



## THE USGS WATER AVAILABILITY AND USE SCIENCE PROGRAM: NEEDS, ESTABLISHMENT, AND GOALS OF A WATER CENSUS<sup>1</sup>

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**ABSTRACT:** Many reports have recognized the need for a national water census for the United States and have called upon the U.S. Geological Survey to undertake this challenge. For example, the National Science and Technology Council stated: “*The United States has a strong need for an ongoing census of water that describes the status of our Nation’s water resource at any point in time and identifies trends over time.*” Responding to the need for this information, the U.S. Congress established the SECURE Water Act. The directives are to provide a more accurate assessment of the status of the water resources of the United States; determine the quantity of water available for beneficial uses; identify long-term trends in water availability; assist in determination of the quality of the water resources; and develop the basis for an improved ability to forecast the availability of water for future economic, energy production, and environmental uses. This article provides summary and new information on the process and progress on work to estimate water budget components nationwide, involvement of stakeholder interests, efforts to examine water-use characteristics throughout the Nation, studies of water availability in geographically focused areas and the initiation of methods to provide open access to existing and new water resources information contributing to Open Water Data Initiative (OWDI) efforts and objectives.

(KEY TERMS: water resources assessment; data management; Open-Water Data Initiative (OWDI); watershed processes; monitoring.)

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### INTRODUCTION

Many reports have recognized the need for a national water census for the United States (U.S.), and have called upon the U.S. Geological Survey (USGS) to undertake this challenge (for example, U.S. Water Resources Council, 1968, 1978; National Research Council, 2002, 2009; and National Science and Technology

Council, 2007). In their 2007 report, the National Science and Technology Council stated: “*The United States has a strong need for an ongoing census of water that describes the status of our Nation’s water resource at any point in time and identifies trends over time.*” The U.S. General Accounting Office (2003) noted “*National water availability and use has not been comprehensively assessed in more than 30 years.*” Responding to the need for this type of information, the U.S.

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Congress, in the Omnibus Public Land Management Act of 2009 (Public Law 111-11) under Subtitle F, established the SECURE Water Act. The Act contains substantive mandates for both the USGS and the U.S. Bureau of Reclamation. In particular, Section 9508 of the SECURE Water Act establishes a “national water availability and use assessment program.” In accordance with the provisions in the Act, the goals are to:

1. Provide a more accurate assessment of the status of the water resources of the U.S.;
2. Assist in the determination of the quantity of water that is available for beneficial uses;
3. Identify long-term trends in water availability;
4. Use each long-term trend to provide a more accurate assessment of the change in the availability of water in the U.S.;
5. Assist in the determination of the quality of the water resources of the U.S.;
6. Develop the basis for an improved ability to forecast the availability of water for future economic, energy production, and environmental uses; and
7. Develop and implement methods to provide open access to existing and new water resources information.

The USGS began implementation of the SECURE Water Act in 2011 through the Department of the Interior’s WaterSMART Initiative. This initiative provided resources to begin work on estimating water budget components nationwide, to augment resources for examining water-use characteristics throughout the Nation, to launch studies of water availability in geographically focused areas and to provide open access to existing and new water resources information. These efforts and programs are consistent with the goals of the Open Water Data Initiative (OWDI) initiated three years later. OWDI was launched with a proposal by the Federal Geographic Data Committee and Advisory Committee on Water Information (ACWI) in 2014 (Castle *et al.*, 2014). The OWDI was formally presented at the 2014 American Water Resources Association (AWRA) Annual Conference (Bales, 2015). Rea *et al.* (2015) discuss the development, objectives, organizational participation, and progress of the OWDI in a featured issue of American Water Resources Association (2015).

### *Water Budgets as a Unifying Theme*

In order to more fully meet the SECURE Water Act mandates, the USGS established the Water Availability and Use Science Program (WAUSP), which includes water census projects that focus on improving methods and tools to measure and estimate components

of the water budget and the development of a web data portal to provide open access to existing and new water resources data, estimates, models, and other information from individual gaging stations to hydrologic units to watersheds to specialized study areas over a wide range of spatial and temporal scales.

A water budget is an accounting of water stored within and water exchanged among some subset of the compartments, such as a watershed, a lake, or an aquifer. Unfortunately, information about most water-budget components is not available in a consistent form across the Nation. Therefore, the WAUSP will provide estimates of selected water-budget components, such as surface water, groundwater, evapotranspiration, and water-use, at consistent spatial and temporal scales through a series of topical area studies. 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 environmental water, which quantitatively examines the relations between water availability and healthy ecosystems. In addition to providing a basis for national indicators of water flow and storage, these topical studies will support analyses of water availability by local and regional agencies and will contribute to research quantifying the national and global water cycle.

A long-term objective of the WAUSP is to provide measured or estimated information for all water-budget components on a monthly time step and at the 12-digit hydrologic unit code (HUC-12) scale, an average drainage basin size across the Nation of 37 square miles. This information can then be aggregated for larger watersheds. The USGS is making this information available as part of its contribution to the OWDI. Although monthly data and HUC-12 scale information is established as a long-term goal for the WAUSP, many types of data currently can be determined only at coarser scales.

### *Advisory Groups*

The USGS is actively working with partners to ensure that information produced as part of the water census projects in the WAUSP can be aggregated with other types of water-availability and socioeconomic information. The USGS is working with two groups to coordinate the design and development of these efforts and to help identify existing and future water availability, quality and related information needs: the Federal Advisory Committee on Water Information and an *Ad hoc* Advisory Group of national, state, nongovern-

mental, and other water resource information user stakeholders. These groups are continuing to provide input on OWDI and the development of the provision of data, information, and analyses.

## AVAILABILITY AND USE STUDIES

To better understand components of the water budget, studies are organized as either topical or focused geographic studies. Topical area studies are different from geographically focused studies, in that they research means of providing a consistent coverage of a particular water budget component, at the watershed scale. An example would be a topical study to research means of estimating daily streamflow (an important water budget component) at all watersheds in the Nation. The topical studies are designed to develop methods to estimate components of the water budget at a national scale, while the geographically focused studies are designed to address stakeholder issues in areas where competition for water resources is high.

Both the topical and focus area studies emphasize compiling and reporting information in a way that is useful for water management and natural resource decisions. The information developed in these studies will deliver national and high resolution estimates of water budget components for local watersheds, water-use data for counties, tools to calculate statistics of daily streamflow records, modeled daily streamflow in ungaged basins, and access to records of aquatic biology observations.

### TOPICAL STUDIES

Topical studies develop new methodologies, improve data accessibility, and quantify and reduce data uncertainty. Examples of topical studies are: developing methods to estimate streamflow in ungaged basins, estimating evapotranspiration, groundwater assessments, improving water-use information by collecting, compiling, and developing new methods to estimate site-specific water-use data and developing stream classification schemes to help further understand the relations between streamflow and aquatic organisms.

#### *Estimating Streamflow*

The SECURE Water Act calls for annual updates of river-basin flows and analysis of historical trends.

The USGS operates a network of approximately 8,000 streamgages that provide real-time information and historical context for water-resources planning and assessment. Because the streamgage network cannot provide direct observations of streamflow at every location of interest, information about streamflow in ungaged basins is needed. The USGS 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. The USGS is making this streamflow information available and more accessible as part of its contribution to the OWDI.

In order to determine the best methods to estimate streamflow in ungaged basins, a pilot study in the southeastern U.S. was conducted to apply five different streamflow prediction methods and evaluate each method with a wide set of performance metrics (Farmer *et al.*, 2014). The study examined both statistical and deterministic methods for streamflow prediction in ungaged basins to determine the best for regional and national implementation. Through these comparisons, two methods emerged as the most generally accurate for streamflow prediction methods: the nearest-neighbor implementations of nonlinear spatial interpolation using flow duration curves and standardizing logarithms of streamflow by monthly means and standard deviations. To determine how well these methods perform nationally, additional areas in the Midwest and the Intermountain Region of the West are currently being tested to determine the best approach(es) for national implementation.

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 and climate change. Changes in streamflow 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.

#### *Estimating Evapotranspiration*

Evapotranspiration (ET) is an essential component of water-budget determinations for water availability. ET measured or estimated from irrigated cropland is also a fundamental variable of consumptive water-use 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.

The USGS is applying satellite remote-sensing techniques to estimate ET using 1-km-resolution National Aeronautics and Space Administration Moderate Resolution Imaging Spectroradiometer land-surface temperature imagery from the archive at the USGS Earth Resources Observation and Science (EROS) Center (Senay *et al.*, 2013). Although such images are collected daily, energy-budget calculations are made on eight-day composites that greatly reduce problems of cloud cover. The method uses remotely sensed thermal data and model-assimilated weather fields to produce ET for the contiguous U.S. at monthly and seasonal time scales. The method is based on the Simplified Surface Energy Balance operational (SSEBop) model, which uses predefined boundary conditions that are unique to each pixel for the “hot” and “cold” reference conditions. The SSEBop model uses MODIS and Global Data Assimilation System (GDAS) data streams to compute monthly, seasonal, and annual summaries at the spatial scale of 12-digit HUCs covering the period from 2000 to 2013. The USGS is making this ET information available as part of its contribution to the OWDI. More research is required to improve the representation of the predefined boundary conditions in complex terrain at small spatial scales. The SSEBop approach can also be applied with other thermal sensors such as Landsat. In the future, the USGS plans to use a combination of MODIS and Landsat to improve spatial and temporal resolution of ET estimates.

### *Groundwater Assessments*

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. The USGS has a long history of investigating the role of groundwater in water availability and an overview of groundwater resource investigations of the USGS can be found at <http://water.usgs.gov/ogw/gwrp/>. 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. Additional 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 groundwater withdrawals for public and domestic supply in the U.S., and an estimated 22.5 million people rely on the glacial aquifer system for their drinking water.

### *Improving Water-Use Information*

The human impact on the water budget results in a need to understand the demand side of water availability and use; 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 and regular evaluation of water-use data provides trend information, which is critical to decision making for future water needs. The USGS has been producing national compilations of water-use every five years since it issued its first compilation for calendar year 1950.

Improvements in measuring and collecting, as well as developing new methods to estimate, site-specific water-use data are primary objectives of the SECURE Water Act. The USGS has begun several efforts to populate the USGS site-specific database for water-use information. The first of these efforts is aimed at developing methods to estimate site-specific water withdrawal and consumptive use at thermoelectric plants. The model is based on linked heat and water budgets and is used in conjunction with reported thermoelectric water withdrawals and consumption to produce withdrawal and consumption estimates by facility, including thermodynamically plausible ranges of minimum and maximum withdrawal and consumption. In 2010, for 1,290 water-using thermoelectric plants in the U.S., the total estimated withdrawal was about 129 billion gallons per day (Bgal/day) and total estimated consumption was about 3.5 Bgal/day (Diehl and Harris, 2014). In contrast, total withdrawal reported by the U.S. Department of Energy, Energy Information Administration (EIA) was about 24 percent higher than the modeled estimates, and total EIA-reported consumption was about 8 percent lower (Diehl and Harris, 2014). Site-specific thermoelectric information will be generated again for the 2015 water-use compilation. The USGS is making this thermoelectric water-use information available as part of its contribution to the OWDI.

Another effort underway will populate the site-specific database with public supply information. This



effort will be completed in fiscal year 2017 and will allow the USGS to incorporate public supply water-use data (withdrawals, deliveries, consumptive use) into its assessments. The USGS intends to provide as much data as possible on a site-specific basis to allow managers to combine data by county, HUC, city, or other combinations that are useful for decision making. The USGS is making this water-use information available as part of its contribution to the OWDI. Finally, for the 2015 water-use compilation we plan to develop methods for estimating consumptive use for irrigation. This effort is in the planning stages, but will build on the work being developed as part of the ET topical study.

### *Stream Classification for Environmental Water*

Classification schemes are an important step in developing an understanding of how natural systems respond to changes associated with resource management actions and are identified as one of the first steps in the Ecological Limits of Hydrologic Alteration (ELOHA) framework (Poff *et al.*, 2010). ELOHA was designed to support the development of environmental flow standards at the state or watershed level and emphasizes the use of hydroecological metrics that characterize the five major components of the flow regime—duration, magnitude, frequency, rate of change (rise and fall), and timing and seasonality of flow events. Classification is the process of systematically arranging streams and rivers into groups that are most similar with respect to flow regime characteristics. It is an objective process that explicitly accounts for uncertainty, is readily interpretable by users, can be applied at multiple spatial scales, and provides meaningful stream types. Stream classification also provides a foundation for discerning differences in ecological character, allows the development of meaningful relations between hydrology and ecology, and provides a baseline by which the response of aquatic assemblages to hydrologic alteration can be assessed. Sites are typically grouped using statistics derived from a daily streamflow time series at USGS streamflow gages which are used to compare natural and altered hydrologic regimes, and ultimately to determine the effects of streamflow alteration and water withdrawals on aquatic ecosystems.

Despite recent advances in stream classification processes, the absence of an updated national-scale stream classification for the U.S. has been an impediment to effective resource management. The recent study by Archfield *et al.* (2013) developed a set of seven parsimonious, objective hydro-ecological classification variables to classify flow based on more than 1,500 USGS gaging stations across the conterminous

U.S. These seven hydro-ecological variables represent the mean, coefficient of variation, skewness, kurtosis; autoregressive lag-one correlation coefficient, amplitude and phase of the seasonal signal. These variables were chosen because they account for a broad array of ecologically relevant streamflow statistics (that is, duration, magnitude, frequency, etc.) that have commonly been used to classify streams in the past, but with far fewer variables. This approach also allowed a more objective classification that resource managers can use when determining instream flow criteria. The results of this investigation demonstrated that these seven variables did a better job at classifying streams than a much larger set of commonly used streamflow statistics. This parsimonious classification approach had a number of added benefits including overcoming the subjective process of choosing a subset of flow metrics from a very large assortment of variables, implicitly accounting for the five major components of streamflow, a high level of stability among stream classes, and a reduction in redundancy among variables. The USGS is making this classification information available through the National Water Census Data Portal as part of its contribution to the OWDI.

In addition to this national streamflow classification structure, a set of flexible tools are being developed that will allow stakeholders to basins at varying scales (HUCs). These tools are being designed to serve both a predetermined set of stream classes derived from a subset of existing baseline hydrographs and, alternatively, to provide the users with the option of deriving a set of stream classes based on user-specified input. These tools are meant to complement existing local and regional efforts to classify streams that stakeholders may be using for more detailed assessment and management purposes.

## GEOGRAPHIC FOCUS AREA STUDIES

The geographic focus area studies provide opportunities to test and improve approaches for quantifying water-budget components and pilot the application of regional water budgets to stakeholder identified water-management challenges (Alley *et al.*, 2013). These studies also provide an opportunity to inform and “ground truth” the methods and applications of the topical studies with local information. There were three initial focus area studies, the Apalachicola-Chattahoochee-Flint River Basin, Colorado River Basin, and Delaware River Basin (Figure 1). Three new geographic focus area studies will begin in 2016. These are the Upper Rio Grande Basin, Red River

Basin, and Coastal Basins of the Carolina. Each study area will compile water-use at the HUC-8 (or smaller) scale as part of the study requirements. All of the geographic focus area study information will be available through the National Water Census Data Portal as part of USGS's contribution to the OWDI.

*Apalachicola-Chattahoochee-Flint River Basin Focus Area Study*

The Apalachicola-Chattahoochee-Flint (ACF) River Basin is both physiographically and biologically diverse. The basin has numerous water demands that include recreation, municipal water supply, power generation, ecological flow requirements, and agriculture. To help regional resource managers the USGS is developing deterministic streamflow and groundwater models that can be linked to produce estimates of streamflow in ungaged locations, developing ecological models that analyze flow effects on species persistence and colonization, and developing water-use estimates at the HUC-8 scale for the entire basin.

The calibrated basin-wide streamflow model will be used to develop finer scale models for selected sub-basins in six locations in the ACF which will be used to parameterize ecological models that relate modeled hydrology for each basin to population and metapopulation dynamics. In this case, metapopulation dynamics refer to the localized colonization and extinction of separate populations of the same species, which are geographically separated from one another. These models will allow stakeholders to improve estimation of streamflow requirements for ecological purposes.

*Delaware River Basin Focus Area Study*

Competing water needs in the drainage basin of the Delaware River make it an ideal case study for developing tools for sustainable management and water conflict resolution. The following issues were identified as priorities by stakeholders in the Delaware River Basin:

1. Acquisition, management, and integration of improved water-use and water-supply data;
2. 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; and
3. 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

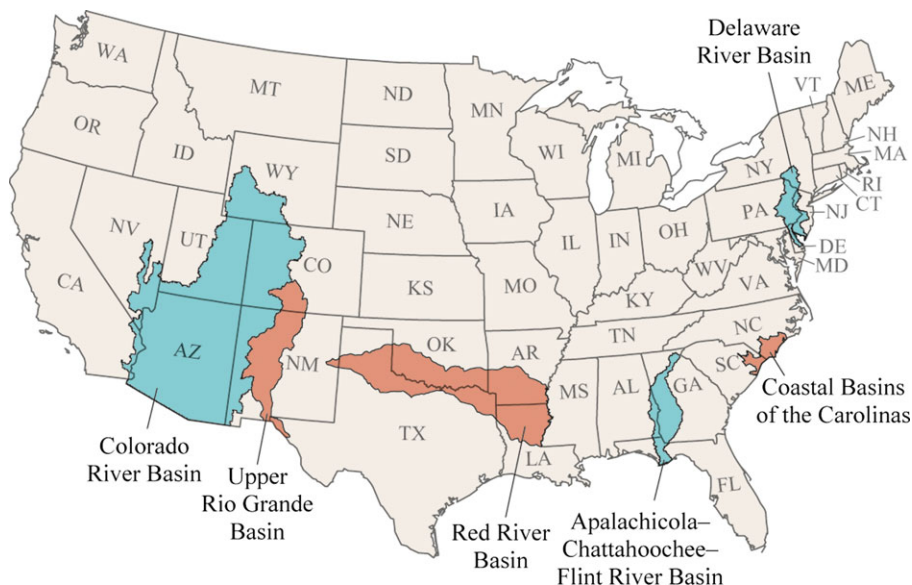


FIGURE 1. Geographic Focus Area Study Locations. Basins in green represent existing studies and those in brown are studies that will begin in Fiscal Year 2016.

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.

Ecological water science activities in the Delaware River Basin are being implemented to broaden the capabilities of an integrated Decision Support System (DSS) (<http://water.usgs.gov/watercensus/delaware-dss.html> and Maloney *et al.*, 2015) 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 wedge mussel). 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 DSS 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. In the future, the research, tools, and applications being developed as part of this study's ecological water science efforts are expected to have applicability nationally.

#### *Colorado River Basin Focus Area Study*

This basin is experiencing rapid population growth and increased water demands by many sectors, including energy, agriculture, and municipal water supplies. Given the large size of the river basin, certain aspects of the Colorado River Basin Focus Area Study (FAS) were conducted at the subregional basin- and subbasin-scale in order to answer the relevant questions and inform the appropriate management decisions. The study focuses on estimating current and historical trends in water-use, with a focus on consumptive water-use, completing regional and field-scale assessments of water budget components, snowpack water content and snow sublimation, and identifying geologic controls on groundwater flow and

determining the relative importance of groundwater discharge to streams for sustaining surface-water supplies and environmental needs. Water-use information is being compiled for the basin at the HUC-8 scale, which will allow an investigation of water-use trends by sector. Water-use sectors, including self-supplied commercial water-use and hydroelectric water withdrawals will be estimated for years 2000, 2005, and 2010 and trends analysis will be conducted back to 1985.

To better understand estimated runoff from snowmelt, a component of the Colorado River Basin FAS study compared independent, ground-based snow survey data in the Colorado Rocky Mountains to the SNOW Data Assimilation System (SNODAS). SNODAS estimates at the 1-km<sup>2</sup> scale (Clow *et al.*, 2012). SNODAS estimate in forested areas explained 72% of the variance in snow depths and 77% of the variance in snow water equivalent (SWE). In alpine areas SNODAS estimates only explained 16% of the variance in snow depth and 30% of the variance in SWE. The study developed a method to adjust estimates that uses relations between prevailing wind direction, terrain, and vegetation to account for wind redistribution of snow in alpine terrain. These adjustments improved agreement between measurements and SNODAS estimates.

Another component of the FAS developed a method that uses discrete specific conductance (SC) data to estimate base flow at a daily time step using the conductivity mass balance (CMB) approach. Regression-derived CMB base flow estimates were more similar to base-flow estimates obtained using a CMB approach with measured high frequency SC data than were the graphical hydrograph separation base-flow estimates at 12 snowmelt dominated streams and rivers. There was a near perfect fit between the regression-derived and measured CMB base-flow estimates at sites where the regression models were able to accurately predict daily SC concentrations. It is possible to use the regression-derived approach to estimate base flow at large numbers of sites, thereby enabling future investigations of watershed and climatic characteristics that influence the base-flow component of stream discharge across large spatial scales.

#### MANAGING AND DELIVERING INFORMATION

A WAUSP program-wide data-management plan and policy for funded projects is being developed to provide a framework that will guide and document these activities. Data-management planning spans the entire data life cycle to include data acquisition, documentation, processing, analysis, preservation,



and delivery (access). 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 the Advisory Committee on Water Information as part of the OWDI will ensure that the data are useful to a wide range of users and purposes.

As the projects described here come to completion, the information resources they produce will be published using standards and approaches in line with the OWDI. They will be discoverable through the National Water Census Data Portal. It will provide an index that exposes data resources to the Internet and a portal to access and aid exploration and use of national and detailed water budget data, streamflow statistics, aquatic biology, water availability and use studies and other information and applications. 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 ongoing activities.

The WAUSP will provide a wide array of previously unavailable data to the community consistent with the OWDI including more detailed water budgets, water availability and use studies, groundwater assessments, improved evapotranspiration and water-use information, and geographic focus area studies information. Development of an open water data information resources portal will greatly advance understanding, management, and planning of water resources and will help achieve many of the recommendations for water resources information which have been made over the last several decades.

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