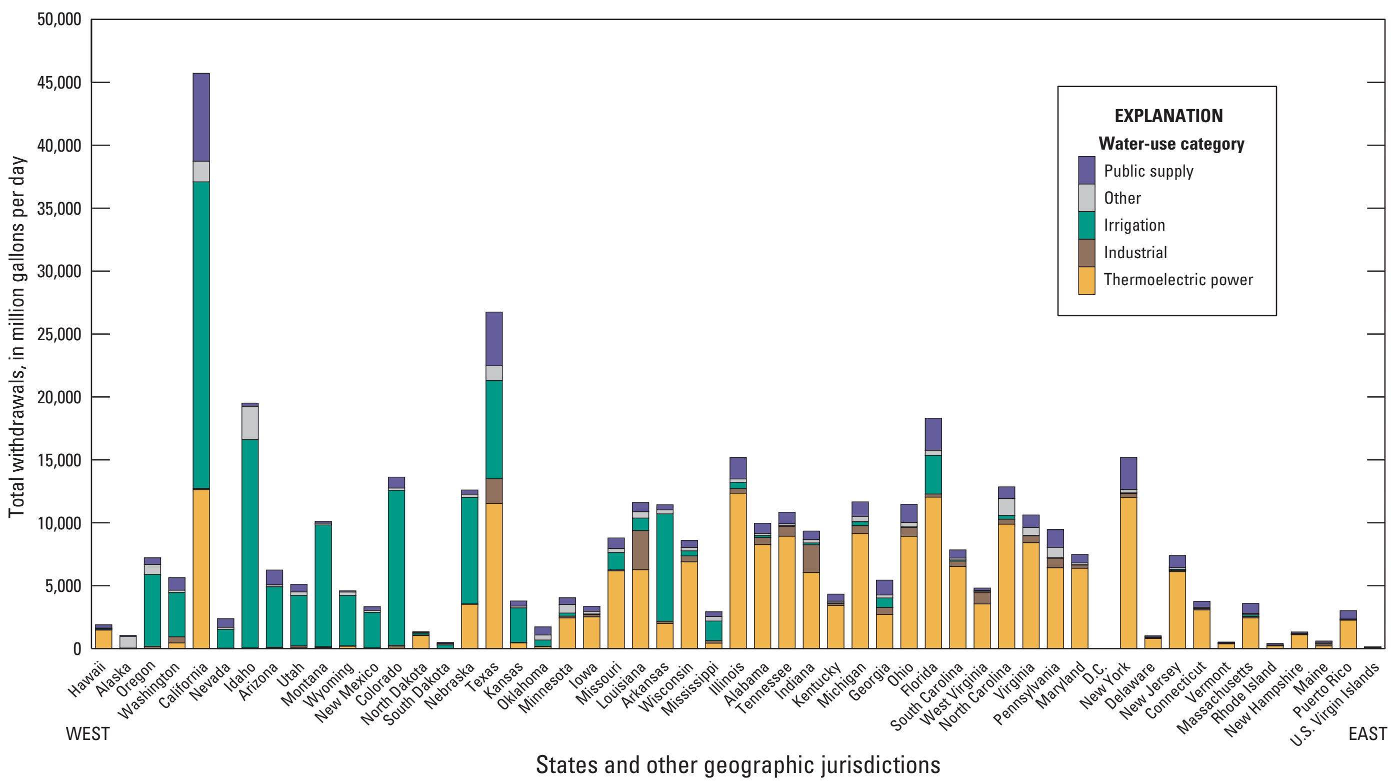


Figure 10. Graph showing 2005 water withdrawals in the United States by water-use category. (States and other geographic jurisdictions are arranged from west to east.) (From Barber, 2010)

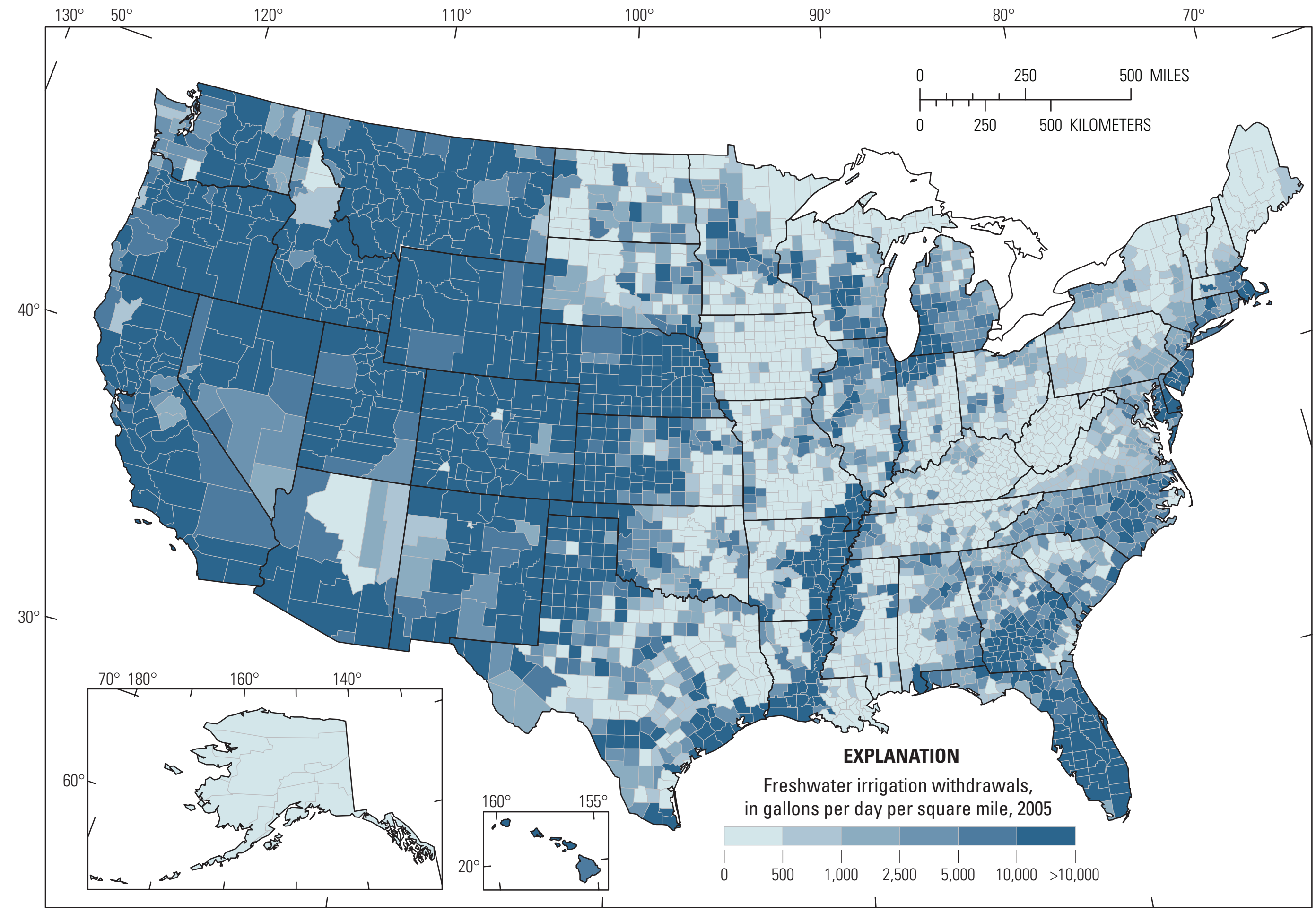


Figure 11. Freshwater irrigation withdrawals in the United States by county, 2005.

a state irrigation withdrawal estimate by using an indirect method involving irrigated acreage, consumptive water requirement by crop, and potential water losses while irrigating. Estimates made by using the indirect method were compared to the published 2005 estimates for selected states as a means of evaluating both the indirect method and a potential benchmark to quality assure future state irrigation estimates. Another effort is underway to develop improved irrigation estimates for the New England, Mid-Atlantic, and a few southern states. Deriving estimates for these regions is difficult as a result of a lack of observed irrigation water use, smaller crop sizes, and humid climate conditions that mask typical irrigation water-use practices and preempt estimation methods that are used in the West.

A major goal with respect to water use is to refine the scale of water-use information from the county level, as given in the current USGS national reports, to the finer watershed scale. Efforts are underway to develop a national site-specific water-use database as part of the USGS National Water Information System (NWIS) that will contain withdrawal, conveyance, use, and discharge information. Withdrawal locations, conveyances, and water-system information are initially being entered for the public-supply sector. Thermoelectric power plant locations and withdrawals will be added to the database, followed by other sectors for which site-specific information can be developed. Detailed, long-term information on withdrawals, conveyances, consumptive use, and return flows will provide the critical demand component for studies of the interactions between human water use and the natural hydrologic system.

4.5 Ecological Water Science

Ecological water science is the study of the quantity, timing, and quality of water flow and storage required to sustain freshwater and estuarine ecosystems and the human well-being and livelihoods that depend on them. Water flow and storage include stream and river flows as well as variations in water levels in lakes, rivers, streams, springs, wetlands, and aquifers. Ecological water science has advanced greatly over the past two decades, driven largely by a need to better understand the relation between ecological water uses and the streamflows required to maintain those uses, prevent degradation of freshwater ecosystems, and improve the balance between human and ecological water needs.

As part of the Water Census, the USGS will develop innovative tools and Web-available resources that provide stakeholders and ecological water science practitioners with the hydrologic and biological information necessary for comparing natural and altered hydrologic regimes and determining the effects of streamflow alteration and water withdrawals on aquatic ecosystems. This approach is being applied nationally as well as to large river basins as part of the Geographic Focus Area Studies.

In support of ecological water science at the national scale, the Water Census is developing and comparing flow-simulation modeling tools for building a national foundation of baseline hydrographs that will ultimately provide hydrologic statistics for all ungaged streams in the U.S. A baseline hydrograph is a graph that reflects the natural fluctuations in the duration, magnitude, timing, frequency, and rate of change in streamflow. This information will be served directly to stakeholders by means of a map-based National Data Platform that will enable connections to other large data compilations, including those collected by other Federal, state, and Tribal organizations. Estimates of daily streamflow as well as a suite of ecologically relevant hydrologic measurements will be integrated with biological observations in the platform through a common spatial framework. In addition, a national streamflow classification structure and set of flexible tools are being developed that will allow stakeholders to evaluate a region of interest at the scale necessary for sound management. These tools are being designed to serve a predetermined set of stream classes derived from a subset of existing baseline hydrographs and, alternatively, to provide users with the option of deriving a set of stream classes based on user-specified input.

In addition to the national-scale efforts, ecological water science is part of each of the Geographic Focus Area Studies at the large-river-basin scale. These efforts are as follows.

Apalachicola-Chattahoochee-Flint (ACF) River Basin—The physical and biological diversity of this basin and its importance to the many water users provide an ideal context for developing tools that will allow stakeholders to improve estimation of streamflow requirements for ecological purposes. Ecological water science activities in the ACF River Basin combine basinwide streamflow models with on-the-ground measurements of changes in the occurrence or abundance of various kinds of fish and mussel species. These biological measurements (conducted seasonally in six ACF subbasins) will allow scientists to calibrate simulation models that project changes in species occurrences in relation to changes in streamflow patterns. It is envisioned that the findings of this study will have broad transferability to other river basins and regions throughout the U.S. Extension to other systems may be achieved by expressing models in terms that describes the characteristics of those fishes or mussels that respond most strongly to various changes in streamflow (such as lower or more variable flow during warm months). For example, models relating daily water withdrawal to changes in number of fluvial specialists (species that rely on flowing water for survival) provide a basis for estimating effects of increasing water demand on the persistence or abundance of valued imperiled and recreational fish species (see Box E).

Colorado River Basin—This basin is experiencing rapid population growth and water demands by many sectors, including energy, agriculture, and municipal water supplies. Resource managers are concerned with finding the most effective means of supporting diverse riparian and aquatic ecosystems in this highly regulated basin. Given the large size of the river basin, a subregional basin- and subbasin-scale perspective will inform questions about the appropriate scale for management decisions. The upper Verde River (see Box F) is the first subbasin in the Colorado River Basin to be the subject of ecological water analysis. The analysis includes determining the hydrologic record, the magnitude of departure of the seasonal hydrology from the historic record, the amount of habitat needed to support different types of aquatic species under different flow volumes and groundwater levels, the status of the native and nonnative species, and a water budget that includes groundwater and helps identify reaches that are vulnerable to drying.

Delaware River Basin—Competing water needs in the drainage basin of the Delaware River, the longest undammed river east of the Mississippi, make it an ideal case study for developing tools for sustainable management and water-conflict resolution. Ecological water science activities in the Delaware River Basin are being implemented to broaden the capabilities of an integrated Decision Support System to better understand and simulate the effects of alternative water-management scenarios on habitat availability for key native species (for example, trout, American shad, and dwarf wedgemussel; see Box G). Detailed field and laboratory experiments are underway to develop habitat suitability criteria that simulate the relation between the physiological response of key species and changes in temperature and hydrology. Simulation estimates of habitat characteristics are also being developed for large mainstem reaches of the Delaware River Basin across a range of discharge conditions. Planned work with the Decision Support System will help identify data gaps, support evaluation of the feasibility of extending the modeled area farther down the mainstem, and provide options for several alternative water-management scenarios.

Research findings and modeling tools developed as part of the ecological water science effort will be useful to state and Federal natural-resource agencies and other stakeholders charged with ensuring that water-management actions are consistent with (1) meeting human needs and protecting biological integrity as mandated by the Clean Water Act, and (2) conserving imperiled and (or) recreationally valued species. Developing modeling tools with a high degree of transferability is an important element of the Water Census, and the research, tools, and applications being developed as part of the ecological water science efforts are expected to have applicability well beyond the borders of the study areas for which they were developed.

Box E. Ecological Water Science—Apalachicola-Chattahoochee-Flint (ACF) River Basin

Local colonization and extinction of fishes and mussels (referred to as metapopulation dynamics) are being tracked in six ACF subbasins representing Blue Ridge, Piedmont, and Coastal Plain streams. Field data will be combined with fine-scale hydrologic data and models within each subbasin to investigate changes in species distributions in response to streamflow variation, including drought, flood, and intermediate flow conditions.

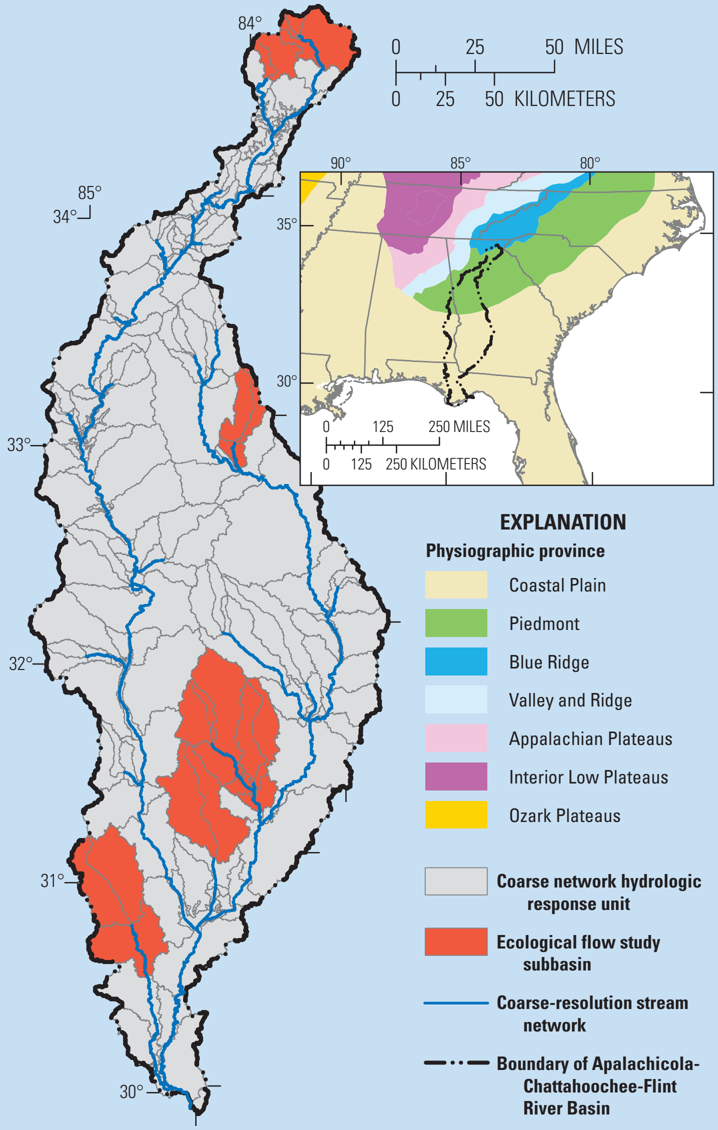


Figure E1. Ecological flow study subbasins in the Apalachicola-Chattahoochee-Flint River Basin.

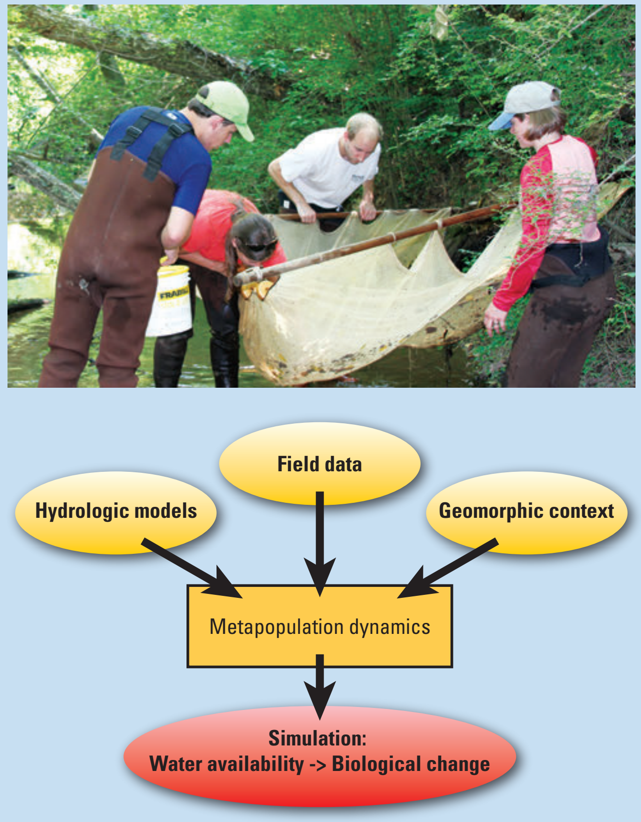


Figure E2. Fish assemblage sampling in the upper ACF River Basin. Field data will inform models that can be used to simulate biological responses to changes in water availability. (Photo by M. Freeman, U.S. Geological Survey)

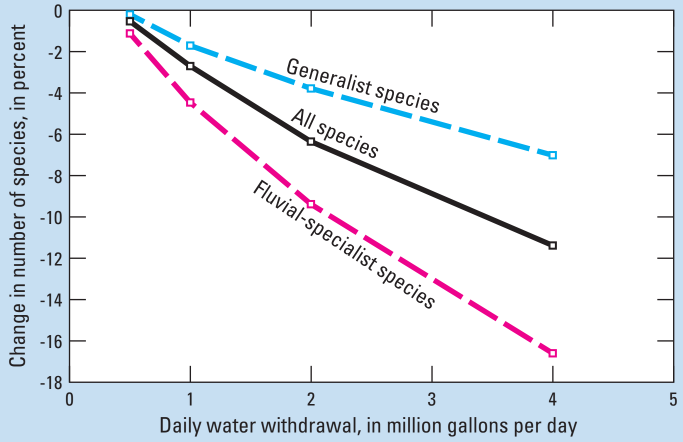


Figure E3. An example ecological water science product showing relations between simulated daily water withdrawals and the predicted change in the richness of fish species in Potato Creek, Georgia (From Freeman and others, 2012). This example shows how changes in water withdrawals from 0.5 to 4.0 million gallons per day may result in a 16-percent loss in the richness of fluvial-specialist species (pink line). Such relations can provide water managers, stakeholders, and policy makers with insight into how best to meet ongoing human water demand while minimizing the proportional loss of important recreational fish species that depend on streamflow for survival and reproduction.

Box F. Ecological Water Science—Colorado River Basin

Two to three subbasins within the Colorado River Basin will be used to examine in detail the Ecological Limits of Hydrologic Alteration (ELOHA) framework (a scientific framework that evaluates ecological water needs at multiple spatial scales) as a basis for understanding the relations between streamflow characteristics and aquatic-species response. The upper Verde River was initially selected because a collaborative ecological water study was underway in the basin. The study began in 2010 and the transferability of the approach to other subbasins is being evaluated.

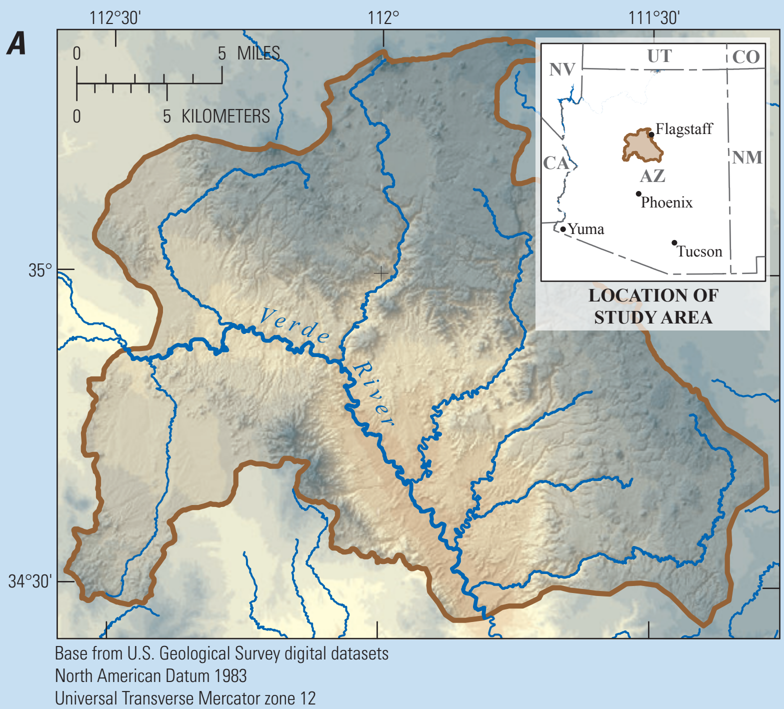


Figure F1. *A*, Ecological flow study area and, *B*, aquatic-invertebrate assemblage sampling in the upper Verde River, Colorado River Basin. (Map by Nicholas Paretti, U.S. Geological Survey; photo by A. Brasher, U.S. Geological Survey)

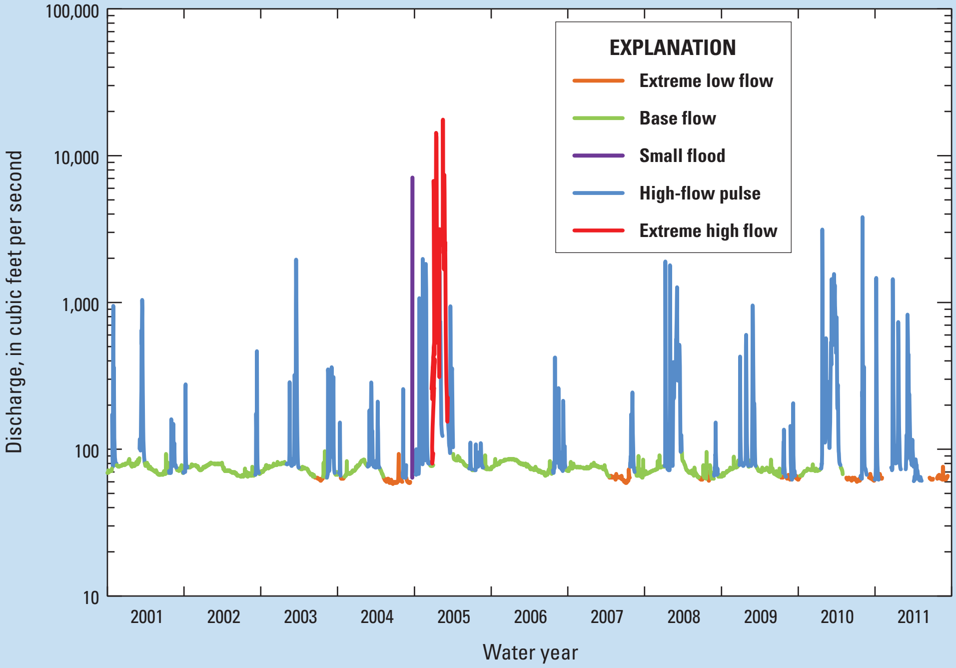


Figure F2. Streamflow characteristics for the Verde River near Clarkdale, AZ (U.S. Geological Survey station number 09504000). Hydrologic data-collection efforts support the development of habitat availability models across a range of water volumes and provide information on seasonal flow characteristics that may be limiting the abundance and distribution of aquatic fauna in the upper Verde River (Nicholas Paretti, U.S. Geological Survey, written commun., 2013).

Box G. Ecological Water Science—Delaware River Basin

Prior and ongoing research efforts have illustrated a highly variable flow regime in the Delaware River as a result of stormflow and water-management operations. It is not uncommon for extensive areas of the riverbed, submersed under median flow, to be exposed during low-flow events. In a relatively short time period, these same areas can experience highly turbulent conditions during high-flow events. These rapid changes (that is, rises and falls) in the hydrograph may negatively affect the abundance and distribution of riverine fauna and flora.

Figure G1. Delaware River near Callicoon, NY (U.S. Geological Survey station number 01427510): *A*, median flow conditions in late August 2010 (1,430 cubic feet per second), facing upstream from the Callicoon bridge; *B*, low flow in late September 2010 (653 cubic feet per second), facing downstream; and *C*, high flow during October 2010 (63,814 cubic feet per second), facing upstream. (Photos A, B, and C by Kelly Maloney, U.S. Geological Survey)

To provide better management solutions, several USGS Science Centers are working collaboratively to broaden the capabilities of a decision support system (DSS). The DSS is an integrative tool with a user-friendly Graphical User Interface (GUI) that combines habitat suitability criteria (HSC) with modeled estimates of habitat for large reaches of the Delaware River Basin. DSS users can modify the HSC, visualize alternative flow scenarios, examine available habitat over the entire range of the hydrograph, and identify areas with the greatest capacity to support key species of concern (for example, trout, American shad, and dwarf wedgemussel).

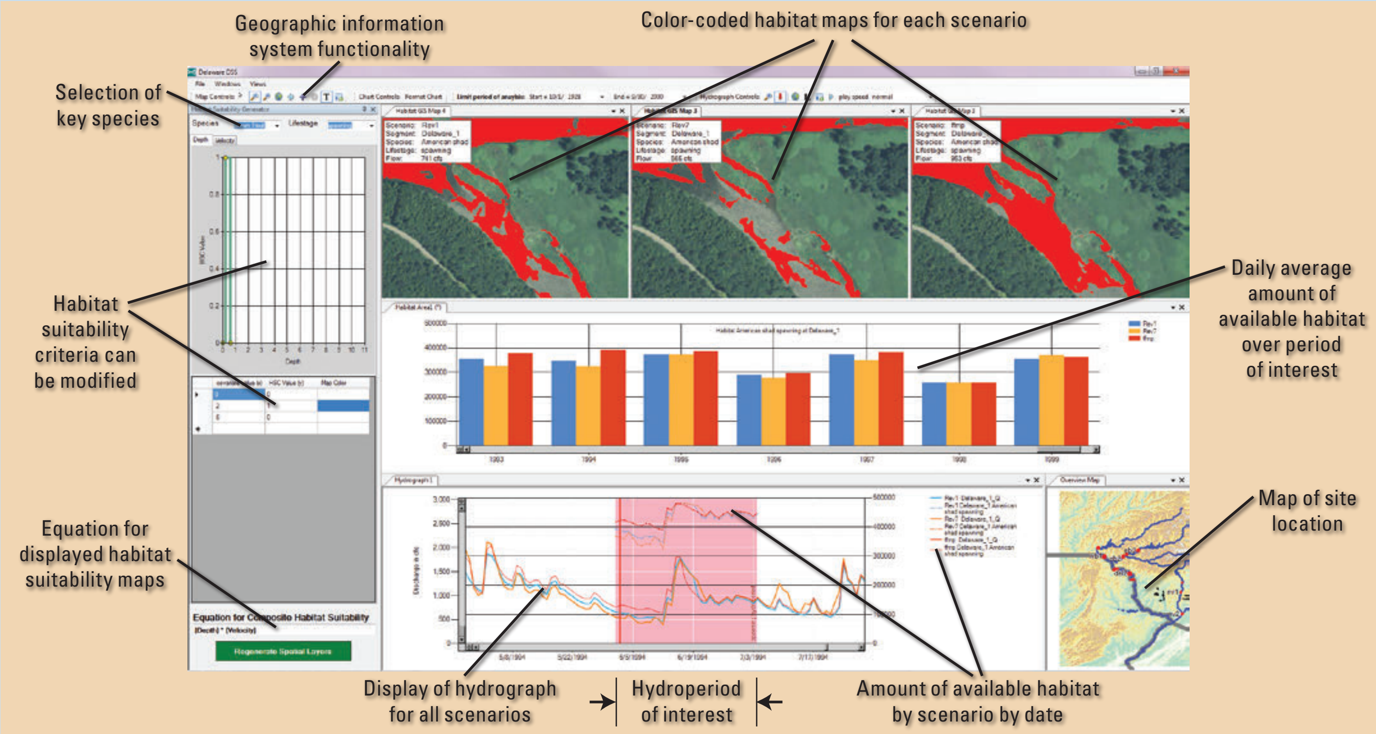


Figure G2. Graphical User Interface for the Decision Support System tool that is being developed as part of the Delaware River Basin Focus Area Study. Example shows three alternative flow-management scenarios (Rev1, Rev7, and ffmp) for the spawning stage of the American shad.

5.0 Water Availability and Water Quality

Determining the relation between water availability and water quality is critical to the maintenance of water availability for human uses and aquatic ecosystems. Even plentiful water supplies might not be suitable for use if water quality is impaired. The connections between water availability and water quality manifest in various ways. The most obvious water-quality constraint on water availability results from the release of anthropogenic contaminants to the environment, but naturally occurring contaminants, such as arsenic, radium, and uranium, also can affect water quality and its availability for particular uses. Salinity and sediment also commonly affect water availability. Moreover, water- and land-use practices, such as groundwater pumping and urban development, can modify groundwater flow and chemistry in ways that mobilize contaminants.

Since 1991, the USGS has evaluated the quality of the Nation's streams and groundwater through the National Water-Quality Assessment (NAWQA) Program. During 1991–2000 (Cycle 1), the NAWQA Program focused on interdisciplinary, baseline assessments of the quality of streams, groundwater, and aquatic ecosystems in 51 of the Nation's largest and most important river basins and aquifers (see *http://water.usgs.gov/nawqa/nawqa_sumr.html*). During 2001–12 (Cycle 2), the NAWQA Program built upon the baseline assessments completed in the previous decade through (1) increased emphasis on assessment of long-term trends, (2) assessments of water quality in major river basins that discharge into some of the Nation's key estuaries (see *http://water.usgs.gov/nawqa/studies/mrb*), (3) regional assessments of water quality in 19 of the Nation's 62 principal aquifers (see *http://water.usgs.gov/nawqa/studies/praq/*), and (4) an initial assessment of contaminants in currently used sources of drinking water. Results of studies conducted by the NAWQA Program relating the distribution of contaminants in domestic wells, of nitrate contamination in deep groundwater, and of the pesticide atrazine in streams draining agricultural areas in the United States are shown in figure 12. These studies demonstrate the effect of water quality on water availability.

The Cycle 1 and 2 studies conducted as part of the NAWQA Program provide a foundation for examining the relations between water quality and water availability as part of the upcoming Cycle 3 studies. In a recent review of the NAWQA Program, the National Research Council (NRC) noted that the "NAWQA program can be particularly effective in contributing to forecasts of water availability through the program's ability to relate its assessment of water quality and ecosystem health to changes in land use and land cover, natural and engineered infrastructure, water use, and climate change" (National Research Council, 2012).

Of particular importance will be the development and application of water-quality models that integrate information on water quality, chemical use, land use, and environmental factors to explain how water-quality conditions vary regionally and nationally (see *http://water.usgs.gov/nawqa/modeling*). The integration of modeling with monitoring helps to extend water-quality understanding to unmonitored areas under a range of possible circumstances. The models are essential tools for cost-effective management of water resources because managing contaminants requires far more information than we can afford to measure directly for all important places, times, and contaminants. In addition, many management decisions—including how much to spend on implementing a management strategy, monitoring priorities, and registering pesticides—inherently depend on predicting the potential effects on water quality for locations that have little to no monitoring.

6.0 Delivering the Data

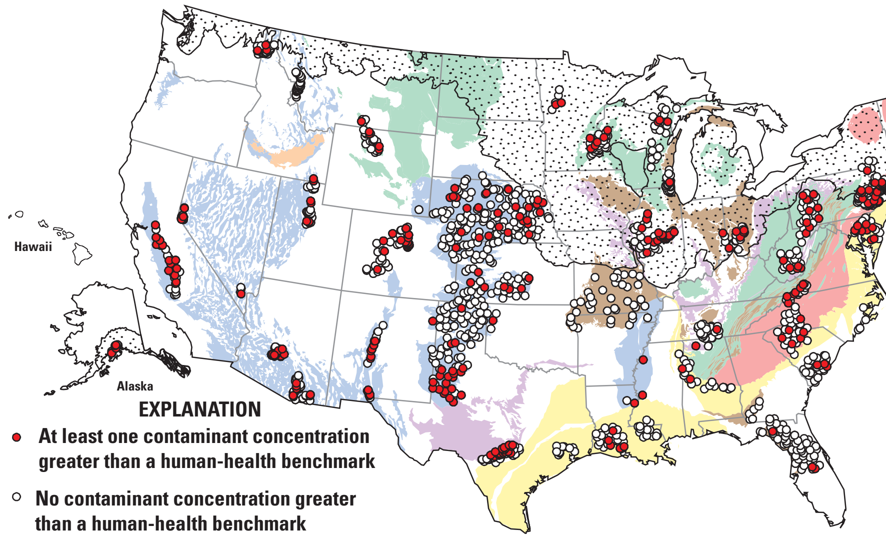
To meet the objectives of the Water Census, data from multiple disciplines and sources need to be assembled and integrated. Some of these data will be obtained from existing sources within the USGS and partner agencies, whereas other data are being developed directly as part of the Water Census activities. Many of the "data" developed by the Water Census are derived from models, statistical estimation, and other transformation processes.

A data-management plan is being developed to provide a framework that will guide and document these activities across the entire Water Census effort. Data-management planning spans the entire data life cycle to include data acquisition, documentation, processing, analysis, preservation, and delivery. The data-management plan will emphasize adoption of existing international and Federal standards for data elements, processing, preservation, and delivery to serve as unifying and integrating criteria to facilitate interoperability with partners. Coordination of data activities with partners, data providers, and Federal advisory organizations such as ACWI will ensure that the Water Census data are useful to a wide range of users and purposes.

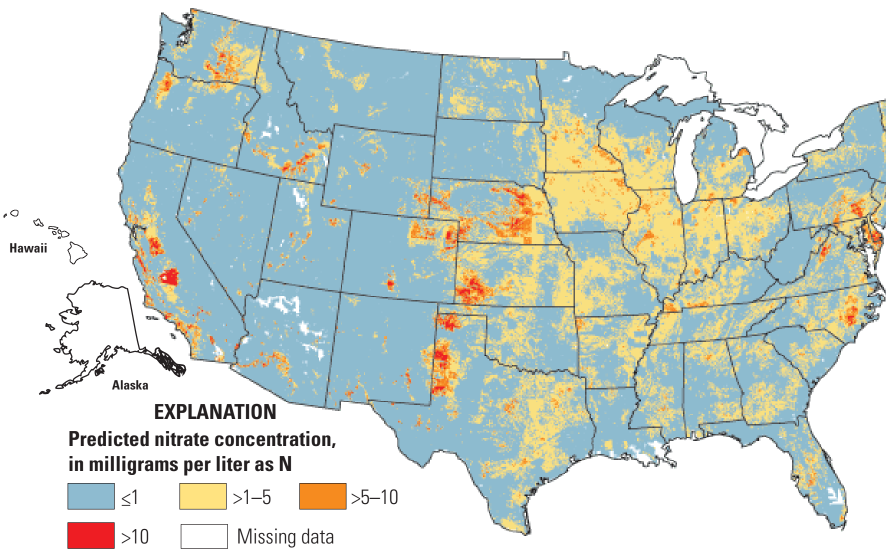
6.1 Data Integration and Mapping

Conceptually, the data resources made available by the Water Census can be seen as a nationally consistent base layer of well-documented data covering the five topical areas (ET, groundwater, surface water, water use, and ecological water) and water quality. These data represent a collection of values associated with points, lines, areas, and grids, and are derived from a range of activities as diverse as collecting of fish in individual stream reaches and the interpretation of satellite imagery.

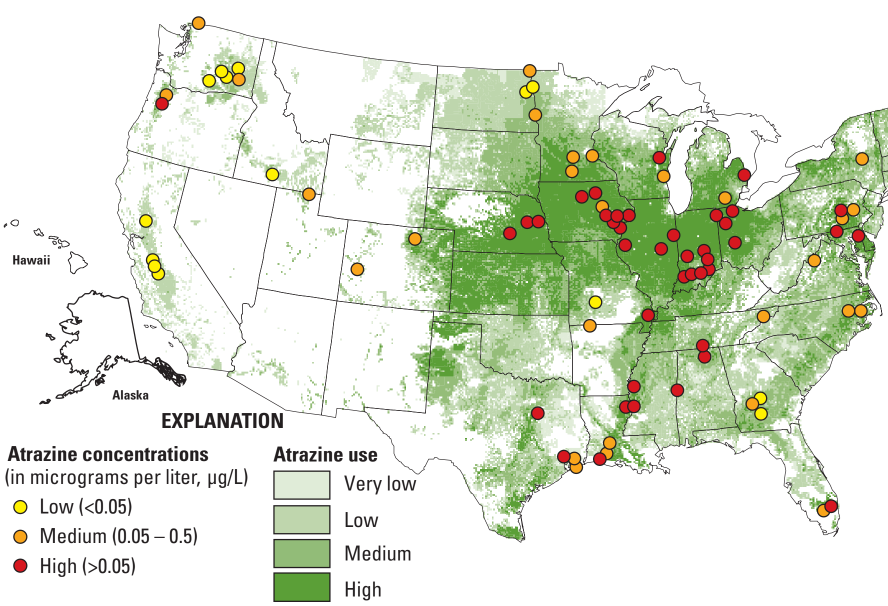
A map view is a convenient model for organizing and coordinating the Water Census data, and a map interface is one of the most useful means of presenting raw data and analytic products to users. For the Water Census, a map of HUC-12 watersheds will be the base layer used to integrate



More than 20 percent of private domestic wells sampled nationwide (more than 2,100 wells in 25 principal aquifers, shown by background colors) contained at least one contaminant at levels of potential health concern. About 43 million people—or 15 percent of the Nation's population—use drinking water from private wells. These results are prior to any on-site treatment by homeowners. Community water systems using groundwater from these aquifers test and treat the water supply to meet drinking-water standards. (From DeSimone and others, 2009)



Results from a national statistical model for deep groundwater used as drinking water suggest moderate (shown in yellow and orange) to severe (shown in red) nitrate contamination in relatively deep groundwater (greater than 164 feet or 50 meters below land surface). These areas typically are associated with large nitrogen input; natural soil, landscape, and geologic features that promote rapid transport of groundwater; and a lack of biogeochemical processes that convert nitrate to other forms of nitrogen. (From Dubrovsky and others, 2010)



The concentrations of atrazine measured in agricultural streams correlated with the distribution of its use on crops—primarily corn. Some of the highest concentrations occurred in the corn-growing areas of Illinois, Indiana, Iowa, Nebraska, and Ohio. (From Gilliom and others, 2006)

Figure 12. Example findings from the U.S. Geological Survey National Water-Quality Assessment Program (From DeSimone and others, 2009; Dubrovsky and others, 2010; and Gilliom and others, 2006).

water-budget components and will serve as the exploratory framework for the representation of data to users. Other data that can be included in the map are various natural and geopolitical boundaries, descriptive layers such as soil and land-cover characteristics, and the National Hydrography Dataset of streamlines and associated features. Although many data layers of various scales can be useful to data exploration, the analytic and reporting scale of the Water Census is targeted at monthly HUC-12 values.

6.2 The National Data Platform

The USGS has a long history of building national-level, Web-accessible data stores that can serve various types of users simultaneously while providing them with tools for evaluating the data, including mapping, graphing, and other forms of data exploration and visualization (examples include the NAWQA Program, WaterWatch, StreamStats, the National Map, NWIS Web, and the Water Quality Portal). A National Data Platform will enable stakeholders and other interested parties to explore and focus their data activities on areas and times of interest, offer appropriate filters to narrow their data retrieval, and make available other tools to fit their specific needs. The platform will follow the President's Digital Government Strategy by using a rich set of Web services to provide underlying data. This strategy will allow any data system or interactive Web-based analytical service to leverage the Water Census data by making automated queries and retrievals from the data store. The National Data Platform will use Web services to create a comprehensive and nationally consistent interactive map interface and a set of trend-analysis and other tools that work directly with the data.

Data products from individual components of the water budget will be made available as stand-alone datasets to serve the specific needs of users who need information from particular portions of the data store. In addition, value-added and integrated data will be provided, removing the integration effort from the user and promoting a uniform approach to combining datasets that may have originated in mixed scales and standards. It is critical that the sources and transformations of the data being served by the Water Census are fully documented and available with the data.

Serving Water Census data to users will involve the technology needed to mediate language and format issues that would otherwise make a Web-based delivery system inconsistent and nonintuitive. The approach planned for the National Data Platform will incorporate current technologies and best practices–such as searchable metadata catalogs, semantic services that facilitate the conceptual relation of data to other data, and format mediation to handle data translation and provide user-selected output types–allowing users to focus on the discovery, exploration, and retrieval of the data rather than on reconciling inconsistencies in the data served by the system.

Many effective programs are underway to measure aspects of our water resources. However, simply stated, quantitative knowledge of U.S. water supply is currently inadequate.

Report of the National Science and Technology Council, Committee on Environment and Natural Resources, Subcommittee on Water Availability and Quality (2007)

7.0 Planning for the Future

Progress toward a Water Census has been made by integrating information from a number of programs, including new funding targeted toward the Water Census; ongoing national-scale efforts such as those undertaken by the USGS National Water-Quality Assessment (NAWQA) and Groundwater Resources Programs; and the legacy provided by long-term monitoring and assessment programs such as the USGS Cooperative Water Program and the National Streamflow Information Program (NSIP). Over the next few years, progress will continue with existing efforts and expand as funding allows. In addition to completing the ongoing work described in this report, priorities for future work (not in priority order) are as follows.

Expand Geographic Focus Area Studies

Geographic Focus Area Studies provide an opportunity to test new approaches and leverage and support ongoing water-availability studies. As the three current Geographic Focus Area Studies are completed, future Geographic Focus Areas will be identified by using criteria being developed as part of future implementation planning for the Water Census.

Evaluate impaired surface water and groundwater that may be important future sources of water supply

The national water availability and use assessment, described in the SECURE Water Act, includes assessment of "impaired surface water and groundwater supplies that are known, accessible, and used to meet ongoing water demands." Likewise, the Act calls for an assessment of brackish groundwater. Since the SECURE Water Act was passed, the USGS Groundwater Resources Program has undertaken preliminary work to develop approaches for assessing brackish water in three areas. This work will be expanded and enhanced.

Continue to develop ways to bring information together from multiple sources

It is critical that the Water Census use information available from multiple sources to the maximum possible extent. The Water Census program will continue to work through the Federal Advisory Committee on Water Information to enhance this capability, including investigating possibilities for data portals that provide ready access to data from multiple agencies, similar to the one proposed by the advisory group's Subcommittee on Ground Water.

Work with Federal, state, and other agencies to enhance water-use datasets

Studies summarizing water use highlight limitations and inconsistencies in water-use-data collection and reporting across the United States (National Research Council, 2002; U.S. Government Accountability Office, 2009). Reported water use relies heavily on estimates by state agencies, and estimation procedures vary from state to state. The Water Census provides an opportunity to establish agreed-upon standards for estimating, reporting, and storing water-use data for various use categories and sources. In addition, the USGS has increased efforts to work with other Federal agencies such as the Department of Energy's Energy Information Administration (EIA) and the Department of Agriculture, particularly with respect to water-use data related to thermoelectric power generation and irrigation water use. These efforts need to be expanded to leverage the capacity, knowledge, and data available from other organizations.

Identify areas of greatest uncertainty in various types of data

The Water Census must focus efforts on the most critical gaps and needs rather than spread its effort equally across the resources and geographic areas. One factor to consider in focusing efforts is where the uncertainty in different types of data is greatest. The Water Census is assessing the use of uncertainty analysis from models to help address this issue.

Expand links to water availability in Cycle 3 of the NAWQA Program

The NAWQA Program in Cycle 3 will place an emphasis on its national water-quality monitoring networks for streams and groundwater, which have gradually eroded over the past 15 years as inflation has reduced the number of monitoring sites that could be supported. These monitoring networks provide the only nationally consistent and long-term water-quality monitoring of its kind. These data, along with the continued use of models to boost understanding of undersampled areas (National Research Council, 2012), will provide key information needed to integrate water-quality and water-availability information by the Water Census.

In summary, the USGS is working with partners to build the capabilities necessary to provide policymakers, citizens, and natural-resource managers with fundamental information about the Nation's water availability through a National Water Census. To complete this effort, the Water Census must address surface-water flows and storage, groundwater flows and storage, reservoirs, lakes, springs, storage in snow pack and ice fields, soil moisture, evapotranspiration, and all facets of water use, including withdrawals, water reuse, consumptive use, interbasin transfers, and return flows. The Water Census must additionally address how water quality influences water availability. The information presented will be current and up to date, and will include trends in historical data. The USGS envisions the Water Census to be an ongoing and continuous activity.

The resources available to support the Water Census are finite and necessitate the use of an incremental process. The USGS envisions that estimates of flow at ungaged locations and estimates of evapotranspiration will be among the earliest products. Providing complete water-use information and adequately assessing the Nation's groundwater resources with respect to water availability will require additional time. Providing the public with ecological water science that addresses a classification system for streams and provides access to biological and streamflow databases that can be analyzed with statistical tools needed by biological managers will take most of the next decade to accomplish.

Although the existing data are limited and much work remains to be done, funding over the past 2 years has allowed substantial progress to be made toward a Water Census. The effort is well matched to the USGS's capabilities and mission. The USGS will continue to work with partner agencies and organizations to maximize the utility of the information for a broad range of uses.

8.0 Acknowledgments

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Non-Federal Agencies and Organizations

- Association of American State Geologists (AASG)
- Association of Fish and Wildlife Agencies (AFWA)
- Association of State Drinking Water Administrators (ASDWA)
- American Water Resources Association (AWRA)
- American Water Works Association (AWWA)
- Interstate Council on Water Policy (ICWP)
- National Ground Water Association (NGWA)
- National Tribal Water Council (NTWC)
- The Nature Conservancy (TNC)
- Water Systems Council (WSC)
- Western States Water Council (WSWC)

Federal Agencies

- National Aeronautic and Space Administration (NASA)
- National Oceanic and Atmospheric Administration—National Weather Service (NOAA—NWS)
- U.S. Army Corps of Engineers (USACE)
- U.S. Department of Agriculture—Economic Research Service (USDA—ERS)
- U.S. Department of Agriculture—Forest Service (USDA—FS)
- U.S. Department of Agriculture—National Agricultural Statistics Service (USDA—NASS)
- U.S. Department of Agriculture—Natural Resources Conservation Service (USDA—NRCS)
- U.S. Department of Energy (USDOE)
- U.S. Department of the Interior—Bureau of Reclamation (USBR)
- U.S. Environmental Protection Agency (USEPA)
- U.S. Fish and Wildlife Service (USFWS)

9.0 References Cited

Archfield, S.A., Vogel, R.M., Stevens, P.A., Brandt, S.C., Weiskel, P.K., and Garabedian, S.P., 2010, The Massachusetts Sustainable-Yield Estimator: A decision-support tool to assess water availability at ungaged stream locations in Massachusetts: U.S. Geological Survey Scientific Investigations Report 2009–5227, 43 p., available online at *http://pubs.usgs.gov/sir/2009/5227/*.

Barber, N.L., 2010, Summary of estimated water use in the United States in 2005: U.S. Geological Survey Fact Sheet 2009–3098, 2 p., available online at *http://pubs.usgs.gov/fs/2009/3098/*.

Dennehy, K.F., 2005, Ground-water resources program: U.S. Geological Survey Fact Sheet 2005–3097, 4 p., available online at *http://pubs.usgs.gov/fs/2005/3097/*.

DeSimone, L.A., Hamilton, P.A., and Gilliom, R.J., 2009, The quality of our nation's waters—Quality of water from domestic wells in principal aquifers of the United States, 1991–2004—Overview of major findings: U.S. Geological Survey Circular 1332, 48 p., available online at *http://pubs.usgs.gov/circ/circ1332/*.

Dickens, J.M., Forbes, B.T., Cobean, D.S., and Tadayon, Saeid, 2011, 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: U.S. Geological Survey Scientific Investigations Report 2011–5166, 60 p., available online at *http://pubs.usgs.gov/sir/2011/5166/*.

Dubrovsky, N.M., Burow, K.R., Clark, G.M., Gronberg, J.M., Hamilton P.A., Hitt, K.J., Mueller, D.K., Munn, M.D., Nolan, B.T., Puckett, L.J., Rupert, M.G., Short, T.M., Spahr, N.E., Sprague, L.A., and Wilber, W.G., 2010, The quality of our Nation's waters—Nutrients in the Nation's streams and groundwater, 1992–2004: U.S. Geological Survey Circular 1350, 174 p., available online at *http://pubs.usgs.gov/circ/1350/*.

Faunt, C.C., ed., 2009, Groundwater availability of the Central Valley, California: U.S. Geological Survey Professional Paper 1766, 225 p., available online at *http://pubs.usgs.gov/pp/1766/*.

Frederick, K.D., and Schwarz, G.E., 1999, Socioeconomic impacts of climate change on U.S. water supplies: Journal of the American Water Resources Association, v. 35, no. 6, p. 1563–1583.

Freeman, M.C., Buell, G.R., Hay, L.E., Hughes, W.B., Jacobson, R.B., Jones, J.W., Jones, S.A., Lafontaine, J.H., Odom, K.R., Peterson, J.T., Riley, J.W., Schindler, J.S., Shea, C., and Weaver, J.D., 2012, Linking river management to species conservation using dynamic landscape-scale models: River Research and Applications, available online at *http://dx.doi.org /10.1002/rra.2575*.

Gilliom and others, 2006, The quality of our Nation's waters—pesticides in the Nation's streams and ground water, 1992–2001: U.S. Geological Survey Circular 1291, 172 p., available online at *http://pubs.usgs.gov/circ/2005/1291/*.

Gordon, D.W., Peck, M.F., and Painter, J.A., 2012, Hydrologic and water-quality conditions in the lower Apalachicola–Chattahoochee–Flint and parts of the Aucilla–Suwanee–Ochlockonee River basins in Georgia and adjacent parts of Florida and Alabama during drought conditions, July 2011: U.S. Geological Survey Scientific Investigations Report 2012–5179, 69 p., 1 sheet, available online at *http://pubs.usgs.gov/sir/2012/5179/*.

Healy, R.W., Winter, T.C., LaBaugh, J.W., and Franke, O.L., 2007, Water budgets: Foundations for effective water-resources and environmental management: U.S. Geological Survey Circular 1308, 90 p., available online at *http://pubs.usgs.gov/circ/1308/*.

Kenny, J.F., Barber, N.L., Hutson, S.S., Linsey, K.S., Lovelace, J.K., and Maupin, M.A., 2009, Estimated use of water in the United States in 2005: U.S. Geological Survey Circular 1344, 52 p., available online at *http://pubs.usgs.gov/circ/1344/*.

Lins, H.F., 2012, USGS Hydro-Climatic Data Network 2009 (HCDN–2009): U.S. Geological Survey Fact Sheet 2012–3047, 4 p., available online at *http://pubs.usgs.gov/fs/2012/3047/*.

National Research Council, 2002, Estimating water use in the United States: A new paradigm for the National Water-Use Information Program: Washington, D.C., National Academies Press, 176 p., available online at *http://www.nap.edu/catalog.php?record_id=10484*.

National Research Council, 2009, Toward a sustainable and secure water future: A leadership role for the U.S. Geological Survey: Washington, D.C., National Academies Press, 114 p., available online at *http://www.nap.edu/catalog.php?record_id=12672*.

National Research Council, 2012, Preparing for the third decade (Cycle 3) of the National Water-Quality Assessment (NAWQA) Program: Washington, D.C., National Academies Press, 220 p., available online at *http://www.nap.edu/catalog.php?record_id=13464*.

National Science and Technology Council, 2004, Science and technology to support fresh water availability in the United States: Washington, D.C., Report of the National Science and Technology Council, Committee on Environment and Natural Resources, Subcommittee on Water Availability and Quality, 19 p.

National Science and Technology Council, 2007, A strategy for federal science and technology to support water availability and quality in the United States: Washington, D.C., Report of the National Science and Technology Council, Committee on Environment and Natural Resources, Subcommittee on Water Availability and Quality, 35 p.

Reeves, H.W., 2011, Water availability and use pilot—A multiscale assessment in the U.S. Great Lakes basin: U.S. Geological Survey Professional Paper 1778, 105 p., available online at *http://pubs.usgs.gov/pp/1778/*.

Reilly, T.E., Dennehy, K.F., Alley, W.M., and Cunningham, W.L., 2008, Ground-water availability in the United States: U.S. Geological Survey Circular 1323, 70 p., available online at *http://pubs.usgs.gov/circ/1323/*.

Senay, G.B., Budde, M.E., and Verdin, J.P., 2011, Enhancing the Simplified Surface Energy Balance (SSEB) approach for estimating landscape ET—Validation with the METRIC model: Agricultural Water Management, v. 98, p. 606–618.

Slack, J.R., and Landwehr, J.M., 1992, Hydro-climatic data network—A U.S. Geological Survey streamflow data set for the United States for the study of climate variations, 1874–1988: U.S. Geological Survey Open-File Report 92-129, 193 p., available online at *http://pubs.usgs.gov/of/1992/ofr92-129/*.

Thenkabail. P.S., and Wu, Z., 2012, An automated cropland classification algorithm (ACCA) using Fusion of Landsat, MODIS, secondary, and in-situ data: Remote Sensing, Open Access Journal, in press.

Tillman, F.D., Cordova, J.T., Leake, S.A., Thomas, B.E., and Callegary, J.B., 2011, Water availability and use pilot—Methods development for a regional assessment of groundwater availability, Southwest Alluvial basins, Arizona: U.S. Geological Survey Scientific Investigations Report 2011–5071, 118 p., available online at *http://pubs.usgs.gov/sir/2011/5071/*.

U.S. Bureau of Reclamation, 2011, Colorado River Basin water supply and demand study: Interim Report No. 1, Status Report, June 2011, 69 p., accessed January 16, 2013, at *http://www.usbr.gov/lc/region/programs/crbstudy/report1.html*.

U.S. Department of the Interior, 2012, WaterSMART—A three-year progress report, 61 p., accessed January 16, 2013, at *http://www.usbr.gov/WaterSMART*.

U.S. General Accounting Office, 2003, Freshwater supply—States' views of how Federal agencies could help them meet the challenges of expected shortages: U.S. General Accounting Office GAO-03-514, 110 p.

U.S. Geological Survey, 2002, Report to Congress—Concepts for national assessment of water availability and use: U.S. Geological Survey Circular 1223, 34 p., available online at *http://pubs.usgs.gov/circ/circ1223/*.

U.S. Geological Survey, 2007, Facing tomorrow's challenges—U.S. Geological Survey science in the decade 2007–2017: U.S. Geological Survey Circular 1309, 70 p., available online at *http://pubs.usgs.gov/circ/2007/1309/*.

U.S. Government Accountability Office, 2009, Energy-water nexus: Improvements to federal water use data would increase understanding of trends in power plant water use—U.S. Government Accountability Office GAO-10-23, 72 p., also available online at *http://www.gao.gov/new.items/d1023.pdf*.

U.S. Water Resources Council, 1968, The Nation's water resources: Washington, D.C., U.S. Government Printing Office, 480 p.

U.S. Water Resources Council, 1978, The Nation's water resources 1975–2000—Second National Water Assessment: Washington, D.C., U.S. Government Printing Office, 768 p.

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