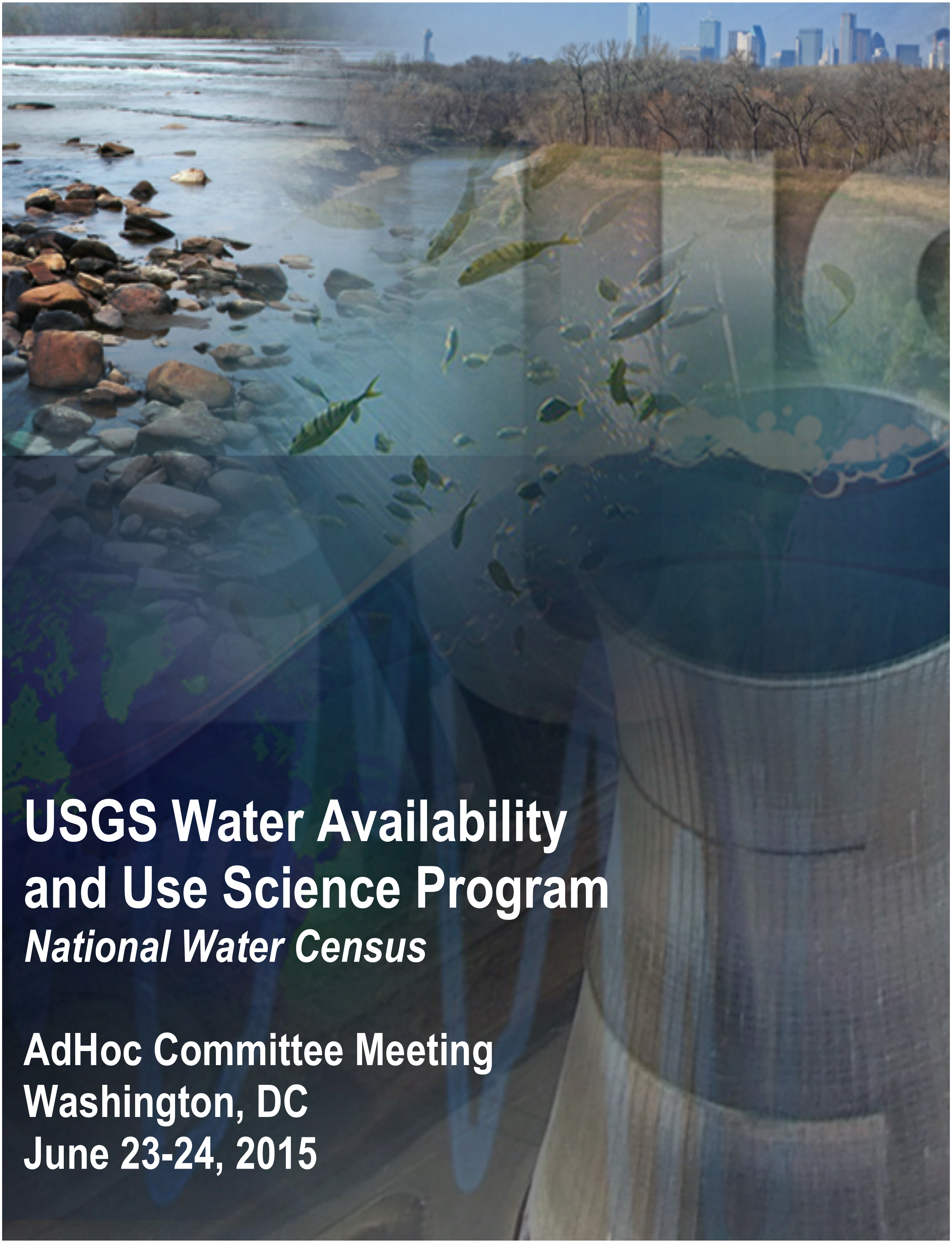

USGS Water Availability and Use Science Program

National Water Census

AdHoc Committee Meeting
Washington, DC
June 23-24, 2015

National Water Census Ad Hoc Committee Meeting
Main Interior Building, Rachel Carson Room
Washington DC, June 23 and 24

Tuesday June 23, 2015

8:30am	Welcome and Introductions	*Eric Evenson*
9:00am	Overview of National Water Census Activities	*Sonya Jones*
9:30am	USGS updates to the Ad Hoc Committee on completed and current NWC Topical and Focus Area Study projects	
	• Flow in ungaged basins	*Julie Kiang*
	• Environmental water	*Jonathan Kennan*
	• Evapotranspiration	*Gabriel Senay*
	10:40am Break (20 minutes)	
	• Water Use	*Molly Maupin*
	• Groundwater	*Kevin Dennehy*
	• Focus Area Studies	*Bret Bruce*
12:10pm	Lunch	
1:00pm	National Water Census Data Portal	*Dave Blodgett*
	The National Water Census Data Portal provides national estimates of water budget components for local watersheds, water use data for counties, tools to calculate statistics from daily streamflow records, modeled daily streamflow at ungaged locations, and access to records of aquatic biology observations. http://cida.usgs.gov/nwc/	
2:00pm	Break	
2:30pm	Facilitated feedback from the Committee	*Melinda Dalton*
5:00pm	Adjourn	

Wednesday June 24, 2015

8:30am	Overview of Day 1	*Sonya Jones*
9:00am	Discussion of Future Work	
	Facilitated group discussion on the future directions of National Water Census research priorities	*Melinda Dalton*
10:00am	Break	
10:30am	Continue group discussion	*Melinda Dalton*
11:30am	Wrap up	*Sonya Jones*
12:00pm	Adjourn	

National Water Census web page link:
http://water.usgs.gov/watercensus/

National Water Census Ad Hoc Committee Meeting
Main Interior Building, Rachel Carson Room
Washington DC, June 23 and 24

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National Aeronautics and Space Administration	David L. Toll	301-614-5801	david.l.toll@nasa.gov				

National Water Census Selected Publications

2015

Miller, M.P., D.D. Susong, C.L. Shope, V.M. Heilweil, and B.J. Stolp (2015) A new approach for continuous estimation of baseflow using discrete water quality data: Method description and comparison with baseflow estimates from two existing approaches: Journal of Hydrology 522 (2015) 203–210 (PDF)

Farmer, W.H., Archfield, S.A., Over, T.M., Hay, L.E., LaFontaine, J.H., and Kiang, J.E., 2014, A comparison of methods to predict historical daily streamflow time series in the southeastern United States: U.S. Geological Survey Scientific Investigations Report 2014-5231, 34 p., http://dx.doi.org/10.3133/sir2014-5231

Caldwell, Kennen et al, A comparison of hydrologic models for ecological flows and water availability: Wiley Online Library -- Ecohydrology (PDF)

2014

Maupin, M.A., Kenny, J.F., Hutson, S.S., Lovelace, J.K., Barber, N.L., and Linsey, K.S., 2014, Estimated use of water in the United States in 2010: U.S. Geological Survey Circular 1405, 56 p., http://dx.doi.org/10.3133/cir1405.

Diehl, T.H., and Harris, M.A., 2014, Withdrawal and Consumption of Water by Thermoelectric Power Plants in the United States, 2010: U.S. Geological Survey Scientific Investigations Report 2014-5184, 28 p., http://dx.doi.org/10.3133/sir20145184.

Clarke, J.S., and Painter, J.A., 2014, Influence of septic systems on stream base flow in the Apalachicola-Chattahoochee-Flint River Basin near Metropolitan Atlanta, Georgia, 2012: U.S. Geological Survey Scientific Investigations Report 2014-5144, 68 p., http://dx.doi.org/10.3133/sir20145144.

Garcia, A., Masbruch, M.D., and Susong, D.D., 2014, Geospatial database of estimates of groundwater discharge to streams in the Upper Colorado River Basin, U.S. Geological Survey Data Series 851, 6 p. http://dx.doi.org/10.3133/ds851

Miller, M.P., D.D. Susong, C.L. Shope, V.M. Heilweil, and B.J. Stolp (2014) Continuous estimation of baseflow in snowmelt-dominated steams and rivers in the Upper Colorado River Basin: A chemical hydrograph separation approach, Water Resour. Res., 50, doi:10.1002/2013WR014939

2013

Alley, W.M., Evenson, E.J., Barber, N.L., Bruce, B.W., Dennehy, K.F., Freeman, M.C., Freeman, W.O., Fischer, J.M., Hughes, W.B., Kennen, J.G., Kiang, J.E., Maloney, K.O., Musgrove, MaryLynn, Ralston, Barbara, Tessler, Steven, and Verdin J.P., 2013, Progress toward establishing a national assessment of water availability and use: U.S. Geological Survey Circular 1384, 34 p. http://pubs.usgs.gov/circ/1384

Archfield, S. A., Kennen, J. G., Carlisle, D. M., & Wolock, D. M. (2013). An Objective and Parsimonious Approach for Classifying Natural Flow Regimes at a Continental Scale. River Research and Applications. [Journal Article]

Callegary, J.B., Kikuchi, C.P., Koch, J.C., Lilly, M.R., Leake, S.L., 2013, Review: Groundwater in Alaska: Hydrogeology Journal, Vol. 21, Issue 1, pp 25-39. Invited submission to special issue on cold-region hydrology. [Journal Abstract]

Diehl, T.H., Harris, M.A., Murphy, J.C., Hutson, S.S., and Ladd, D.E., 2013, Methods for estimating water consumption for thermoelectric power plants in the United States: U.S. Geological Survey Scientific Investigations Report 2013-5188, 78 p. http://pubs.usgs.gov/sir/2013/5188/

Kiang, J.E., Stewart, D.W., Archfield, S.A., Osborne, E.B., and Eng, Ken, 2013, A national streamflow network gap analysis: U.S. Geological Survey Scientific Investigations Report 2013-5013, 79 p. plus one appendix as a separate file, http://pubs.usgs.gov/sir/2013/5013/.

Levin, S.B., and Zarriello, P.J., 2013, Estimating irrigation water use in the humid eastern United States: U.S. Geological Survey Scientific Investigations Report 2013-5066, 32 p., http://pubs.usgs.gov/sir/2013/5066/

Senay, Gabriel B., Stefanie Bohms, Ramesh K. Singh, Prasanna H. Gowda, Naga M. Velpuri, Henok Alemu, James P. Verdin. 2013. Operational Evapotranspiration Mapping Using Remote Sensing and Weather Datasets: A New Parameterization for the SSEB Approach. Journal of the American Water Resources Association (JAWRA). 49(3):577-591 [Journal Abstract]

2012

Bruce, B.W., 2012, WaterSMART-The Colorado River Basin focus-area study: U.S. Geological Survey Fact Sheet 2012-3114, 6 p. http://pubs.usgs.gov/fs/2012/3114/

Clow, D.W., Nanus, L., Verdin, K.L., Schmidt, J., 2012. Evaluation of SNODAS snow depth and snow water equivalent estimates for the Colorado Rocky Mountains, USA. Hydrological Processes 26, 2583-2591.

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. http://pubs.usgs.gov/sir/2012/5179/

Kahle, S.C. and Futornick, Z.O., 2012, Bibliography of groundwater resources of the glacial aquifer systems in Washington, Idaho, and northwestern Montana, 1905-2011: U.S. Geological Survey Open-File Report 2012-1053, 32 p. http://pubs.usgs.gov/of/2012/1053/

2011

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. http://pubs.usgs.gov/sir/2011/5166/

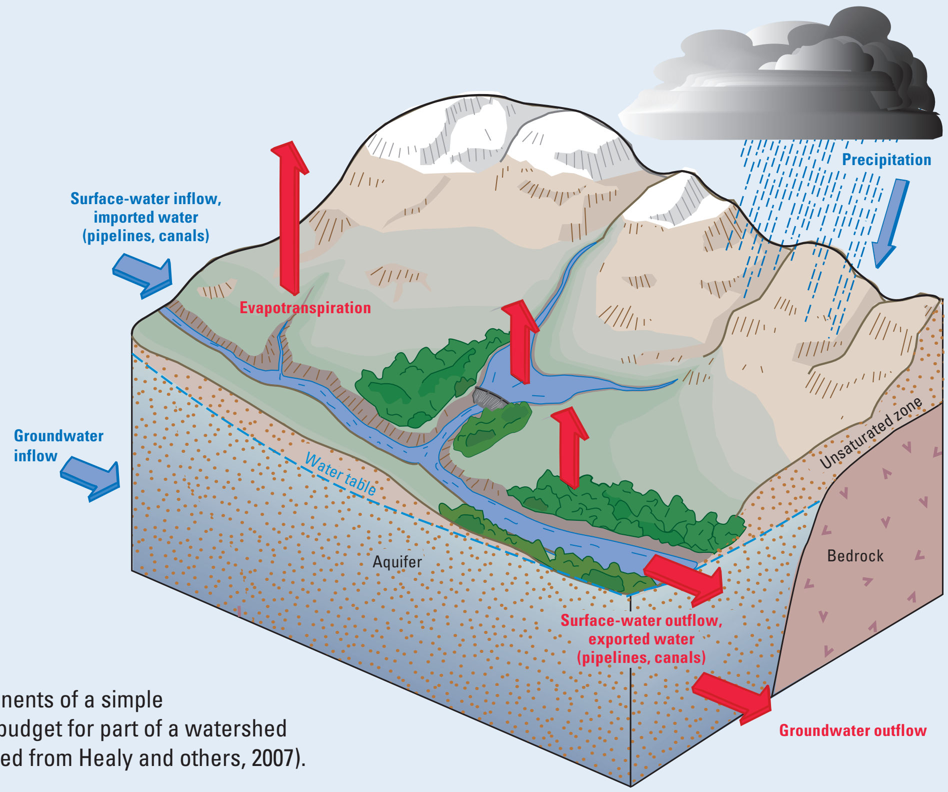
Progress Toward a National Water Census

Increasing demand and competition for limited regional water resources make it difficult to ensure adequate water availability for both human and ecological needs now and into the future. Recognizing the need to improve the tools and information that are available to effectively evaluate water-resource availability, the U.S. Geological Survey (USGS) identified a National Water Census (NWC) as one of its six core science directions for the decade 2007–17 (U.S. Geological Survey, 2007). In 2009, the SECURE Water Act (Public Law 111–11) authorized the USGS to develop a national water availability and use assessment program that would update the most recent national assessment of the status of water resources in the United States (U.S. Water Resources Council, 1968, 1978) as well as develop the science to improve forecasts of water availability and quality for future needs.

By evaluating large-scale effects of changes in land use and land cover, water use, and climate on occurrence and distribution of water, water quality, and human and aquatic-ecosystem health, the NWC will also help to inform a broader initiative by the Department of the Interior, WaterSMART (Sustain and Manage America's Resources for Tomorrow), which provides multiagency funding to pursue a sustainable water supply for the Nation as directed under the SECURE Water Act. Through the NWC, the USGS actively engages Federal, regional, and local stakeholders to identify research priorities and leverages current studies and program activities to provide information that is relevant at both the national and regional scales.

The NWC will produce a current, comprehensive scientific assessment of the factors that influence water availability by (1) developing nationally consistent datasets that reflect the status and trends of major water budget components (diagram below), as well as water use, for the Nation; (2) improving the current understanding of flow requirements for ecological purposes; and (3) evaluating water-resource conditions in selected river basins, or Geographic Focus Areas, where competition for water is elevated. Future research goals of the NWC include (1) evaluating the relations between water supply and quality for both human and ecological uses, including the potential use of impaired water supplies; (2) development of Geographic Focus Area studies in additional basins; and (3) the continued improvement of uncertainty analysis.

Much of the information developed as part of the NWC is derived from models, statistical estimation techniques, and other transformation processes. The National Water Census Data Portal has been developed to allow users to access a comprehensive and nationally consistent interactive map interface to download data visualizations, retrieve stand-alone data for further analysis, or integrate multiple datasets with built-in and downloadable data-analysis tools.



Components of a simple water budget for part of a watershed (modified from Healy and others, 2007).

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

Fact Sheet 2015–3045
June 2015

Developing a National Water Budget

Data and other information produced as part of the NWC can be used to define the components of a water budget; unfortunately, consistent data for many water-budget components are not currently available either regionally or nationally. The unifying goal of the NWC is to develop and improve estimates of water-budget components at consistent spatial (basin) and temporal (monthly) scales. This goal will be achieved through a series of topical area studies that are designed to quantify the amount of water that resides in, or is moving through, water budgets.

Topical Areas

As part of the NWC, the USGS will conduct studies that focus on streamflow, groundwater, precipitation, evapotranspiration, and water use to develop and improve the data needed to achieve a comprehensive and up-to-date assessment of water availability at both national and basin scales. An additional topical area study will advance the science of ecological flow by quantitatively examining the relations between water availability and healthy ecosystems.

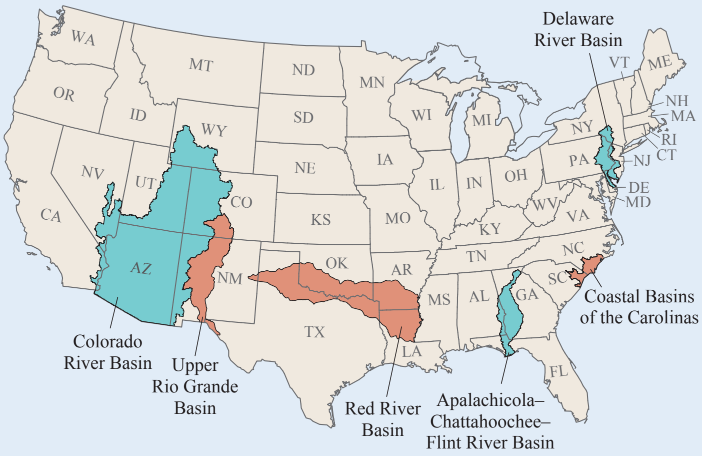
Each topical area study seeks to enhance available data and associated information through the research and development of new methodologies, improving data accessibility, and quantifying and reducing data uncertainty. In addition to providing a basis for national indicators of water flow and storage for the NWC, these studies will support analyses of water availability by local and regional agencies and will contribute to research quantifying national and global water cycles.

Geographic Focus Area Studies

Competition for water resources is focused regionally where competing water needs—either human needs (for example, potable water, irrigation, energy development, industrial use) or flow requirements for healthy ecosystems—are outpacing current supplies. As a counterpart to the topical area studies, a series of Geographic Focus Area studies, or regional assessments, will provide opportunities to test and improve approaches for quantifying water-budget components and pilot the application of regional water budgets to the water-management challenges of large river basins. These studies will also provide an opportunity to inform and "ground truth" NWC methods and applications with local information.

The first three Geographic Focus Area studies are underway in the Apalachicola–Chattahoochee–Flint, Colorado, and Delaware River Basins (map upper right); specific basin research and products include: water-use databases that estimate current and historical trends, including consumptive use; developing a tool to estimate streamflow at ungaged streams and coupling surface- and groundwater flow models; and developing decision support systems and ecological models to predict changes in fish and mussel species associated with climate and land-use change and water use.

Three new Focus Area studies will begin in October 2015 in the Red River and Rio Grande Basins, and the Coastal Basins of the Carolinas. Planned research includes impacts of dust on snow, refinement and coupling of groundwater and surface-water models, and development of methods to evaluate agricultural irrigation.



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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 at http://pubs.usgs.gov/circ/2007/1308/.

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. 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.

Additional Information and Contacts

Detailed information about the current status and activities of the National Water Census can be found in U.S. Geological Survey Circular 1384, "Progress Toward Establishing a National Assessment of Water Availability and Use." This publication is available online at http://pubs.usgs.gov/circ/1384/. For additional information, please visit http://water.usgs.gov/watercensus/ or contact:

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Implementation of the USGS National Water Census Program, 2010-2020

Compilers: Eric Evenson, Sonya Jones, and Melinda Dalton

Draft Version: June 16, 2015

Table of Contents

Executive Summary

There are major gaps in the knowledge and information needed to conduct a national water availability and use assessment. To date there have only been two comprehensive assessments of water use and availability for the Nation, the first in 1968, the second in 1975. Since the last assessment, population growth and land use and land cover change have impacted water resources. Recently, there has been an increasing call for further evaluation of the Nation's water resources, especially in regard to ensuring water availability into the future for both human and ecological needs. In 2010, the USGS initiated the National Water Census research program to synthesize and report hydrologic and ecological 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 and natural resource management. In 2015 the USGS Water Mission Area restructured and the National Water Census is now a part of the National Water Availability and Use Science Program.

To ensure maximum use of the data and information produced the USGS works with Federal and non-Federal agencies, universities, and other organizations to ensure that the information collected and produced by the National Water Census 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. Early in the process 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. This report outlines the implementation approach for the USGS National Water Census, beginning in 2010, for the next ten years. Funding levels will play a significant role in the long-term development of a National Water Census; the original authorization from Congress devoted $20 million per year for the next 10 years to plan and implement a National Water Census, actual funding has been about $5 million. More information on the National Water Census can be found at http://water.usgs.gov/watercensus/.

Implementation of the USGS Water Availability and Use Science Program, National Water Census, through 2020

History of the National Water Census

Water availability and use have not been comprehensively assessed at the National level in more than 30 years (U.S. General Accounting Office, 2003). The first national water availability and use assessment was published by the U.S. Water Resources Council in 1968 and 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).

On March 30, 2009, Subtitle F of the Omnibus Public Land Management Act of 2009 (Public Law (P.L.) 111-11) was passed into law. Also known as the SECURE Water Act, it contains substantive programmatic mandates for both the U.S. Geological Survey (USGS) and the U.S. Bureau of Reclamation (USBR). Specifically, Section 9508 of the SECURE Water Act requires that the USGS establish a "national water availability and use assessment program" that will:

- 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.

Initial concepts for a National Water Census (NWC) were developed by USGS 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) and 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 respondents emphasized the potential for improved methodologies and standards for consistency for national 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 NWC builds upon these comments and recommendations. The first report to Congress that tracks progress on the NWC can be accessed at *http://pubs.usgs.gov/circ/1384/*.

Stakeholder Process for the National Water Census

The USGS is developing plans for the NWC 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 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 (EPA).

The USGS receives guidance on the NWC through the Federal 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 nonprofit 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 has several subgroups examining water-quality monitoring, data methods and comparability, spatial water data, hydrology, streamgaging, cooperative water programs, and science issues.

Stakeholder defined issues of concern

The USGS worked with the Sustainable Water Resources Roundtable in ACWI to convene a multi-organization ad hoc committee of stakeholders in water availability that make recommendations on the priorities, design, and methods of presentation of the NWC. As part of that process the ad hoc committee provided feedback on the priorities of their agencies for the NWC, including the data, tools, and products that a national assessment of water use and availability should produce (table 1). Some of the most frequently mentioned priorities include improving estimates of consumptive use for evaluating and designing policies that will result in real water conservation rather than reduction in withdrawals while actually increasing the amount of water consumptively used; extension of water use assessments to all river corridors; fund and establish, in cooperation with state or local governments, a National Ground Water Monitoring Network; report on the status and trends of water use, consumptive use and return flow, including through managed aquifer recharge projects regionally; integrate land use, ground and surface water, and quality and quantity information, including the ability to model or track system interconnections; forecasting ecological impacts in response to climate change and identify relevant hydrologic indicators; and, develop remote sensing methods that allow real-time analysis of flows, river channel condition at a range of flows, and water quality for all watersheds at any point to include both gaged and ungaged systems.

Table 1. Five-, ten-, and twenty-year science priorities identified by the National Water Census Ad Hoc Committee of Stakeholders.

Five Year Priorities:	Ten Year Priorities	Twenty Year Priorities
1. Estimates of Consumptive Water Use and Evapotranspiration	1. Improved Water Use and Consumptive Use Estimates	1. Water Census fully integrated within a broader economic, environmental and community information system scalable from site to local to regional to state to national along natural and political units as users demand
2. Improved Water Use Information	2. Water Availability Decision Tool	2. Factors affecting water consumption trends – climate, demography, socioeconomic change
3. Improved Monitoring Data and Coverage, More Comprehensive Data	3. Ecological Flow Science	3. Realtime analysis of streamflows and water quality
4. National Groundwater Database, including National Groundwater Levels and Quality Networks	4. Water Quality Modeling	4. More Streamgages
5. Improved Water Budgets, Nationally and Regionally	5. Investigations of Streamflow and Water Quality	5. Video Cameras at streamgages
6. Reference Condition Hydrographs	6. Groundwater and Water Quality – Status and Trends	6. Planning and resource management evolution write-up
7. Web Portal Development for Data Delivery	7. Air Temperature / Water Temperature / Water Quality	7. Periodic reports of trends in groundwater levels and water quality
8. Groundwater / Surface Water Interactions	8. Develop and release a national database of Aquatic Biology	8. Monthly regional groundwater budgets
9. Historical Data on Hydrologic Variables – N-values; Froude Estimates; Bank full Estimates	9. Provide Guidance to the National Agricultural Census on how it could provide information to the Water Census	9. National implementation of linked surface water and groundwater models and water use estimation techniques.
10. Forecasting Future Water Demand	10. Linked Groundwater / Surface Water Models	10. Improved water supply forecasting
11. Ecological Flow Science	11. Synthetic Hydrographs for Ungaged Areas	11. Fine-scale resolution digital elevation models, soils, geology, land use, ecology – all integrated with the Water Census.
12. Increase Realtime Water Quality Network at Streamgages	12. Water Budget Analysis	12 Status and trends in surface water flows.
13. Saline Groundwater Assessment	13. Water-Energy Nexus	13. Complete water use tracking
	14. Water Planning Case Studies	14. Focus Area reports
	15. Climate Change Affects on Water Availability	15. Ecological flow science
		16. Estimation of salt balance.

Roles of USGS Programs in leveraging science through Cooperative Planning

There are seven Programs within USGS that combine resources to meet the goals of the NWC: Fisheries, Land Change Science, Land Remote Sensing, National Cooperative Geologic Mapping, National Geospatial, National Water Quality Program, and Water Availability and Use Science, Each Program has a significant investment and role to play in the success of the National NWC. Joint planning and implementation of the NWC is managed by a National Coordinator, with regular collaboration among the USGS Program offices.

Annually, USGS Program Coordinators and NWC project coordinators and scientists meet to discuss overall program progress, highlighting accomplishments from the previous year, have rigorous scientific dialog about on-going and planned research techniques and methods, and determine the next steps required for each component of the NWC to meet its' goals and objectives. This coordination effort is fundamental to the success of the NWC.

Goals of the National Water Census

The USGS NWC has three goals that are defined as part of the SECURE Water Act. :

- Provide a nationally consistent set of information (water budget components) that reflects the status and trends relating to the availability of water resources in the United States.
- Provide information and tools that allow users to better understand the flow requirements for ecological purposes.
- Report on areas of significant competition over water resources and the factors that have led to the competition (focus areas).

The following chapters of this report describe in more detail how the NWC will meet the objects listed above.

A National Water Budget

Water availability in a region depends on several key factors including: (1) hydrology and the water budget, (2) basin properties including hydrogeology and surface storage, (3) water quality, (4) existing human water use, and (5) constraints for in-stream flow related to recreation, transportation, maintenance of water quality, and ecological function. The NWC will provide data and analysis on these five factors at scales relevant for water-resources assessment by providing timely and accurate water budget information to decision makers and the public.

The main unifying concept of the NWC is the water budget; ultimately, all products from NWC should fit into the water budget equation. Water budgets (Fig. 1) are a way of accounting for the inputs, outputs, withdrawals, and changes in amount of water in each component of the water cycle. By quantifying the various components of a watershed's water budget, we take the first steps in assessing water availability. The water budget equation is:

$$P + Q^{sw}_{in} + Q^{gw}_{in} = ET + \Delta S^{sw} + \Delta S^{snow} + \Delta S^{gw} + Q^{gw}_{out} + RO + Q^{bf}$$

P is precipitation
Q^{sw}_{in} is surface water flow into the watershed
Q^{gw}_{in} is groundwater flow into the watershed
ET is all evapotranspiration
ΔS^{sw} is change in surface water storage
ΔS^{snow} is change in snow and ice storage
ΔS^{gw} is change in groundwater storage
Q^{gw}_{out} is groundwater flow out of the watershed
RO is surface runoff
Q^{bf} is baseflow out of the watershed

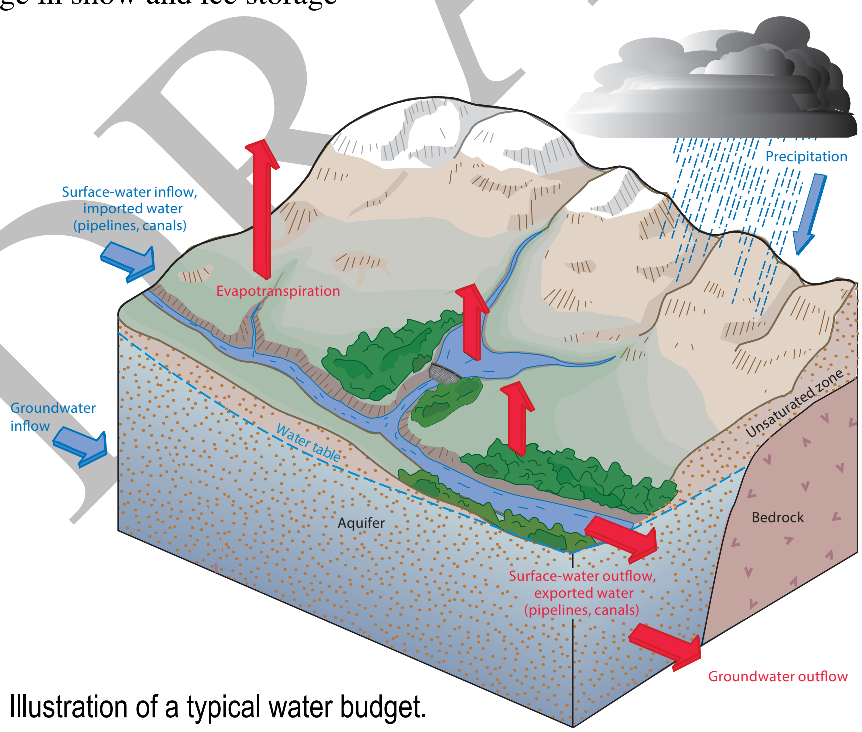

Figure 1. Illustration of a typical water budget.

This equation is written for an undisturbed watershed, absent of any human withdrawals or return flows. If human water withdrawals or return flows are present, they can either be accounted by adding additional terms on either side of the equation ($Q^{sw\text{-}human}_{in}$, $Q^{gw\text{-}human}_{in}$, $Q^{sw\text{-}human}_{out}$, $Q^{gw\text{-}human}_{out}$) or by including human water transfers in the appropriate existing terms. By measuring or estimating the amount of water for each of these terms over time for the watersheds across the nation, the NWC will provide the user with the capability to calculate a water budget for their area of interest. The water budget equation can become as detailed as the user requires by adding separate terms for various losses (e.g. consumptive uses), watershed processes (e.g. recharge or infiltration) and other components of the hydrologic cycle (e.g. the unsaturated zone).

National Water Census Approach to Water Budgets

Precipitation (P) data is obtained from the National Weather Service. Monthly precipitation and air-temperature data is obtained from the U.S. Historical Climatology Network (HCN) dataset that was developed and is maintained at the National Climatic Data Center. The NWC will work with the National Weather Service to see if it is possible to provide gridded daily coverages of precipitation in the future. If not, monthly precipitation data or disaggregated monthly precipitation data will have to be used in the water budget analysis.

Measurements for surface water flow (Q^{sw}) will be provided by the USGS streamgaging network of approximately 8,000 streamgages that 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. Qualified flow records provided from other sources, basin characteristics, and statistical and deterministic modeling tools that provide an estimated daily hydrograph for all ungaged areas in the country also will be used in calculating water budgets. Because of the coverage of streamgages, the period of record, and the number of streamgages free of significant flow regulation, accuracy of flow estimation will vary significantly from one part of the nation to another.

The NWC will explore data sources to provide measurements of storage (ΔS) of water in man-made lakes and reservoirs, it is assumed that water stored in natural lakes, where the lake level is not artificially maintained, are negligible to the water budget equation. For water budget analysis, the change in storage is the factor that is most often sought and, from a water availability perspective, users usually want to know the trends in storage over the long-term. Information on snow and ice storage in the Western US will be obtained through the SNOTEL network coordinated by the USDA's Natural Resources Conservation Service. In the Eastern US, the USGS will work with the National Weather Service and the relevant States who run snow surveys to provide information on the status of water in storage in snowpack.

Groundwater (Q^{gw}) inputs into the water budget will be a major focus of the NWC. Regional analyses of groundwater availability will be completed 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

Evapotranspiration (*ET*) data will be obtained from discrete measurements and from ET networks currently in operation and from historical water budget analysis. Evapotranspiration estimates will be provided on a monthly basis in a gridded format for the nation. Methods for developing better evapotranspiration estimates will be explored in cooperation with the National Weather Service as part of the NWC topical studies.

Water use data ($Q^{sw\text{-}human}$, $Q^{gw\text{-}human}$) will be provided in cooperation with the USGS National Water Use Information Program (NWUIP), which has been reporting water use by sector every five years since 1950. Data provided by the NWUIP will include estimates of withdrawals, public-supply deliveries, wastewater returns, and consumptive use for 11 sectors (public supply, domestic, commercial, irrigation, livestock, aquaculture, industrial, mining, thermoelectric power, hydroelectric power, and wastewater treatment at the HUC-8 and county level; although water-use data at the county level is difficult to use for watershed-based water budgets. Several sectors of water use will be targeted for improved estimates at a monthly time step as part of a water use topical study; the first three areas that will be explored for improved estimates will be the largest sectors, thermoelectric, irrigation, and public supply.

Scope of a National Water Budget

The size of watershed area and time period for which the water budget is calculated are of primary importance to the user. Using too large of a watershed area can mask water availability problems that become very apparent at the smaller scale. Conversely, a water budget for a small watershed may not provide the regional or national representation of water availability that the user desires. Water budgets may theoretically be calculated over any time period. However, most water budgets are calculated on a time step as short as a month, ranging up to a year. In order to capture seasonal variations, it is often desirable to conduct the water budget on a monthly basis, which can be aggregated up to an annual budget. The most significant limiting factor is access to accurate data on a monthly basis. Annual water budgets are useful for many water availability analyses, but may suppress issues related to seasonality of flows, climate, and water use variability throughout the year– all critical issues to water resource managers and the environment.

Spatial Scale

The United States is divided and sub-divided into successively smaller hydrologic units classified into six levels: regions, sub-regions, accounting units, cataloging units, etc. Each hydrologic unit is identified by a unique hydrologic unit code (HUC; Fig. 2) consisting of two to twelve digits based on the six levels of classification and are arranged within each other, from the smallest (12-digit) to the largest (2-digit). This coding system provides an orderly way to classify watersheds for the purpose of water availability analysis.

The long-term objective of the NWC will be to provide measured or estimated information for all relevant water budget terms at the HUC 12-digit scale. This information may then be aggregated up to the HUC 10-, 8-, 6-, 4-, and 2-digit scales. Although the goal of the NWC is to provide data at the HUC 12-digit scale, measured information is generally more readily available at the larger scales where there is less uncertainty associated with measurements. Because of the uncertainty associated with estimated values at the smaller-scale, some data will be constrained to agree with measured values at the larger scales.

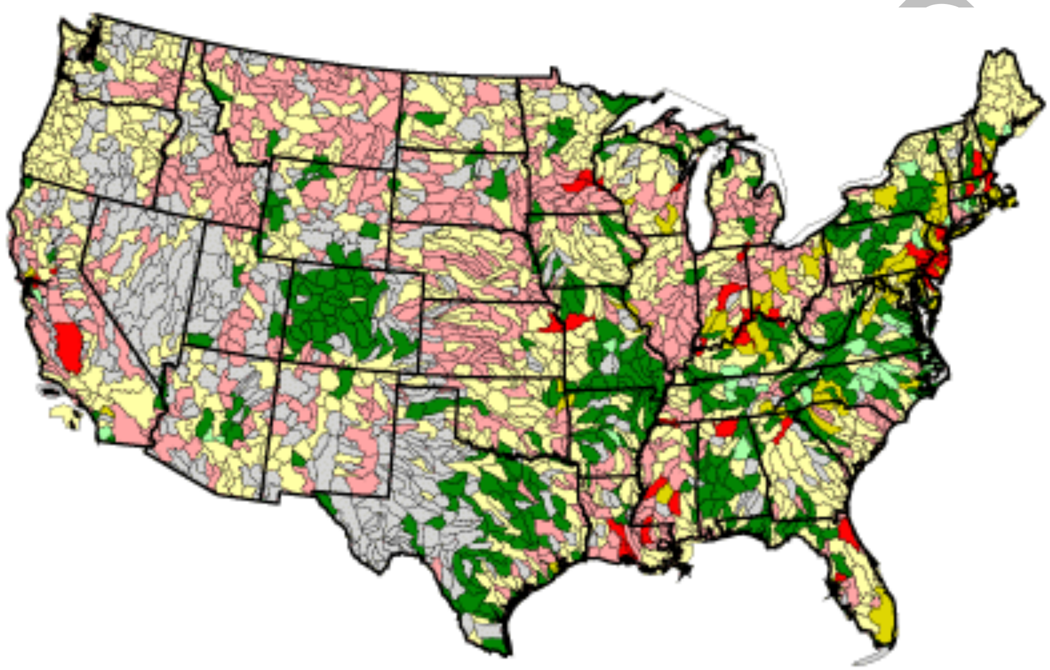

Figure 2. HUC-8 basins of the conterminous US

Temporal Scale

For purposes of the NWC, the long-term objective will be to provide measured or estimated information for all relevant water budget terms on a monthly basis. Some components of the water budget have a continuous time series of data, such as streamflow information from a surface water gaging station; others have a daily time record, such as gridded precipitation coverages from the National Weather Service. Many components of the water budget however, such as reported water use withdrawals and discharges, are not reported consistently across states. For water budget purposes, because of data constraints, we must use the longer, monthly time step in the calculations. Otherwise, we would be introducing significant uncertainty by disaggregating the monthly water use withdrawal and discharge information into daily values. Therefore, monthly water budgets will be the temporal scale used by the NWC until better data is available. In some states, annual water use data reporting is the best that is available at the present time; the USGS will be working with those states to improve the frequency of data collection as well as to develop technically defensible methods for disaggregating historical annual data.

In addition to the water budget analysis, there are other uses of continuous time series data and daily records that will be of use to NWC users. This includes measured or estimated streamflow information from gaged and ungaged basins for ecological flow analysis, interpretation of water quality information; daily precipitation and evapotranspiration records for climate analysis and flood studies; daily changes in surface storage for water supply management; etc. The NWC will provide, where available, these hydrologic indicators on a daily basis for those other uses.

Refining Components of the Water Budget

Information about most water-budget components is not available in a consistent form across the Nation; the goal of the NWC is to provide estimates of selected water-budget components at consistent spatial and temporal scales both nationally and regionally. Therefore, a major investment of the NWC will be focused on improving methods of estimating individual components of the water budget (surface water, groundwater, evapotranspiration, and water use) through a series of topical area studies.

Topical Studies – Improving Water Budget Components at the National Scale

NWC topical area studies will provide quantitative information about the amount of water that resides in, or is moving through, each water-budget component. 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. The following sections of this chapter provide more detail on the implementation of new or improved methods for calculating estimates of water budget components.

Surface Water

Estimates of daily streamflow time series is critical to any number of hydrological investigations. The USGS has developed hydrologic tools for evaluating conditions at existing gaging stations that provide estimates of flood, drought, and runoff (WaterWatch; *http://waterwatch. usgs.gov*) and streamflow statistics (StreamStats; *http://streamstats.usgs.gov*). The USGS streamgage network cannot provide direct observations of streamflow at every location of interest; improving estimates of streamflow at ungaged locations was identified as an area of need for the Ad Hoc Advisory Committee of the NWC. Specifically, estimates of daily streamflow at ungaged locations will be used to evaluate ecological flow needs, assess the effects of hydrologic alteration on ecological services, and understand the effects of climate and land use change on water resources.

The NWC aims to improve upon the information that is currently available for ungaged locations by providing estimates of daily streamflow for sub-watersheds nationally through a "point-and-click" Web application. The USGS will develop methods for estimating daily time series of natural flow at ungaged locations by assessing which models perform best in what parts of the country will be needed. The project will define and develop metrics for model comparison; evaluate competing models using established metrics; choose case study areas to apply the chosen methods; and, provide a description of a pilot delivery system. Flows will be generated for HUC-12 basins.

Model Comparison

Methods to estimate daily streamflow range from relatively simple statistical models that require few input parameters to complex process-based models. Each of these models offers their own respective advantages, uncertainties, and limitations; however, a rigorous comparison, and possible combination, of these methods across varying hydroclimatic regimes is needed. A comparison of streamflow estimates for a large-scale watershed will be made based on simulations from statistically based models (SBM), a water balance model (WBM), physically-based watershed models; and, a hybrid approach – combining monthly water balance models with statistical disaggregation.

Models will be evaluated by comparing calibration data sets, daily-time series at the validation basins, streamflow statistics at the validation basins performance criteria for (a) daily-time series of streamflow and (b) streamflow characteristics and (c) analysis of results and report(s). This framework will be used as a guide to evaluate and compare the SBM, WBM and physically-based watershed approaches to modeling streamflow in ungaged basins. Products resulting from this research include:

1. Guidance on the advantages/disadvantages/applicability of each method to estimate daily streamflow.
2. General approach to regionalizing WBM and physically-based watershed model parameters for ungaged basins across the US that combines both a priori information on model parameters and regional information on expected watershed dynamics.
3. A web-based portal that builds on USGS previous efforts to distribute results and relevant derivatives from this study.
4. Tools for defining hydrologic response units (HRUs) and calibrating large areas that could be extended across the Nation.

Statistically Based Models

Previously published statistically based models by Archfield and Vogel (2010) and Archfield et al. (2010) will be used to estimate daily streamflow time series at ungaged locations within the study basins. These methods scale streamflows from a gaged basin by some measureable characteristic or set of characteristics available at the ungaged basin. At least two such scaling methods – the drainage-area ratio (as applied by Archfield and Vogel, 2010) and the flow-duration curve/QPPQ transform method (as applied by Archfield et al., 2010) – will be developed for the study basins.

Index basins will be identified using the map correlation method (Archfield and Vogel, 2010), which identifies the index basin as the basin with streamflows most correlated with the ungaged basin. Alternative methods to select the donor basin, such a similarity among basin characteristics or hydrologically similar regions, will be used as a contingency for areas where the map correlation method may not perform as well as expected. In particular, basin attributes that explain cross-correlation between basins may be used as an alternative metric to select the donor basin.

Daily flows at ungaged sites will be estimated using three statistical models: 1) drainage area ratios, 2) QPPQ, and 3) UFINCH. Drainage area ratios are often used immediately upstream or downstream of gages to estimate streamflow time series or statistics. The method estimates flow at an ungaged site by multiplying flow at the gaged site by a ratio, determined based on the difference in drainage area for the two locations. It can be modified using a single regional regression equation to better account for scaling differences in watersheds of different sizes, in addition to being simple to use and effective just upstream and downstream of gages. The drainage area ratio method will be used to produce baseline estimates of daily flows.

QPPQ was originally developed by Fenessy (1994) and transfers information using flow duration curves. The flow duration curve is estimated at an ungaged site using a series of regional regression equations. Daily flows are estimated by assuming that on any day, the flow at the ungaged site is at the same flow duration as flow at an index gage. For example, during a low flow period the flow at an index site may be at the 90% flow duration level. QPPQ assumes that the ungaged site also has a flow value equal to the 90% flow duration.

UFINCH is a new statistical model being developed at the USGS Michigan Water Science Center. UFINCH is a drainage area ratio method that has been enhanced to route flows through a stream network by considering time of travel along NHD reaches.

Water Balance Models

The WBM analyzes the allocation of water among various components of the hydrologic system using a monthly accounting procedure based on the methodology originally presented by Thornthwaite (Thornthwaite, 1948; McCabe and Markstrom, 2007). The WBM will be partitioned into modeling units based on an aggregation of the NHDPlus catchments. Inputs to the model are mean monthly temperature, monthly total precipitation, and the latitude of the location of interest. The WBM produces 7 output variables: potential and actual evapotranspiration, soil moisture, snowpack water equivalent, snow melt, direct surface runoff, and total runoff.

Physically-based Watershed Models

Physically based rainfall runoff models simulate the processes involved in runoff generation. When run at daily or better timestep, the data requirements for these models can be considerable. In order to apply such models at ungaged sites, a regional calibration method must be used. Regional calibration requires gaged basins from which to transfer parameter values. Techniques include either direct transfer of parameters from similar basins, transfer based on regional relations for parameter values, or calibration to regionalized flow metrics.

There are many different rainfall-runoff models available. This effort will focus on the Precipitation Runoff Modeling System (PRMS) and Water Availability Tool for Environmental Resources (WATER derived from TOPMODEL) for early efforts.

Case Study Area Selection

Initially, model comparisons will be focused in the ACF Basin, one of the focal area study basins of the NWC. An effort will be made to work additional areas where one or more of these models already exist so that existing work can be leveraged. For example, the ACFB has been the focus of research for the last several years including the multidisciplinary USGS Flint Thrust project and the USGS National Climate Change and Wildlife Science Center Southeast Regional Assessment Project (Gregory and others, 2006; Hughes and others, 2007; Dalton and Jones 2010). Other considerations for choosing geographic areas for testing the models include gage density and ensuring that different hydroclimatic regions are represented.

Groundwater

The movement of water in the atmosphere and on the land surface (hydrologic cycle) is conceptually easier to visualize than the movement of groundwater. Aquifer systems are complex, three-dimensional geologic features that move and store water recharged from the land surface; they cover great distances, often do not conform to surface water divides, and may obtain most of their recharge at locations quite remote from where the water discharges to a stream, estuary, or well. Groundwater systems can be a perennial source of water supply to stream, lakes, and estuaries, therefore a direct influence on surface water and ecosystem health, and dynamic nature of the groundwater reservoir can also moderate the variability inherent in surface-water supplies.

Water budgets require improved understanding and measurement of changes in water entering, being stored, and leaving a system. Frequently, groundwater and surface water constitute a single resource (Winter and others, 1998), and should be studied and characterized at scales that make hydrologic sense (stream segment, watershed, basin, region).

Because of aquifer complexities, groundwater will be incorporated into the national water budget as part of the USGS Regional Aquifer Studies (RAS); however, focal area studies will produce more regionalized groundwater data for refinement of local water budgets. RAS will provide the information related to seasonal and long-term changes in storage and recharge, relative to the watershed of interest. For areas of the nation that have not yet been investigated by a RAS, different methods will have to be used for the estimates. If there is a groundwater observation well network in the watershed, the NWC will have access to data showing the trend in groundwater storage. Coupling this information with groundwater withdrawal data can provide an estimate of the terms for the water budget equation. One of the challenges of the final implementation plan for the NWC will be to develop a method for estimating groundwater terms for the water budget equation where there is no groundwater study. These methods will be documented and used to develop groundwater estimates for the NWC.

Evapotranspiration

Evapotranspiration (ET) is an essential component of water-budget, and a fundamental variable of water use, especially for irrigation, with important implications for administration of western 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. Progress has been made in meeting this challenge by using satellite imagery to make estimates of ET across the landscape. The USGS is applying its satellite remote-sensing resources and expertise to quantify ET for the Water Census. Specifically, the USGS will develop and improve methodologies to estimate ET monthly, seasonally, and annually at the basin scale for the conterminous US; cooperate with universities, states, and other federal agencies to develop specifications and guidelines for estimating crop ET in the West using remote sensing; and, assess field-scale remote sensing methods that are being used to evaluate water productivity by mapping crop yields and water use.

National Evapotranspiration Estimates

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. ET estimates are being made for monthly and seasonal totals across the continental U.S., initially at the HUC-8 level, and eventually at the HUC-12 level, covering the time period 2000-2012.

The Geographic Focus Area Study of the Colorado River Basin (CRB) provides the context for testing ET remote-sensing methods for eventual application across the western United States and the country as a whole. Building on the Landsat scale (100 m) full landscape annual ET estimates in the CRB for 2010, joint use of MODIS and Landsat will be used to disaggregate and produce monthly Landsat ET for the CRB. Furthermore, the Simplified Surface Energy Balance (SSEBop) model will be applied for the first time to land surface temperature data from Landsat 8 for 2013. Results are being compared with site-specific data from stations in the CRB to provide uncertainty estimates for the MODIS satellite approach.

Cropland Evapotranspiration

Water-use reporting requires estimates of ET at the scale of agricultural fields. An established ET remote-sensing community with a history of estimating crop water use with Landsat imagery already exists in the western US. In order to build on the experience and expertise of this community and reduce the potential for duplication of effort and disputes over differing methods and results, the USGS has entered into a partnership with Utah State University to develop specifications and guidelines for estimating crop ET in the West. The goal is to develop 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 the eastern US, the quantification of water use for supplemental irrigation is also being addressed with ET remote sensing. The Geographic Focus Area Studies of the Delaware River Basin (DRB) and Apalachicola-Chattahoochee-Flint River Basin (ACFB) provide a context for testing an approach in which satellite imagery is used. Application of the SSEBop at Landsat scale in the East will be done for the first time by modeling ET in the ACFB. This will provide estimates of gross ET on agricultural lands and supporting water balance calculations will make it possible to estimate the amount due to supplemental irrigation. This will be followed by an exploratory examination of supplemental irrigation in the southern part of the DRB, including parts of New Jersey and Delaware.

Water Productivity

The USGS is also assessing the applicability of ET remote sensing methods to evaluate irrigation water productivity. In the Central Valley of California, the USGS is developing and testing automated cropland classification algorithms (ACCA) for monthly estimation of growing season water productivity in cropland and fallowed land areas. ACCA derived monthly croplands will be compared with USDA NASS remote sensing derived cropland areas, as well as Farm Service Agency (FSA) farmer-reported cropped and fallow land areas.

Water Use studies will be supported by estimating the amount of cropland lying fallow each year. This is also an important variable for understanding the degree of impact of water shortages due to drought, and will contribute to the information assembled by the National Integrated Drought Information System (NIDIS). Water productivity will be evaluated using spectro-radiometer data and field biophysical data for five irrigated agricultural crops (wheat, rice, corn, cotton, and alfalfa). Fields will be analyzed to determine their crop water productivity and the development of:

- allometric equations between various crop biophysical parameters; and,
- spectro-biophysical models of the 5 crops. Spectral data will come from an ASD 400-2500 nm spectro-radiometer. Biophysical parameters include biomass, leaf area index, and percent cover.

Water Use Associated with Unconventional Oil and Gas Development

Over the last decade, development of energy resources related to unconventional oil and gas development has created an additional demand on water resources across the US. Of particular concern is the amount and source of fresh water required to extract these resources, the U.S. Environmental Protection Agency (EPA) estimates that hydraulic fracturing uses between 70 and 140 billion gallons of water each year (Kusnetz, 2012). The effects of this change in water-use patterns on the hydrologic cycle are unknown. Moreover, fresh water supplies are potentially affected during oil and gas extraction through spills and mishandling of produced waters (brines) and flowback water contaminated during well development. Energy development is expected to continue for the next 30 years, with a continual increase in the number of wells drilled and municipal populations, raising questions by local, state, tribal, and federal stakeholders as to the source and availability of water to meet this future demand, effects on downstream users, and the effects on the environment including the highly sensitive ecosystems.

This project will (1) obtain and analyze water use and treatment data for direct (e.g., hydraulic fracturing, borehole maintenance) and indirect uses of water (e.g., crew camps, road dust abatement) related to unconventional oil and gas development in the US, (2) develop water-use coefficients and consumptive-use coefficients for UOG processes, (3) project water use requirements and availability associated with future UOG development, and (4) quantify consumptive use associated with UOG water use and development.

Water use Associated With Energy Development

The UOG Topical Study will assemble water use estimates for the study area from previous national compilations. Estimate water use, for both direct and indirect uses, will be compiled annually. Direct water use and treatment processes are those processes that are directly related to energy extraction such as: drilling oil and gas wells, developing wells using hydraulic fracturing, withdrawal of oil, gas, and associated water (brine), treatment of water used in well development and flowback waters, maintenance of the borehole, and maintenance and operation of the surface well pad and equipment. Indirect water use and treatment processes are those processes that are not directly related to the energy extraction. Indirect water use processes include workforce residence, commercial support, and environmental requirements. Data collection for the workforce residence includes waste water treatment, septic systems, domestic self-supplied, public-supplied domestic, crew camps supplied by public supplies, crew camps supplied by self-supply, crew camps supplied by transported water. Commercial support includes municipal supply for such activities as laundries and restaurants. Environmental requirements include road dust abatement and car washes for noxious weed transport mitigation. Standardization of these data across state, tribal, and commercial boundaries is important and will require the voluntary participation of numerous private industries such as water depots, oil companies, and crew camp (a.k.a. man camp) operators.

Develop Water Use Coefficients for Energy-Development Processes and Water Use Modeling

Water use coefficients, similar to crop coefficients, will be computed for water use, both direct and indirect processes, associated with energy development. Statistical models will be developed to compute the water use coefficient as well as to evaluate coefficients' uncertainty and applicability. Generalized additive models for location, scale, and shape (Rigby and Stasinopoulos, 2005) will be used to model the probability distributions of the coefficients as a function of ancillary water-use data. Potential errors in water use estimates computed using statistical sampling methods will be incorporated in the model estimation and uncertainty analysis.

The uncertainty associated with each of the UOG water use coefficients will also be calculated. Uncertainty is primarily based on the variability within the process and available sample data. The uncertainty for each coefficient will be calculated using a combination of techniques to be developed during this investigation depending on the type of data and its underlying distributions. The applicability and limitations of these coefficients will be addressed based on the uncertainty and variability of the process. For example, water used for road dust abatement is directly related to climate factors such as wind speed, temperature, and humidity. For this analysis, the applicability and limitations of the water use coefficients will be qualified.

A water use model for unconventional oil and gas development will be developed that will enable resource managers to estimate water use based on projected development scenarios. The model will incorporate the water-use coefficients and will require the user to input the descriptors that are important for describing the development such as the number of wells and the increase in population.

Water use trends and availability associated with future UOG development

Over the past decade, the supply of water for energy development has not only been obtained from new wells and water depots, but has also come from the change in use of water previously used for irrigation or municipal supply. The nature of these changes in use has in some cases increased water use in these regions as irrigators and municipalities convert their water allotment or the unused portion of their allotment.

Trends in water use will be examined to determine the primary drivers of water use and the changes in water use magnitudes, conveyance, and treatment. The progression of water use associated with UOG is driven by the number and geographic progression of wells, requirements for road dust abatement, increasing populations, and increasing maintenance. Just as important are the factors facilitating water delivery or the factors limiting water delivery such as pipeline infrastructure, road traffic, tanker trucks, permitted and developed depots, water rights, and regulatory moratoriums. A trends analysis will include technical factors (geology, vertical versus horizontal boreholes, high rate versus high viscosity well development, borehole length, number of stages, etc.) as well as qualitative factors (infrastructure, regulatory, and market factors associated with water use).

Project water use requirements and availability associated with future UOG development

Three primary techniques will be used in conjunction to forecast future water use within the study area. The first technique is a water use and proppant use assessment approach developed as an extension of existing USGS petroleum-assessment methods (U.S. Geological Survey, 2007; Ferrero and others, 2013; Haines and others, 2014). The second technique was developed through the Wyoming Landscape Conservation Initiative to model land use/cover changes and determine areas with a high potential for development and those likely to remain undisturbed (Garman and McBeth, 2014). The model uses geospatial data of existing land cover, well pads, and roads along with current and future energy fields. Regulations for well spacing determine the simulated locations of future well pads, and the associated infrastructure. The advantage of this technique is that direct and indirect effects on wildlife and aquatic habitat for future development can be assessed using known disturbance effects for individual species and their habitat-pattern requirements (Preston and others, 2014). The third technique employs the use of groundwater models. With stakeholder involvement, water use scenarios will be developed to drive input routines for two USGS groundwater availability models: the Williston Basin model (i.e., WAPR; Long and others, 2014; Thamke and others, 2014) and the Williston Glacial Aquifer model. The models will be used to ascertain the effects of development on groundwater storage, water levels, and GW/SW interactions over the next two decades. Current and potential regulatory restrictions such as moratoriums on aquifer withdrawals will also be evaluated using the models. Changes in water use and/or water sources will also be included in the scenarios.

Quantifying consumptive use associated with UOG water use and development

Consumptive use will be calculated for each of the distinct water use processes associated with UOG development. Water used for energy development will be partitioned between evaporation, lost to the formation, disposed through injection, and returned to freshwater surface water bodies or aquifers. Consumptive use coefficients will be added to the UOG water use development model.

Water use coefficients will be calculated for each process based on data or field analysis. The current hypothesis is that almost all water directly involved with hydraulic fracturing is consumed. The indirect water-uses are more variable and may provide returns to freshwater sources (e.g., septic systems). Uncertainty estimates will be calculated for the coefficients based on the process variation and sample data.

Changes of use of water from irrigation and municipal supply to energy production will change the consumptive water use and fluxes within the hydrologic cycle such as irrigation return flows and septic system discharges. These flux changes will be estimated based on the consumptive use coefficients and regulated changes. Additionally land and associated water use change will be estimated using remote sensing.

Focus Area Studies: Integrating Indicators, Ecological Flow Needs, and Water Use at the Regional Scale

Competition for water resources is focused regionally where the demands of competing uses--whether for human needs (potable water, irrigation, energy development, industrial use, etc.) or flow requirements for healthy ecosystems--are a growing concern. As a counterpart to the topical studies, a series of regionally focused assessments (Geographic Focus Area studies) will refine the water budgets of large river basins by providing opportunities to test and improve approaches of water-availability assessments regionally as well as inform and "ground truth" the NWC with local information. The first three Geographic Focus Area studies in the Apalachicola-Chattahoochee-Flint, Colorado, and Delaware River Basins will be completed in 2015. Each basin is unique not only in its hydrogeological setting, but also in the pressures and demands on water resources in the basin for both human and ecological purposes. In fiscal year 2016, three more focal areas will begin further regional refinement of the national water budget: the Red River and Rio Grande basins and the Coastal Basins of the Carolinas (Fig. 3).

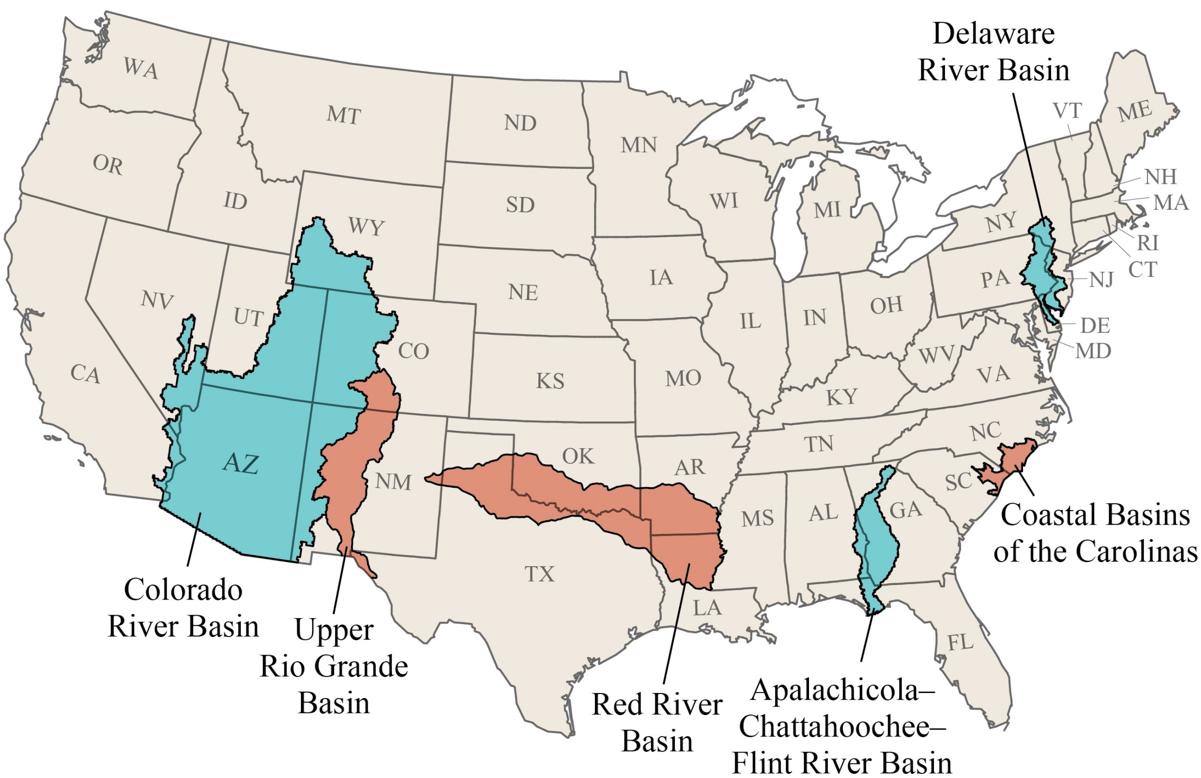

Figure 3. Focus Area Study Basins

Apalachicola-Chattahoochee-Flint River Basin

The Apalachicola–Chattahoochee–Flint River Basin (ACFB; Fig. 3) encompasses about 19,256 square miles (mi^2), mostly in western Georgia and parts of southeastern Alabama and northwestern Florida (Jones and Torak, 2006). In the northern part of the ACFB, surface water is the major water source, with Lake Lanier impounding a large percentage of the basin-wide available storage. Major water users include the city of Atlanta, as well as Gwinnett, DeKalb, Fulton, and Cobb Counties. In these four counties over 333 million gallons per day (MGD) was withdrawn during 2005, primarily for public supply. In the lower part of the basin, groundwater is the principal water source mainly irrigation pumpage in this heavily agricultural region. Nearly 780 mi^2 are irrigated with groundwater from about 4,000 wells completed in the Upper Floridan aquifer (Torak and Painter, 2006). During 2002, groundwater withdrawal from the Upper Floridan aquifer in the Flint River Basin averaged about 340 MGD (Hook and others, 2005). The principal rivers and tributaries in the lower basin drain karstic and fluvial plains and are hydraulically connected to the Upper Floridan aquifer one of the most productive carbonate aquifers in the United States. Because of the karst setting in much of this area, ground and surface waters are highly interconnected and pumping for irrigation directly impacts surface-water flows.

Previous research focused in the basin allows the NWC to build upon existing data and models recently developed as part of a USGS Science Thrust project (Gregory and others, 2006, Hughes and others, 2007), and the Southeast Regional Assessment Project (SERAP; Dalton and Jones 2010), which examined the potential effects of climate and land use change on streamflows and aquatic biota in the ACFB. Improving the science used for understanding potential effects of management actions on stream- and river-dependent biota is viewed as a key component to developing water management agreements that bridge multiple societal demands. Tools developed through research in the ACFB should also have broad relevance and applicability to environmental flow issues elsewhere.

Three science themes have been identified to improve technical understanding of the ACFB, (1) development of techniques to better estimate water withdrawal and consumptive use information (2), evaluation of surface-water and groundwater interactions, and (3) evaluating environmental flow requirements; including extinction/colonization dynamics of fishes/mussels, impacts of changes in flow regime, and water quality relations to ecology.

Water Use

Water use data will be compiled in coordination with the USGS NWUIP; however additional work will be done to meet the needs to the ACFB focus area study. Researchers will work to improve the information and data currently available on water withdrawals and return flows in the ACFB. This information will be utilized in both the surface and groundwater models being developed and updated as part of this study. Specifically, available water use data will be improved by:

- compiling all available water withdrawal and return flow data for 1999-2011 at the HUC-12 scale;
- estimating net water use by evaluating return flow; and,
- projecting future water use demands due to climate and land use change.

A major focus of the water use effort in the ACFB is the development of new technologies to improve agricultural irrigation estimates. Building on work being done in the Yazoo River Delta region of Arkansas and Mississippi by the USGS Eastern Geographic Science Center, satellite imagery will be used to develop maps of latent heat to identify irrigated areas. Additionally, as part of a cooperative program with the Georgia Soil and Water Commission, the Georgia Water Science Center is developing a statistical technique that estimates irrigation as a function of (1) the types of crops grown, (2) their respective irrigated acreages, and (3) weather conditions.

Surface-Water/Groundwater Interactions

Existing surface and groundwater models will be enhanced and modified, and eventually linked, to evaluate surface and groundwater interactions in the basin. This coupled approach will refine estimations of water budget components and water availability, while also providing streamflow data for the environmental flows section of the study. Estimations of surface and groundwater flow data will be improved by:

- simulating land-surface hydrologic processes, including evapotranspiration, runoff, infiltration, interflow, snowpack, and soil moisture on the basis of distributed climate information (temperature, precipitation, and solar radiation) by refining an existing Precipitation Runoff Modeling System (PRMS) for the entire ACFB;
- updating an existing steady-state groundwater flow model and calibrating to transient conditions, where the Floridan aquifer provides a significant portion of river discharge, the lower ACFB;
- linking surface and ground water models and using the linked model to estimate future flow conditions in the basin in response to changing climatic and water use demands;
- calculating water budgets at the HUC-12 scale with temporal scales ranging from days to centuries; and,
- creating a modular design that allows the selection of alternative hydrologic-process algorithms from either the standard module library or user-provided provisional modules and integration with models used for natural-resource management or other scientific disciplines.

Environmental Flows

In the ACFB ecological responses to selected biological processes (survival, reproduction and colonization) that drive population dynamics in stream ecosystems will be evaluated in response to modeled changes in streamflow regimes and water quality. Key to understanding these processes will be the evaluation of alternative hypotheses regarding the effects of high and low streamflows, or stable and variable streamflows, on stream biota. Specifically researchers will incorporate newly collected data and data provided by enhancements made to the surface and groundwater models, including improved water use data, to:

- evaluate hypotheses concerning effects of changing streamflow conditions on fish and mussel populations, using existing and newly collected data for the multiple physiographic regions of the ACFB at the HUC-12 scale; and
- evaluate new approaches for integrating effects of variation in water quality into models of ecological response to hydrologic alteration using data collected that advances current understanding based on correlations between water quality and biological condition.

Colorado River Basin

The Colorado River is a critical water supply for much of the Southwestern United States; supplying water to more than 25 million people and irrigating more than 3 million acres of cropland across seven "basin states." Increasing population, decreasing streamflows, and the uncertain effects of a changing climate urge a better understanding of water use and water availability in the Colorado River Basin (CRB; Fig. 3).

In consultation with basin stakeholders, the USGS has identified three water-budget components where understanding could be improved: (1) current water use—in particular the "consumptive" use of water; (2) regional and field scale assessments of water losses from evapotranspiration and snowpack sublimation; and (3) groundwater discharge to streams, and the relative importance of the regional groundwater flow system in annual streamflow volumes. Better quantification of these components of the basin water budget will contribute to the overall assessment of water availability in the CRB, thereby complementing ongoing work by other agencies.

Estimating Water Use

The CRB is a region where future projections of water demand along the river outpace the limited and potentially declining surface-water supply (Colorado River Basin Water Supply and Demand Study Team, 2011). Water use data will be compiled in coordination with the USGS NWUIP; however additional work will be done to meet the needs to the CRB focus area study; for example, improving regional databases; advancing new data collection technologies and methods; promoting cooperation between federal, state, and local partners; and, integrating these efforts to enhance the understanding of water use impacts on ecological flows. These objectives will be accomplished using the following approaches:

1. Regional databases will be coordinated with the USGS 2010 water-use compilation, which compiles county-based annual withdrawals by source for major and minor categories of use. Data will be reaggregated at the HUC-8 level.
2. A site-specific public-supply database (SWUDS; Site-Specific Water Use Database System) will be built that populates wells and surface water intakes, including diversions and estimates of population served by system, transfers, or sales between systems. Withdrawals will be reported monthly as available, by source.
3. Incorporation of site-specific return flows (discharge) from municipal and industrial facilities to surface-water bodies to help compute consumptive use for those sectors.
4. Map points of diversion on the National Hydrologic Dataset-Plus (NHDPlus) within these sub-basins for Public Supply, Irrigation, and Thermoelectric water uses.
5. Develop interactive web-based data delivery tool, based on StreamStats technology, or other proven Decision Support Systems, that will allow for analysis of user-defined estimates of water use and water budget information that are aggregated upstream from any stream point within the sub-basin.
6. Use remote sensing technology to estimate evapotranspiration and consumptive use for cropland in particular, but include other vegetated lands as well.
7. Integrate water-use data with web-based enhance stream-flow statistics (e.g. StreamStats) to support site specific user-defined water-budget calculations in gaged and ungaged basins. Raw data sets (within parameters of Homeland Security and USGS, USEPA security protocols) will also be made available for download.

Estimating snowpack water content and sublimation for the Colorado River Basin

Snow accumulation in higher elevation settings of the western US is an integral component of the western regional water budget. In the mountains of the western US, seasonal snowpacks act as a large natural water-storage “reservoir” providing, on average, 70 to 80% of annual surface-water runoff (Doesken and Judson, 1996). In the upper CRB the percentage is even higher, with 85% of streamflow derived from snow melt (Edwards and Redmond, 2005). The quantity of water stored in seasonal snowpacks is expressed as the snow water equivalent (SWE). Springtime SWE is one of the most important inputs to hydrologic models used to forecast runoff in the western US because it is the main source of water to streams during late spring and early summer (Clark and Hay, 2004; Slater and Clark, 2006). Snowpack sublimation, which is analogous to evaporation from land surfaces or water bodies, represents an important, but poorly quantified, loss of water from the snowpack (Hood et al., 1999). Sublimation represents one of the major uncertainties in runoff forecast models, and is thought to be particularly important during drought years, when water is scarce.

Researchers in the CRB focus area study will develop regional SWE and sublimation estimates using moderate- and high-resolution gridded models and ground-based validation measurements to inform hydrologic modeling studies, water availability studies, and water use assessments by:

- Estimating snowpack SWE and sublimation for the CRB based on NOAA's moderate-resolution (1-km) SNOw Data ASsimilation (SNODAS) model. Results will be provided for each 8-digit HUC in the CRB at monthly, seasonal, and annual time scales for the period of record (2004 to present).
- Estimating snowpack SWE and sublimation in select areas using a high-resolution (≤0.1 km) snowpack modeling system called SnowModel at monthly, seasonal, and annual time scales. Results will be compared to those from SNODAS. SnowModel study areas will be co-located with historical or ongoing ground-based measurements to allow model validation.
- Evaluating the accuracy of SNODAS and SnowModel results by comparing them to ground-based measurements of SWE and sublimation.
- Evaluating strengths and weaknesses of the moderate- and high-resolution snowpack models, and identifying which would be most appropriate for estimating SWE and sublimation at various basin scales.

Groundwater Discharge to Streams in the Upper Colorado River Basin

Groundwater is an important resource influencing water availability in the CRB; users in many parts of the basin depend on groundwater for water supply because aquifers are more widely distributed and readily available than surface water. Compared to surface water, however, groundwater storage and flow are often difficult to measure, making it difficult to adequately address groundwater as part of the overall water budget. The rate and spatial distribution of aquifer recharge, discharge, and use, in particular, are critical for understanding long-term water availability in the basin.

Groundwater flow paths and residence times provide important information about vulnerability of water resources to natural and anthropogenic changes in the CRB. For example, local groundwater flow systems are generally more susceptible to drought and/or groundwater pumping and water-quality impacts related to changing surface conditions and human activities (Tetzlaff and Soulsby, 2008; Gardner and others, 2011). Surface-water supplies, for the most part, are fully allocated in the CRB, which may lead to increased development groundwater resources in the future. Groundwater development has the potential to affect the groundwater and surface water dynamics, potentially decreasing surface-water base-flow during dry periods, putting additional pressure on an already stressed resource.

In the CRB, to better understand the interaction of ground and surface water resources in the basin, the NWC will quantify and assess the spatial distribution of groundwater discharge to streams and watersheds by: 1) developing estimates of the volume of groundwater discharge to watersheds in the CRB and estimate the total groundwater fraction of streamflow spatially and temporally; 2) identifying where and from what aquifers groundwater is discharged to streams in the CRB; 3) determining relative age, residence time, and flow paths of groundwater discharging to watersheds in the CRB; and, 4) classifying and mapping watersheds that will be most affected by changes in groundwater discharge due to anthropogenic and natural change. Results can be use by water-resource managers to assess the vulnerability of water resources in watersheds to short-term and long-term climate changes. These results will also have important implications for managing and maintaining aquatic and riparian ecosystems and the prediction of how these systems will respond to drought and climate change.

Researchers in the CRB focus area study will use a hierarchical, nested approach applying multiple techniques and tracers to estimate groundwater discharge to watersheds by focusing on the following set of tasks:

1. Analyzing annual hydrographs by several different methods [ex., Institute of Hydrology (1980), Rutledge, (1998) and Gardner and others (2011)] to estimate groundwater discharge to streams. These results will be compared with estimates of recharge and runoff produced with regional models as well as national estimates of base flow (Wolock, 2003; Rosenberry, 2008).
2. Estimating surface-water storage for each watershed. Surface water storage and diversions can affect the results of hydrograph analysis and these effects will require the scaling of the results.
3. Classifying watersheds using streamflow metrics (ex., mean daily peak flow to low flow ratio) to compare to estimated groundwater discharge within the basin. A 1-dimensional model of advective transport will be used to estimate the proportion of groundwater in the river and to determine groundwater flow paths discharging to the river. Modeling results will delineate the proportion of groundwater discharge from local and regional groundwater flow paths.
4. Groundwater discharge estimates based on hydrograph separation and modeling will be compared to field measurements in the basin (for example Rush and others, 1982; Ruddy, 2010). This comparison will produce a likely range of estimated groundwater discharge and uncertainty.
5. Finally, watersheds in the CRB will be classified by volume of groundwater discharge, source of groundwater and the flow path along which groundwater moves to streams.

Delaware River Basin

The Delaware River basin (DRB) covers approximately 13,500 square miles in parts of four states (New York, New Jersey, Pennsylvania, and Delaware; Fig. 3) with a population of approximately 7.3 million people; however, the water resources of the DRB provide all or part of the water supply for almost 16 million people. Groundwater and surface-water are used to various extents to meet human and ecological demands for water across the Delaware River Basin. The Upper Region and Bay Region are dependent on groundwater for public supply and self-supplied domestic use (Delaware River Basin Commission, 2008). In comparison, the Central Region and Upper and Lower Estuary watersheds of the Lower Region are more dependent upon surface water for drinking water. Not all of the water that originates within the DRB is used within the Basin; a large volume of water is exported to New York City through three reservoirs in the upper basin (up to 800 MGD) and to northern New Jersey water purveyors through the Delaware and Raritan Canal in central New Jersey (100 MGD). Water released from the upper basin reservoirs is used to maintain adequate downstream flows, stream temperatures, estuary salinity, and ecological conditions.

Potentially excessive withdrawals of groundwater to meet growing demands have already created water supply problems in southeastern Pennsylvania, south-central New Jersey, and northern Delaware communities. This has resulted in regulatory action and more efficient use of water, such as conjunctive management of supplies. Additionally, water-supply concerns have emerged as a result of (1) growing populations in the Pocono and selected Delaware Bay watersheds, (2) proposed energy-production activities in groundwater dependent watersheds, (3) the possibility of growth in the thermoelectric and irrigation sectors, and (4) the yet-uncertain instream needs of aquatic ecosystems.

There are many important stakeholder groups in the basin; one of these is the Delaware River Basin Commission (DRBC). The DRBC was established in 1961 to manage a river system without regard to political boundaries and includes representatives of each state and the Federal Government. Historically, water resources in the DRB have been allocated by two Supreme Court decrees and the DRBC, which works to manage the water resources within the basin and address the needs of a very large and diverse group of basin stakeholders. The information, databases, and products developed as a part of the DRB focus area study will contribute significantly to the information needs of the DRBC strategy.

The primary goal for the DRB focus area study is to provide the science information and tools necessary for water-resource managers and stakeholders to evaluate water availability and use in the DRB. With input from over 60 stakeholder groups, including federal, state, and local governments, NGO's, and academia the following objectives were identified as priorities for the DRB focus area study:

- acquisition, management, and integration of water-use and water-supply data;
- development of ecological-flow science including enhancement of the existing Decision Support System for parts of the Delaware River as well as development of a streamflow estimation tool for ungaged sites similar to the Massachusetts Sustainable Yield Estimator (Archfield and others, 2010); and,
- development of a hydrologic watershed model to evaluate water stressors such as growth of population centers, the effects of land-use change, and the effects of climate variability and climate change on water resources in the basin.

Acquisition, management, and integration of water-use and water-supply data

Water-use data compilation work will be coordinated with on-going efforts of the USGS NWUIP; however, additional work will be required to meet the data needs of the DRB Focus Area study. Specifically, objectives for the water use component of the DRB focus area study include:

- compiling a uniform set of 2010 water-use data at the HUC-12 scale including monthly estimates for public supply (including estimation of domestic deliveries), self-supplied industrial, hydroelectric, self-supplied domestic, and irrigation uses, as well as site-specific estimates for thermoelectric and return flow sites;
- developing a method to disaggregate county-level estimates of water use for aquaculture, livestock, and mining to the HUC-12 scale;
- develop consistent methodologies for estimating consumptive use for the categories of public supply, self-supplied domestic, irrigation, livestock, aquaculture, self-supplied industry, and thermoelectric within the DRB.

Development of Ecological-Flow Science

Stakeholders in the DRB identified the need to develop ecological flow science that examines the response of aquatic assemblages (and their ecological structure and functions) to hydrologic alteration (changes in magnitude, duration, frequency, timing and rate of change) in the basin and will assist water managers in developing environmental flow standards for the DRB. Previous efforts to develop ecological flow science individually for the four states within the DRB (New Jersey, Pennsylvania, New York, and Delaware) have been initiated with varying degrees of completion and complexity. This objective is composed of two tasks--ecological flow in the mainstem of the Delaware River and ecological flow in the tributaries--and will develop tools that can be used by water-resource managers and policy makers to better manage the waterways within the DRB and ensure that ecological needs are met while balancing ever-growing human demands for water.

Ecological flow in the mainstem of the Delaware will be evaluated by enhancing a previously developed Decision Support System (DSS; Bovee and others, 2007), an Excel-based program that used flow and temperature input from the DRBCs Operational Analysis and Simulation System (OASIS) and the USGS Stream Network Temperature model (SNTEMP) to develop flow-habitat relationships for a subset of biota. In cooperation with USGS Biological Resources Division Fisheries Program the DRB focus area study will improve the existing DSS because it can be difficult to operate, lacks transparency, has limited meteorological data, and has questionable projections for immobile benthic organisms such as freshwater mussels. Specifically, researchers will:

- extend the aerial coverage of the DSS by partnering with the USGS Coastal and Marine Geology Program to acquire bathymetric LiDAR imagery. LiDAR will be used to generate a bed file for 2-D hydrodynamic modeling which will provide pixelresolution estimates of key hydrologic variables for a variety of flow scenarios (extreme low flow to extreme high flow);

- update habitat suitability models and include additional species of interest into the DSS by completing an exhaustive literature review and laboratory experiments
- improve overall functioning/usability of the DSS by improving and testing the predictive accuracy of the temperature model while extending the meteorological database record and developing deliver a desktop application which provides a user friendly interface.

Development of a Hydrologic Watershed Model to Evaluate Water Stressors

Multiple stressors affecting water resources in the DRB (ex. population growth, land use and climate change, water quality, etc.) will be evaluated by use of watershed or hydrologic models. Researchers will create a surface-water hydrologic model of the DRB based on the modeling software, Water Availability Tool for Environmental Resources (WATER; Williamson and others, 2009) that covers the entire non-tidal DRB and will be statistically validated for the period 2000-present. WATER will evaluate the potential impacts of water use, reservoir operation, and climate land use and populations changes. Specifically WATER will be used to

- simulate streamflow at a daily time step; simulations will be available for any location on the stream network, simulations will include New York City and downstate reservoirs;
- evaluate water use and water availability for individual basins based on a water budget approach, including the effects of changing climate and populations on water demands;
- assess effects of land-use changes and increase in impervious area on surface-water runoff and groundwater recharge and storage; and
- interface with existing operational models (NYC OST and DRBC OASIS) provide a GUI for user interaction and output analyses

Uncertainty

Uncertainty is an inherent factor in hydrologic data collection, estimation techniques, and simulation (modeling). Errors associated with measurement techniques arise from the inability of data-collection networks to fully characterize the natural spatial and temporal variability associated 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 in water budget components specifically may arise from several sources: measurement error, estimation uncertainty caused by the use of either statistical or process-based models at unmeasured locations, and uncertainty arising from inadequate understanding of how water is used to derive goods and services. Projections of future conditions through either statistical or process-based models are inherently uncertain.

The NWC will seek to quantify and communicate uncertainty in water budget components and will support the development of techniques and methods to improve our ability to quantify uncertainty and to effectively communicate this uncertainty. The NWC 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.

Water Use and Availability for Human and Ecological Needs

Water-use information complements the study of surface-water and groundwater availability, and is essential to understanding how future water demands will be met while maintaining adequate water quality and quantities for human and eco-system needs. Water supplies and their uses are affected by factors such as demographics, economic trends, legal decisions, and climatic fluctuations. Sources include surface and groundwater, both fresh and saline. Categories of water use include public supply, domestic, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric power. Historically, “uses” were limited to the “human uses” of water and focused solely on human needs. More recently, the focus has changed to include the ecological uses for water. Practitioners today have a need to assess ecological uses and the environmental flows required to maintain those uses, and prevent degradation of freshwater ecosystems.

Changes in technology, demand, and economic conditions have affected irrigation, industrial, and thermoelectric power water uses and spurred interest in water reuse and reclamation. Additionally, regulations of surface water quality and quantity for ecological purposes has led to a reduction of withdrawals for some thermoelectric and industrial facilities. Limitations on water supplies have led to the use of less water-intensive cooling technologies for producing thermoelectric power in newer plants. Climatic fluctuations have a prominent effect on water availability and withdrawals, particularly those for irrigation, thermoelectric power generation, and public supply. Changes in temperature and precipitation, along with periodic droughts reduces the amount of water available for local and regional water supplies and increases the competition and demand among both human and ecological water users. An important component of the NWC is developing a better understanding of the quality, quantity, and timing of surface and groundwater availability for both human and ecological uses.

Human Water Use

The USGS National Water Use Information program (NWUIP) estimates total water withdrawals in the US, every five-years, for eight categories of use: public supply, domestic, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric-power generation (Kenny and others, 2009). Thermoelectric power is historically the largest category of water use, followed by irrigation and public supply; the remaining categories combine for about 10 percent of total water withdrawals. As part of the NWC, USGS researchers will focus on improving the information available on the largest water use categories: thermoelectric, public supply, and irrigation. Estimates of water use for thermoelectric sources will be improved by developing new methods that improve the accuracy of location and use information; public supply estimates will be improved by developing a site-specific database for reporting data; and, irrigation estimates will be improved regionally by developing techniques based on local irrigation methods.

Thermoelectric Water Withdrawals

Population growth and the accompanying increases in the demand for energy for residential, commercial, and industrial uses in the United States have raised public awareness regarding the availability of water resources to support additional power generation. Thermoelectric water use has been the category with the largest water withdrawals since 1965, and in 2005 made up 49 percent of the total freshwater and saline water withdrawals, and more than half of fresh surface-water withdrawals. The future health and welfare of the Nation's population is dependent upon a continuing supply of uncontaminated fresh water. Increasing withdrawals and increasing demands for instream flows are limiting the water available for future use. Accurate location data for power plants are needed to integrate water supply and water use data to better quantify the stress on existing supplies and to better model and evaluate possible water-supply management options to supplement traditional water-supply approaches. The results of such efforts provide benefits to our Nation's sustainable health, welfare, and prosperity. The locations verified and rectified as part of this study are an integral part of the nationwide assessment of water supply and demand.

The Department of Energy (DOE)-Energy Information Administration (EIA) needs timely and accurate location information and more comprehensive and consistent estimates to better inform public policy for thermoelectric plants to meet internal agency objectives. Several agencies store power plant location information in electronic databases. In 2010, early USGS database evaluations indicated that of the multiple databases, only one database included latitude/longitude coordinates for each power plant; no one database encompassed all available power plant location data; and, concluded that a coordinated, interagency effort would be needed to reconcile location disparities. The purpose of the study is to rectify and verify the geo-coordinates for power plants 1 megawatt and greater stored in the DOE-EIA electricity database. The data and database research component includes many elements that can be grouped into three general areas: data analysis and correction, database development, and trend analysis; more specifically researchers will:

1. identify inconsistencies in existing thermoelectric databases and rectify errors;
2. develop a complete list of thermoelectric power plants, organized by technology, and incorporated into a USGS database designed to facilitate analysis of thermoelectric water use; and,
3. analyze water use data for trends and correlated economic and environmental variables from about 1975 to the present.

Thermoelectric water withdrawals and consumptive use

Consumptive water use also can be regarded as an outflow, or loss to the hydrologic system (water budget). The most recent estimates of consumptive water use were made by the USGS in 1995, and were estimated to be about 3 percent of the total water withdrawals. Although a small percentage of the thermoelectric withdrawals, consumptive is still an important part of the water budget. Along with the concern of increased energy production and the impact of increased water withdrawals and consumptive use on hydrologic systems, there questions about the quality of the reported data on which the projections for freshwater demand of the thermoelectric industry were based.

An analysis by the USGS and other researchers of plant-operator reported water withdrawals and consumptive use to the DOE-EIA has shown that some reported values are outside a thermodynamically possible range. To improve the estimate of water withdrawals and consumptive use, the USGS developed methods for estimating consumptive use and withdrawals based on plant characteristics, fuel-types, and power generation. These estimates should result in a more defensible accounting of the anthropomorphic outflows in a water budget. Return flow is estimated by subtracting consumptive use from water withdrawals. The specific tasks associated with developing a new method to estimate thermoelectric water withdrawals consumptive use fall into three components:

1. Empirical heat-water budgets:
   a. acquire published power plant heat and water budgets as part of literature review; determine if existing private, TVA, and unpublished EPRI heat and water budgets are available; and,
   b. develop detailed heat/water budgets calibrated on data from existing plants, in partnership with other federal agencies.
2. Heat-water budget model:
   a. construct simple heat/water budget models for the existing range of thermoelectric technology;
   b. describe supporting data needs; define data availability and needs for compilation, analysis, and delivery in a form usable for nationwide thermoelectric water consumption;
   c. obtain available databases from which needed supporting data can be extracted on a site-by-site basis. Collect supporting environmental data: monthly average water temperatures, wind speeds, air temperatures and relative humidity; and,
   d. test methods on existing thermoelectric plants representing a range of technologies.
3. Basin application of heat/water budget model:
   a. test and de-bug budget approach for thermoelectric plants in the ACFB, revising method as needed;
   b. produce basin-wide estimates of consumption for the ACFB, CRB, and DRB; and,
   c. produce consumption estimates for selected example thermoelectric plants in additional candidate basins suitable for focused study, example basins include the Delaware, Alabama-Coosa-Tallapoosa, Susquehanna and Potomac, and an additional basin to be selected in the Great Lakes basin.

Public Supply Water Withdrawals

Public supply is defined as water withdrawn by public and private water suppliers that furnish water to at least 25 people or have a minimum of 15 connections. Public suppliers provide water for a variety of uses, such as domestic, commercial, industrial, thermoelectric-power, and public water use. In 2005, public supply accounted for 13 percent of all freshwater withdrawals in 2005 and 21 percent of all freshwater withdrawals excluding thermoelectric withdrawals. The percentage of the U.S. population obtaining drinking water from public suppliers has increased steadily from 62 percent in 1950 to 86 percent in 2005.

In cooperation with the USGS NWUIP, the NWC has begun an effort to store site-specific water-use data in NWIS to support the aggregated values in the 2010 'Estimated Use of Water in the United States' Compilation by developing a nationwide database of withdrawal locations and associated water use that is as comprehensive as possible (SWUDS; Site-specific Water-Use Data System). The goal is to produce a database that is as comprehensive as possible of withdrawal locations and associated water use; including the location and withdrawal information associated with 117,000 wells and 7,000 surface-water intakes sites in NWIS and entered into SWUDS. Specific tasks associated with this effort include:

1. Developing lists of public supply systems, associated withdrawal sites (wells and surface-water intakes), associated data such as permit numbers, and 2010 population served. Note that 2010 water withdrawals will not be provided.
2. Surveying available site-specific data for public supply by State, including cooperator files, data used in previous water-use compilations, etc.
3. Review site information (surface water intakes, wells if using a local data source) and ensure that there is no duplication with NWIS site files.
4. Decide on the SWUDS data model by State.
5. Create groundwater and surface-water withdrawal sites, associated distribution system sites, conveyances, and other database structures to create the public suppliers in SWUDS.
6. When public supply data has been collected for the 2010 water-use compilation, input the data into the SWUDS database.

Irrigation Withdrawals

New techniques are being investigated that may improve irrigation estimates, especially in areas where there is little to no irrigation data available. Because of regional, and even field levels variations in irrigation, these techniques are being investigated at the basin scale, generally as part of NWC ACFB Focal Area Study. Two techniques are being investigated: using satellite imagery to estimate irrigation water use and estimating irrigation as a function of crops type, irrigated acreages, and weather.

In the ACFB, following prototype work currently being conducted in the Yazoo River Delta region of Arkansas and Mississippi by the USGS Eastern Geographic Science Center, maps of latent heat (LE) created from moderate spatial resolution satellite imagery using variations on Crop Water Stress Index (CWSI) approaches (for example, Kustas and others, 1994) will be statistically analyzed to identify irrigated lands and estimate water use through irrigation. CWSI approaches have the advantage that they require little meteorological data and are relatively simple to estimate (as opposed to energy balance approaches) such as Surface

Energy Balance Algorithm for Land (SEBAL; Bastiaanseen and others, 1998) or Mapping Evapotranspiration at high Resolution and with Internalized Calibration (METRIC; Allen and others, 2005). This approach has the following subtasks:

1. Partition GaMP irrigation data into algorithm development and algorithm evaluation subsets through stratified random sampling followed by evaluation dataset quality assessment.
2. Construct a calibrated moderate-resolution satellite database that corresponds to the time frame of the algorithm development data subset for the targeted study areas.
3. Model LE using project developed software.
4. Generate LE estimates for calibrated satellite image dates.
5. Develop statistical relationships (e.g., regressions) among GaMP data and satellite-data.
6. Map irrigated lands based on statistical relationships and evaluate map accuracy using algorithm evaluation data subset.
7. Combine irrigated land map data and LE simulations to estimate total water use for irrigation.

Another technique for estimating agricultural irrigation withdrawals in the ACFB is based on the assumption that actual withdrawals are directly proportional to irrigation demands. Irrigation demands are estimated as a function of (1) the types of crops grown, (2) their respective irrigated acreages, and (3) weather conditions. Irrigation demand estimates for these three basic categories of data can be compared with reported data to assess the accuracy of the estimated demands, including the potential for the presence of bias in the estimates. This approach has the benefit of using readily available, spatially distributed data that could be used to estimate reference crop ET as well as the demands of individual crops as far back as the late 1800's. This could be especially useful for developing the datasets necessary for model simulations of historical conditions or the range of conditions that might be experienced in the future.

National Water Use and Availability Compilations

Two national efforts laid the groundwork for the USGS NWC; the first was a systematic, if rudimentary, national effort titled "*The Nation's Water Resources*" released in 1968 by the U.S. Water Resources Council. Prompted by the Water Resources Planning Act of 1965, this report assesses national water supplies for the first time as part of an effort to regionally assess the adequacy of existing supplies and anticipate future shortcomings. Organized by 20 water resource regions, similar to those still used today, the report provides information on available water supplies for a planning horizon to the year 2020, uses economic indicators as a means to help assess which regions are likely to have long-term water supply problems, and outlines potential future water resource issues for each region. The report was designed to support federal policy analysis and was the first step towards recognizing the long-term value of water use and availability data for the Nation.

A decade later the Council released a more comprehensive report titled "*The Nation's Water Resources 1975-2000*". The Second National Water Assessment provides a comprehensive evaluation of national water requirements (current and projected); potential conflicts that may arise in meeting projected water demands regionally; and an identification of the Nation’s most serious water resources problems.

Every five years, since 1950, the USGS compiles, reports, and publishes county level water use data (http://water.usgs.gov/watuse/50years.html). The USGS NWUIP is responsible for the production of these reports and cooperates with local, State, and Federal environmental agencies to collect water-use information. USGS compiles these data to produce water-use information aggregated at the county, state, and national levels. Data published in these reports can be used to indicate changes in water use over time, among different geographic areas, and from different sources. Water-use information complements the study of surface-water and groundwater availability, and is essential to understanding how future water demands will be met while maintaining adequate water quality and quantities for human and ecosystem needs. In the most recent National report, 2005, water use was reported for eight categories of use: public supply, domestic, irrigation, livestock, aquaculture, industrial, mining, and thermoelectric power. Over the history of these national reports, water use categories have changed (http://water.usgs.gov/watuse/WU-Category-Changes.html). The USGS series of 5-year national water-use estimates serves as one of the few sources of information about regional and national trends in water withdrawals and are available online at http://water.usgs.gov/watuse/. County-level data for all published categories of use for the years 1985, 1990, 1995, 2000, and 2005 may also be downloaded from this site.

Occasionally water use related topics evolve that requires special attention from the NWUIP. In 2000, the NWUIP refined water withdrawal estimates from the 66 principal aquifers that are commonly used as a waters source in the US (Maupin and Barber, 2005). As part of the NWC, the NWUIP is conducting studies to evaluate thermoelectric and consumptive water use and new techniques to estimate irrigation. In 2011, Dickens and others evaluated the impact of important considerations when estimating irrigated acreage and irrigation withdrawals, including estimates of conveyance loss, irrigation-system efficiencies, pasture, horticulture, golf courses, and double cropping. Additionally, many Water Science Centers have active water use programs in cooperation with State partners. Sometimes these programs are specific, for example the Georgia WSC has an active program to evaluate irrigation water use in the ACFB; in most cases these programs look to build upon the national efforts and provide more detailed data locally (Wisconsin WSC; http://wi.water.usgs.gov/data/wateruse.html#reports).

Measured and Estimated Water Use Trends

Water-withdrawal peaked between 1975 and 1980 (Fig. 4), when thermoelectric-power generation and irrigation water use were at their greatest. Irrigation withdrawals generally have declined since 1980 even though the amount of irrigated acreage has increased. Irrigation practices and crop types have changed with time, technology, and the economy, and the increased costs due to reductions in water availability have led to the use of more efficient irrigation methods. In other areas, increases in both water use and irrigated acreage have occurred because of water availability, demand for certain crops, and the desire to improve crop yield by using irrigation to supplement rainfall.

Thermoelectric power withdrawals declined sharply in 1985 but have been increasing since and regained the 1975 level of withdrawal again in 2005. Thermoelectric power has been the category with the largest water withdrawals since 1965, and for 2005 made up 49 percent of total withdrawals. Thermoelectric-power water withdrawals have been affected by limited water availability in some areas of the United States, and also by sections of the Clean Water Act (Amendments to the 1972 Federal Water Pollution Control Act) that regulate cooling system thermal discharges and mandate the use of best available technology for minimizing environmental effects of cooling water intakes (Michelletti and Burns, 2002). Consequently, since the 1970s, power plants have increasingly been built with or converted to recirculating cooling instead of using once-through cooling systems. Use of recirculation water for cooling reduces the intake water requirement at a power plant, resulting in reduced water withdrawals.

Withdrawals for public supply have increased steadily since 1950 as the population served by public-supply systems has grown, as have domestic withdrawals that balanced or made up for declines in self-supplied population water use. Self-supplied industrial water use is the only category that has declined consistently since 1985 when the category was first compiled separately from the commercial, mining, and aquaculture categories. Industrial withdrawals in 2005 were almost 8 percent lower than in 2000.

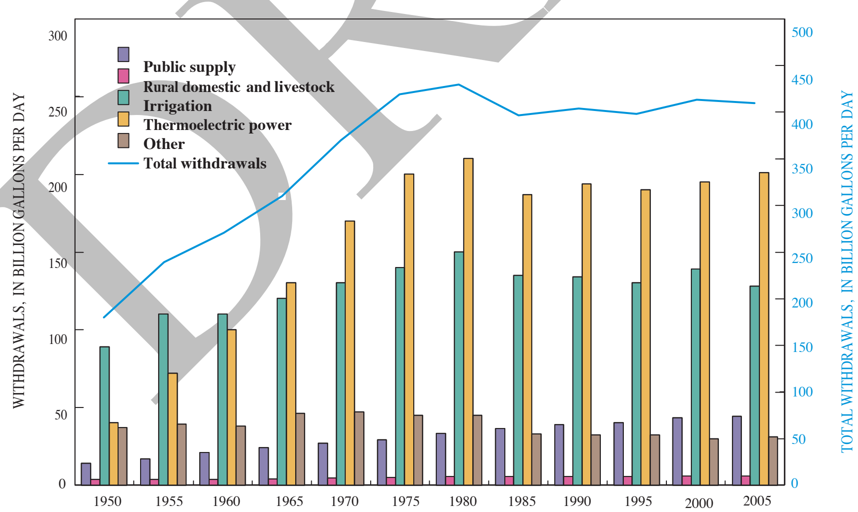

Figure 4. US national water withdrawal estimates, 1950-2005.

Water Use Databases and Integration

Water use data are compiled from various sources, depending on the category and the data available for each State. USGS personnel compile data by State and document the sources and methods used to determine water use. Values calculated using different sources and methods have varying levels of precision, and therefore some estimates are more reliable than others. Because the largest users and the most prominent categories of use within each State have the greatest effect on the totals, obtaining reliable estimates for these large users and categories is the primary focus of the compilation effort.

Sources of information include national datasets, State agencies, individual questionnaires, and local contacts. National datasets available to each State include the U.S. Environmental Protection Agency (USEPA) Safe Drinking Water Information System (SDWIS), U.S. Census Bureau population estimates, U.S. Department of Agriculture (USDA) Farm and Ranch Irrigation Survey, USDA Census of Agriculture, USDA National Agricultural Statistics Service (NASS) crop and livestock estimates, and U.S. Department of Energy (USDOE) Energy Information Administration (EIA) facility reports. Datasets and sources of information used to produce the national estimates for the livestock, aquaculture, and mining categories included the USDA NASS, county extension agents, USGS Minerals Information Team, USDOE EIA, and U.S. Bureau of Mines. Some of these data, such as those from NASS and EIA, are collected annually. Other data are estimated based on the most complete data sets available.

Water Use data are stored in the USGS Water Data for the Nation website (*http://waterdata.usgs.gov/usa/nwis/wu*). National water-use data are reported by source (surface water or groundwater, fresh and saline, and total), and category for the US as a whole. State specific water use estimates are available, by county and water use category via the same website. As part of the NWC, Water Use data will be disaggregated and served at the HUC-8 and HUC-12 scale on the web based NWC Data Platform.

Ecological Flow Needs

Historically, water use definitions were limited to the human uses and needs of water; more recently, the focus has changed to include the ecological water needs. Resource managers must assess ecological uses of water and environmental flows required to maintain habitats and populations and prevent degradation of freshwater ecosystems. There is a distinction between ecological flow science (timing and volume of flow that supports ecological values and sustains ecosystems) and the setting of ecologically-based flow criteria. A quantitative understanding of ecological and ecosystem-service responses to flow alterations are likely necessary to allow decision makers to address tradeoffs between traditional socio-economic water uses and ecological water uses (Jacobson and Galat, 2008). Additional research is needed to define ecological indicators that are robust and sensitive to flow alterations, and that can be determined with acceptable costs. Such indicators may range from fundamental ecological processes (such as residence time of transported carbon) to more socially recognized metrics, like fish community diversity. The NWC will not propose or establish ecologically based flow criteria, but has a distinct role to fulfill in ecological flow science by developing tools that evaluate relations between flow variability and ecological functions that inform resource managers in their efforts to establish ecologically-based flow criteria.

As part of the NWC, the USGS will: (1) build a national hydrologic foundation of baseline hydrographs or hydrologic statistics for all ungaged streams using statistical or rainfall-runoff flow modeling tools; (2) derive and serve a set of ecologically-relevant flow attributes that can be used to classify streams into distinctive regional and national flow regime types; (3) develop classification tools that allow environmental flow practitioners to evaluate a region of interest at the scale necessary for management; and 4) develop a user-driven, web-based, regionally specific hydrologic assessment tool that can compare natural and altered hydrologic regimes.

National Classification of Streams by Hydro-Ecological Type

Stream classification is an important step in developing an understanding of how natural systems respond to changes associated with resource management actions. Traditional hydrologic assessment at the state or watershed level has focused on specific aspects of the hydrograph such as seasonality, flood behavior, or low-flow characteristics. Recently, there has been an emphasis on stream classification using a suite of "ecologically-relevant" hydrologic 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. The absence of an updated national-scale stream classification for the US is an impediment to effective resource management. The derivation of hydrologically based stream types or classes provides a foundation for discriminating differences in ecological character. The spatial context provided by a stream classification would provide stakeholders and environmental flow practitioners with a framework for developing meaningful relationships between hydrology and ecology and provide a baseline by which the response of aquatic assemblages to hydrologic alteration can be assessed.

Classification approach

Hydroecological classification is an objective and interpretable process of systematically arranging rivers and streams into similar groups based on flow regimes, watershed characteristics, and human activities that can be applied at multiple scales. Currently, there are about 7,400 streamgages measuring daily flow; of these streamgages, about 6,400 have complete datasets for at least 10 years since 1990. Watershed boundaries have been delineated using GIS tools for most streamgages in the contiguous US and a variety of geospatial datasets are available to characterize human activities and natural features in watersheds; however, many of these datasets are available only for the conterminous US.

Numerous approaches to classification have been developed that use a variety of streamflow statistics in addition to physical and climatic properties of the contributing watershed. The NWC will support classification based on user-defined selection criteria at spatial scales relevant to stakeholders, in general this will be accomplished at the HUC 12-digit scale. Multiple classification approaches may be developed, applied, and compared for use in a national classification to accommodate a flexible, user-defined classification interface. The result will be a nationally consistent classification system that meets stakeholder's needs regionally.

The first step in classifying streams is to define a set of reference (or "least disturbed") streamgages. Two common requirements for a reference site are: (1) a sufficiently long time period (> 10 yrs.) of streamflow data, and (2) a drainage basin that contains minimal human alteration of the hydrologic cycle. The NWC will develop a set of unimpaired streamgages with limited hydrologic alteration and a period of streamflow record appropriate for estimating streamflow metrics. For stream reaches with no streamflow data or limited data, appropriate methods will be used to estimate flows and compare hydrologic similarity between the unimpaired streamflows or streamflow statistics at the respective stream reach and an unimpaired streamgage.

Development of User-Driven, Web-Available Hydrologic Assessment Tool

Many tools have already been developed that allow users to generate flow statistics to evaluate changes in hydrologic regime. Many of these analytical tools can easily be employed or enhanced to provide a fully integrated suite of ecologically relevant flow metrics accounting for all components of the flow regime at any gaged site. These flow metrics represent the analytical basis of hydroecological classification procedures and can be readily served for stream classification purposes as part of the NWC.

The NWC will serve a variety of streamflow metrics for stream reaches across the Nation using a web-based, clickable, national map interface to maximize access by stakeholders and environmental flow practitioners. The NWC will also generate a series of fixed stream classifications for the Nation based on a variety of physical, climatic, hydrologic or ecologic variables, acknowledging that these fixed classifications address only a subset of important management questions. For example, a classification process to identify and group streams having similar hydrologic function may yield different results than a classification process to identify and group streams with similar capacities to sustain a particular ecologic function. For this reason, the primary challenge to the NWC is to create a set of tools that are flexible enough to meet management goals at a variety of spatial (regional setting, political jurisdiction, watershed) and temporal scales relevant to a variety of users (e.g., stakeholder, scientist, water manager etc.). These tools can be designed to serve both a predetermined set of stream classes derived from a subset of existing baseline hydrographs and, alternatively, it can provide the user with the option of deriving a set of stream classes based on user-specified input.

Ecological Response Relationships

An important challenge to the NWC ecological flow science framework will be to provide the regional context and hydroecological data necessary to allow users to model relationships between altered flow and ecological characteristics. Ideally, these relationship could be developed and expressed in a fully quantitative manner and can be empirically tested with existing and recently collected ecological field data. This approach may assume that ecological data are available for sites having data describing hydrologic alteration. This is not always the case and the capacity of the NWC to serve ecological data simultaneously with hydrologic data is limited by the disparate and disaggregated nature of ecological data. This situation is changing, however, and the National Water Quality program is currently developing a flexible database (called BioData) that will have the capacity to integrate data from many sources (USGS, EPA, NPS, FWS, NOAA, USDA) and act as a retrieval hub (called BioShare) to publically serve ecological data. The NWC will leverage the use of such a database to provide stakeholders with a greater amount of ecological data and better support the development of predictive flow-ecology response models.

Mapping hydrologic alteration

In general, hydrologic alteration at a streamgage is quantified by comparing the altered flow regime to the natural or minimally impacted ("least impaired") flow regime. Computation of flow regime metrics for impacted flow regimes is fairly straightforward. The greater obstacle in quantifying hydrologic alteration is the estimation of flow metrics that represent the natural flow regime. A number of options are available to environmental flow practitioners including the identification of reference sites or employing a flow modeling process to simulate least impaired flow conditions. In some areas of the country (for example, MA, NJ, KT, VA, GA) flow models have already been used successfully to generate baseline and altered flow information. Statistical approaches also have been applied in the US to estimate hydrologic metrics representing the natural flow regime.

Linking key hydrologic indicators with ecological response

Hydrologic and ecological data are needed at a sufficiently fine resolution to match the scale of one or more processes that actually link flow alteration to ecological responses, but also at a sufficiently coarse resolution for regional applicability. Hydrologic and ecological data will provided (nested) at multiple scales, e.g., from river basins defined by drainage boundaries, to sub-basins, to individual watersheds. Data will also be provided at each resolution for geographic and geologic variables known or expected to influence ecological responses to flow alteration (e.g., land use and land cover, including impervious cover, dams, topographic variability, and even historic land use). Data will be linked to other USGS programs, as well as to partner with programs such as the National Fish Habitat Assessment, and will be essential for reducing uncertainty in flow-ecology relations.

Integration of Ecological Use with other components of the Water Census

A primary objective of the NWC will be to improve the quality of information used in planning and management of water resources to meet the current and future demands for both human and ecological uses. The NWC aims to build a national-scale hydrological foundation for provision of value-added hydrologic information about ecological flow science in natural and managed systems. Ultimately, as the components and data related to ecological water use are better defined, the NWC will provide the capability to build these uses into a national water budget.

The NWC will coordinate its efforts on ecological water uses with existing USGS and partner programs (ex. National Fish Habitat Assessment) that are assessing and monitoring the ecological condition of aquatic habitat and communities. By coordinating with partners, NWC products will have very broad applications in planning and resources management, including the interactions with or effects on aquatic and terrestrial plants and animals, communities, and ecosystems.

Role of Water Quality in Water Use and Availability

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 contamination, either naturally occurring or caused by human uses that affect water quality and availability. Salinity and sediment also commonly affect water availability, and 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); beginning in FY16 NAWQA will be restructured as part of the National Water Quality Program (NWQP). Cycle 1 and 2 studies conducted as part of the NWQP 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 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.

Future Directions

Currently, the NWC is focused on improving estimates for the traditional components of the water budget (streamflow, groundwater, water use, and evapotranspiration) along with how water availability impacts ecological flow. As research efforts improve these estimates, the NWC will invest in additional research that will further refine the water budget both nationally and regionally, the following sections discuss in more detail the topics under consideration for further evaluation by NWC researchers.

The Importance of Snow in Regional and National Water Budgets

Snow is critical for water supply in the United States (U.S.), providing water for drinking, irrigation, industry, energy production, and ecosystems for much of the country (McCabe and Wolock 2007). It is an especially important component of the regional water supply in mountainous areas and cold regions, where seasonal snowpacks serve as large natural reservoirs that store water through the winter, and release it during spring and summer months, when demand is greatest – often supplying water to meet demands hundreds of miles away. The quantity of water that is stored in the seasonal snowpack and then released as snowmelt is one of the most important inputs used for forecasting annual runoff and water supply in these regions. There is an urgent need to improve our understanding of the role of snow in water budgets at the regional and national scales. Key questions include: (1) What is the fractional contribution of snow to the annual water budget? (2) How much snowfall ends up in streams and rivers and how much is lost to sublimation, evapotranspiration, and subsurface storage? (3) Can models and/or remotely sensed data be used to accurately estimate snow water content and to simulate snowpack processes across the landscape? (4) How can observations help guide development of snowpack models and remote sensing techniques, and what temporal and spatial resolution is required for those observations?, and (5) How do the dynamics of snow accumulation and snowmelt change in response to changing climate conditions?

Forecasting snowmelt runoff – both volume and timing – is challenging because (1) snow depth and water content vary substantially in space and time across the landscape, and (2) snowpack measurement sites are sparse, especially at high elevations. Snow sublimation, which is analogous to evaporation from water bodies and represents a significant loss of water from the snowpack (Hood, Williams et al. 1999), represents a major uncertainty in snowmelt runoff models. Similarly, the effect of changing climatic conditions controlling upland soil moisture and albedo related to dust deposition could drive significant changes in snowmelt runoff and timing.   Although recently developed moderate- and high-resolution gridded snow models show promise for improving estimates of snow distribution and snowmelt runoff, model results have not been critically evaluated, largely because of the difficulty of making high-quality ground- and satellite-based measurements. Given the uncertainties in modeling snow water content and its seasonal evolution, and the importance of snowmelt in the annual water balance, it is essential to conduct a more comprehensive evaluation of data needs and model capabilities for quantifying water budgets across snow-dominated regions of the U.S.

Initial testing on one of the snow models (SNODAS), conducted as part of the Water Census program, has highlighted strengths and weakness in the model, and helped identify methods for improvement (Clow, Nanus et al. 2012). Additional testing on the accuracy and uncertainty of SNODAS and other snow models is needed to determine their suitability for regional- and national-scale water balance calculations. Research on the assimilation of remote sensing observations and ground-based snow measurements into snowmelt runoff models also needs to be evaluated. These efforts need to be conducted at snow hydrology research sites covering a range of climate and landscapes, and can likely only be accomplished through a collaborative effort within USGS and with other agencies and universities. Key objectives should address the key questions outlined above, with an overall goal of improving the accuracy, accessibility, and usefulness of snow product information to the nation's water resource managers and planners, stakeholders, and scientists.

Reservoir Storage: Developing a Satellite-based Unified Reservoir Fullness (SURF) Index

Over the last century, humans and climate have significantly affected the hydrologic cycle and water availability (IPCC, 2010). Because of these changes, several surface water resources are showing high year-to-year variability. It has become increasingly important to accurately identify, quantify, and monitor freshwater resources. There is up to 27,000 km^3 of water stored in wetlands, large lakes, reservoirs, and rivers in North America (Shilomanov and Rodda, 2003). It is estimated that there are more than 3 million surface water bodies (reservoirs) in the U.S. that are classified as "bigger than farm ponds" (Eric Evenson, 2014, pers comm). Regular information on the hydrologic status of these reservoirs is important for water resources managers to plan and regulate water releases for meetings their designed objectives (flood control, irrigation, industry, etc) while meeting ecological requirements. Moreover, information on volumetric changes in surface water storage is essential to accurately represent water balance components in a basin. The hydrology community is seeking methodologies capable of collecting discharge and storage change measurements globally (Alsdorf et al., 2007). Velpuri et al (2012) at USGS EROS demonstrated such an integration approach for a basin in East Africa where they related satellite altimeter measurements of a lake with Landsat-based surface area to estimate volumetric changes. Also, Senay et al (2013) demonstrated an operational application of the near-real time integration of satellite-derived surface areas and hydrologic models to monitor pastoral waterholes in east Africa as part of a NASA-funded project (http://watermon.tamu.edu/).

Currently, there is a lack of a unified approach and resource center that generates indicators on the status (fullness level) of these reservoirs on a regular basis, covering the entire reservoir system in the U.S. Although reservoir height information exists for most of the large water bodies in the U.S., such information is not available for the ungaged reservoirs. Even for the gaged reservoirs, it is important to express the height information with in a form of a standardized index that will express “fullness” level. Due to the lack of a coordinated mapping and monitoring of reservoir heights on a regular basis, we do not understand the spatial variability of surface water conditions and their potential inability to meet water demands for the various purposes from agriculture to the ecosystem.

NWC will support an innovative data integration approach that combines satellite-derived reservoir surface area and digital elevation model (DEM) to monitor all reservoirs (gage or ungaged) that can be detected with Landsat’s 30 m resolution (this will reliably monitor surface water bodies that are at least 100 m in diameter). The intersection of water surface area with the DEM will provide information on reservoir height variability and volumetric storage changes. With further information on bathymetry of the reservoir, we can estimate volumetric storage levels in absolute terms in addition to relative changes in storage. The possible integration of Landsat (30 m) and MODIS (250 m) will be explored to increase the temporal frequency.

Satellite imagery provides a direct opportunity to monitor variations in surface area. The unique feature of the approach is that (unlike conventional approaches) it does not require an existing knowledge of reservoir surface area to derive volumetric information. Instead, it integrates the topo-bathymetry data and reservoir shoreline, derived from Landsat (partial shoreline is enough) to derive reservoir height/surface area.

Although clouds create a potential problem for optical remote sensing, this approach works well with partial view of the water surface from imagery. Furthermore, the availability of historical Landsat images from USGS EROS will allow the calculation of long-term means for surface area and height. The statistics from the historical data will be used to develop a Satellite-based Unified Reservoir Fullness (SURF) index. NWC will deliver the following monitoring products in near-real time once an imagery is acquired:

- Reservoir surface area estimation and its anomaly in relation to historical (1980s-2014) conditions for as many surface water bodies as deemed necessary to monitor.
- Reservoir height level and its anomalies in relation to historical (1980s-2014) conditions.
- Volumetric change and its anomalies for each of the reservoirs.

The project will be implemented over multiple-years: starting with a proof-of-concept of the approach and model-validation in the first year followed by historical data processing to establish statistics for surface area and height. Operational monitoring and integration with hydrological models will follow a thorough evaluation of the SURF index system.

Saline and Brackish Groundwater Assessment

The amount of fresh or potable groundwater in storage has declined for many areas in the United States leading to concerns about the future availability of water for consumption, agricultural, industrial, and environmental needs. Use of brackish groundwater could supplement or, in some places, replace the use of freshwater sources and enhance our Nation's water security. However, a better understanding of the location and character of brackish groundwater is needed to expand development of the resource and provide a scientific basis for making policy decisions. To address this need, the U.S. Department of Interior's WaterSMART initiative, through the Water Availability and Use Science Program, is conducting a national assessment of brackish aquifers.

Brackish groundwater is potentially abundant. Early studies indicated that mineralized groundwater underlies most of the country. Further, advances in desalination technologies are making treatment and use of brackish groundwater for potable water supply more feasible. Brackish groundwater is directly used for purposes such as cooling water for power generation, aquaculture, and for a variety of uses in the oil and gas industry such as drilling, enhancing recovery, and hydraulic fracturing. For purposes requiring lower dissolved-solids content, especially drinking water, brackish water is treated through reverse osmosis or other desalination processes. In 2010, there were 649 active desalination plants in the United States with a capacity to treat 402 million gallons per day (Shea, 2010). Of the desalination plant capacity in the United States, 67 percent was for municipal purposes, 18 percent for industry, 9 percent for power, and the remaining 6 percent for other uses (Mickley, 2010). A total of 314 desalination facilities are used for municipal purposes, 49 percent of which were in Florida, 16 percent in California, 12 percent in Texas, and the remaining 23 percent dispersed among other states. More than 95 percent of the desalination facilities in the United States are inland (Mickley, 2010), and most facilities are designed to treat groundwater with dissolved-solids concentrations in the brackish range (Shea, 2010). Recent advances in technology have reduced the cost and energy requirements of desalination, making treatment of brackish groundwater a more viable option for drinking-water supplies (National Research Council, 2008).

Despite the need for alternative water sources and the potential availability of brackish groundwater, the most recent national map showing the distribution of mineralized groundwater was published in 1965. An updated evaluation is needed to take advantage of newer data that have been collected over the past 50 years. In addition, consistent information about chemical characteristics (such as major-ion concentrations) and hydrogeologic characteristics (such as aquifer material, depth, residence time, thickness, flow patterns, recharge rates, and hydraulic properties) of brackish groundwater has not been compiled at the national scale. Improved characterization is important for understanding and predicting occurrences in areas with few data and for assessing limitations imposed by different uses and (or) treatment options. This information is needed to understand the potential to expand development of the brackish groundwater resource and to provide reliable science for making policy decisions.

The NWC will improve the understanding and information available about brackish groundwater by compiling existing information that can be used to assess brackish aquifers. Research will describe, to the extent that available data permit, dissolved-solids concentrations, other chemical characteristics, horizontal and vertical extents of aquifers containing brackish groundwater, ability of the aquifers to yield water, and current brackish groundwater use. The NWC will generate national maps of dissolved-solids concentrations as well as identify data gaps that limit full characterization of brackish aquifers.

The national brackish groundwater inventory will be published as digital datasets so that other scientists can conduct assessments tailored to their specific needs. Published digital data relating to brackish groundwater currently are limited to a small number of state and regional studies. Updated dissolved-solids inventories will be used to characterize brackish aquifers at a higher spatial resolution than previous national work. In addition to dissolved-solids distribution, other chemical characteristics (such as major-ion concentrations) and hydrogeologic characteristics (such as aquifer material, depth, residence time, thickness, flow patterns, recharge rates, and hydraulic properties) will be assessed to determine brackish groundwater availability. Improved characterization is important for understanding and predicting occurrences in areas with few data, and also for assessing limitations imposed by different uses and (or) treatment options.

Developing comprehensive surface-water/groundwater budgets— the challenge of integrating aquifer characteristics and groundwater dynamics into surficial watershed budgets

The National Water Census is designed to provide nationally-consistent, well-documented, data and estimates of water budget components such as surface-water and groundwater flows, surface-water and groundwater storage, precipitation, evapotranspiration, and water withdrawals and returns (Dalton, 2014a). These components will be assembled and put into the context of environmental-flow requirements, water-use intensity, and sensitivity to climate variability and change. The long-term objective of the National Water Census is to provide these data and estimates at the hydrologic unit code (HUC) 12-digit scale, a relatively small basin size averaging 34 square miles, across the country (Dalton, 2014b). A second long-term objective is to acquire data and make estimates for water-budget components on time scales capable of capturing monthly and seasonal variation. Water budget information is fundamental to water availability analysis and resource management (Healy and others, 2007).

Groundwater and human-mediated flows and storage are unique components of the watershed budgets because they do not follow watershed boundaries. Additionally boundaries for groundwater or infrastructure may change as infrastructure is developed or groundwater is pumped (Sheets and Simonson, 2006). Representation of interbasin transfers and groundwater components, therefore, is a challenge for the National Water Census. However, progress is being made thought the current regional groundwater availability studies (Reilly and others, 2008). Related groundwater budget components are being assembled at the principal aquifer scale but more work will be needed to determine how best to scale down to the subregional and local scales. For groundwater components, some key issues may be broken down to: what are the hydrogeologic boundaries of principal aquifers and how well are they known? What are the groundwater divides in shallow, intermediate and regional aquifers and how do these divides respond to development or changes in climate? How do local groundwater budgets respond to changes in pumping or climate and how can these dynamics be expressed in budget information summarized for decision makers, stakeholders, and the public?

Quantitative understanding of groundwater-flow budgets and the dynamics of the groundwater system in response to changes in pumping or climate often requires a groundwater flow model that can simulate how inter-related changes storage, discharge, and recharge balance external changes imposed on the system (Bredehoeft, 2002; Healy and others, 2007). Once a model is developed for an area, information from the model can be expressed as local and regional budgets that summarize the dynamics of the system (for example, Faunt, 2009; Clark and Hart, 2009; Feinstein and others, 2010). Water budget information from groundwater-flow models can be combined with other water budget components and water withdrawals and returns to develop various hydroclimatic indicators designed to summarize conditions for a watershed and help managers understand the relation between components (Weiskel and others, 2007; Reeves, 2011; Weiskel and others, 2014). These indicators may prove to be useful for summarizing components within the National Water Census framework in areas where groundwater-flow models are available. In areas where groundwater is an important component of the water budget but a model is not available, local water budgets may provide useful information (for example, Heilweil and Brooks, 2011). In other parts of the country, landscape water budgets that include groundwater will have to be developed to indicate how water-budget components interact (Weiskel and others, 2014; Winter and others, 1998).

Water Use and Water Tracking

Water use is an integral component of the water budget, as well as overall water availability. The NWC is currently involved in research that looks to improve estimates and the methodologies used to evaluate water use as it is related to thermoelectric water use, public supply, and irrigation; in the future the NWC will look to expand water use related activities and research into additional areas in order to further improve our, and out stakeholders, ability to estimate water use both regionally and nationally. The following sections describe areas of research that are being considered for future NWC water use related research;; however, other areas may be considered based on stakeholder input.

Public Supply and Waste Water Tracking

Locations of water sources for public supply systems , type of source (ground, surface water or purchased water) as well as the population served data are provided through the U.S. Environmental Protection Agency's (USEPA) Safe Drinking Water Information System (SDWIS). The data for municipal systems (non-transient and transient systems excluded) are received as a 'frozen' dataset for the compilation year, for all the States, Indian lands, Puerto Rico and territories. The information that has always been lacking is the withdrawals associated with the reported water sources, as well as any information about customer numbers, characteristics or actual volumes of water for domestic, industrial and commercial deliveries.

In the past, withdrawal data has been collected by WSC water-use specialists through state-wide surveys via cooperative agency efforts or estimation methods. A more centralized database of reported municipal system withdrawals through a State agency is available in a few States (e.g. Texas Water Development Board *https://www.twdb.texas.gov/waterplanning/waterusesurvey/index.asp*.); however few States collect this data, nor are the data collected uniformly across the Nation (small and very small systems may not have to report withdrawals). In an effort to provide minimal uniform municipal withdrawal data to all WSC water-use specialists, partnerships could be built with state drinking water agencies responsible for regulating municipal systems to collect annual withdrawal data from each water source for the system. The USEPA uses the number of people served as the basis for system size categories. The categories are listed here: *http://water.epa.gov/infrastructure/drinkingwater/pws/factoids.cfm*. As a minimum, annual data might be collected for very large, large and medium municipal systems, thereby providing withdrawal and water source data for the majority of the population served by purveyors. Optimally, monthly data might be collected but would require more information to understand mixed source systems and seasonal use by different sources in a system (e.g., well fields, surface water intakes mixed with groundwater, seasonal switches from ground to surface water). Municipal suppliers would also have to report the amount of water sold to the different customer types—domestic, industrial, commercial and thermoelectric. All public supply withdrawal and delivery data could be entered into the SWUDS database.

These data are valuable to other programs, most notably to the National Water Quality and Water Availability and Use Science. A complete, accurate and well documented set of data points for drinking water sources and systems that is created and maintained by the NWUIP can benefit other programs and be cost effective.

Compilations of wastewater return flows are currently (2015) not a mandatory water use category, and have not been a mandatory category since 1995. However, through data requests to USEPA's Integrated Compliance Information System (ICIS) (*http://www.epa.gov/enviro/facts/pcs-icis/*) a national retrieval, similar to the data request through USEPA SDWIS, can be made for wastewater return flows for all municipal wastewater facilities. Inclusion of wastewater data in the data request for industrial facilities could be helpful in estimation of industrial withdrawals. Average monthly wastewater return flow data (parameter 50050) may be easily parsed by state, county and facility and provided to WSC water-use specialists to be summed for annual values and included in the compilation. The wastewater data could be maintained in either (or both) the SWUDS or AWUDS databases.

This category offers an opportunity for the continuation of wastewater data to be collected, synthesized, corrected and stored through efforts already underway by SPARROW model teams. Wastewater data collected by the SPARROW teams does not always co-inside with the compilation years, however data collected and checked by water-use specialists would still be beneficial to both programs.

Interbasin Transfer of Water

Interbasin transfer is defined in the USGS National Water Use Program as "A transfer of water from one river basin to another." (USGS, n.d). The interbasin transfer of water may occur through the withdrawal of water for water-use needs, wastewater releases or disposal in other watersheds, or through navigational canals and locks. The interbasin transfers may be tracked or regulated at different basin levels, such as a hydrologic unit level, depending on regulatory authority. The USGS National Water Use Information Program has applied standard definitions and methods to document water withdrawals at a National level through 5-year National water-use compilations and publications. The water-use data allow for an evaluation of the water withdrawals and water-use trends across the Nation. In order to fully provide the information needed to develop water budgets for major river basins and to evaluate water availability for regional water demands, the extent of interbasin transfers needs to be defined (Trotta, 1988). Evaluations of the National Water Use program by the UGS in a report to Congress (USGS, 2002) and by the National Research Council (2002) describe the need to define interbasin transfers of water to fully define the impact of human activities on water resources.

An inventory of interbasin transfer was conducted by the USGS and published in reports on the interbasin transfer of water in the conterminous Western United States (Petsch1985) and the Eastern United States (Mooty and Jeffcoat, 1986). Interbasin transfers, in 1982, were described for 39 hydrologic subregions in the western conterminous United States. The transfer originated in 17 states and totaled about 12.4 million acre-feet in 1982 for transfers between water resource subregions. The lowest reported interbasin transfer in the western United States was about 5 acre-feet and the largest transfer was the export of more than an estimated 3 million acre-feet from the Lower Colorado River basin (subregion 1503) to the Southern Mojave-Salton Sea (subregion 1810) in 1982 (Petsch, 1985). Interbasin transfers, in 1982, originated in 21 states and occurred from 51 subregions in the Eastern United States and totaled more than 5.9 million acre-feet (Mooty and Jeffcoat, 1986). The interbasin transfers in the eastern United States ranged from less than 1 acre-foot to 2.2 million acre-feet transferred through the Chicago Sanitary and Ship Canal to the Upper Illinois River Basin (subregion 0712) in 1982 (Mooty and Jeffcoat, 1986).

The interbasin transfer of water can be used to meet water demands in water-stressed areas and can be a critical component of regional water management. Recognizing the need to understand and reugulated interbasin transfer, many states have established reporting or permit requirements for interbasin transfer. In the southeastern United States, only Alabama and Mississippi do not have statewide regulations on interbasin transfer (Bearden and Elliot, 2014). In addition to interbasin transfers for water supply, other aspects of interbasin transfer have been evaluated. Investigations have described the interbasin transfer of groundwater between hydrologic areas in Nevada (Lopes and Evetts, 2004). Evaluations of the ecological flow requirements for streams to support biological communities have highlighted the need to understand the ecologic needs in terms of interbasin transfer as wells as direct withdrawals. For example, studies have evaluated the need to understand the connectivity between fish communities and biodiversity, water withdrawals, and interbasin transfers of water (Grant and others, 2012) and described the potential impact of increased flow on fish fauna in streams receiving a planned interbasin transfer of water from the Red River basin to the Trinity River basin in Texas (Matthews and others, 1996). Studies have also evaluated the effect of interbasin transfers on water quality (Liscum and East, 2000) and the interbasin transfer of waste water (drilling fluids and produced water) from drilling operations in the Marcellus Shale play in Pennsylvania for 2011 (Maloney and Yoxtheimer, 2012). The interbasin transfer of water for commercial activities through canals and locks has also been evaluated. For example, the transfer of water from the Tennessee River basin to the Mobile River basin through the Tennessee-Tombigbee Water System is described in a report on water use in the Tennessee River basin (Hutson and others, 2004).

The importance of interbasin transfers of water and the need to identify and document those transfers have been recognized by the USGS. The water science strategy for the USGS (Evenson and others 2013) describes the need to clarify linkage between human water use, including the quantification of interbasin transfer, and the natural hydrology of the water cycle as a priority action for the agency. Improvement in quantifying and locating interbasin transfers was identified in a strategic direction as a needed improvement to the National Water Use Information Programs (Evenson and others, 2013). Methods that can be used to estimate water use and interbasin transfers in an urbanized basin have been described and published by the USGS (Horn, 2000). Regular and consistent documentation and reporting of interbasin transfer is needed to provide information on regional water availability. The documentation can be accomplished through a collaborative effort within the USGS and State and Federal water and environmental agencies.

Comprehensive Water-Stress Indicators

Water availability varies among the regions of the U.S. due to differences in climate, population, water-use practices, and water quality. The quantity and quality of water in a given region should, ideally, be sufficient to meet human, economic, and ecosystems needs. When the demand for water exceeds the availability, a region is said to be water stressed. Water stress, due to over-exploitation, drought, and/or pollution, can lead to health issues, economic decline, environmental degradation, and water conflicts. Increases in population will likely exacerbate these issues. Additionally, water supply is expected to decline due to climate change, with the Southwest experiencing the greatest declines (Foti and others, 2010). Not surprisingly, California and the agricultural intense mid-west and high plains regions in the U.S. have experienced within year and multiyear water-stressed periods (Devineni and others, 2015). Streamflow depletion and aquatic habitat degradation can be found in the East as well (Weiskel and others, 2007), and even in water abundant areas, water supplies can be limited (Vörösmarty and others, 2005). A decades-long conflict between Alabama, Florida, and Georgia over the allocation of water of two major river basins crossing their borders provides a humid-region example of competing water demands exceeding availability (Southern Environmental Law Center, 2015). Because of competing interests, water-stress indicators, measures of the amount of water available and water required to meet competing needs, are necessary to facilitate water-resource management and guide policy making.

The development of numerous water-stress indicators demonstrates the desire to consistently quantify and compare water availability and demand at various locations. However, many proposed indices focus on only a few aspects of water availability and demand and fail to adequately characterize water stress across a diverse suite of locations. Characterizing water stress is difficult due to the many equally important facets of demands for water and renewable supplies (Brown and Matlock, 2011). Many current indices analyze data at spatially-coarse scales (country level) obscuring regional differences and areas of high water stress (Perveen and James, 2011; White, 2012). Other tools provide analyses at temporally-coarse scales (annual averages) concealing seasonal variability of water supply and demand (Devineni and others, 2015). Other indicators do not incorporate socio-economic factors of water use (conservation behaviors, technological water-use efficiencies, wealth), man-made sources of freshwater (desalination), recycled and reused water (White, 2012), ecosystem requirements, or water quality.

The USGS recognizes the need for comprehensive water stress indicators across the Nation (Alley and others, 2013). Water stress indicators should be regionally adaptable and measure water availability and demand on a monthly basis. National indices should help to answer key questions such as, (1) How much surface water and groundwater is available, including man-made sources of freshwater and recycled/reused water? (2) How much water is used for the various categories of water use? (3) How does human water use relate to socio-economic factors such as demographics, water conservation behaviors, and technological advances in water-use efficiency? (4) How are water demands and availabilities affected by climate, water quality, and human activities? (5) What are the effects of surface-water and groundwater uses on natural systems? What are the minimum requirements to meet ecosystems services?

Addressing the key questions outlined above will require the definition and characterization of hydrologic regimes, and human and ecological flow needs. Weiskel and others (2007, 2010, and 2014) have developed some of the more promising water stress indices which incorporate a variety of aspects related to water availability and demand. Weiskel and others (2007)characterized the impacts of human activities upon hydrologic systems, developed indicators of anthropogenic streamflow alterations, aquatic habitat fragmentation, and water-quality impairments (Weiskel and others, 2010), and developed a national framework of quantitative water-availability indicators (Weiskel and others, 2014). However, the incorporation of both demand and availability indicators to assess regional water stress at the basin scale nationally has not been executed. Future efforts should build on available indices, integrating socio-economic factors, water quality data, and water-use data with the goal of improving the usefulness of demand and availability indicators in assessing water stress.

Virtual Water

Virtual water is defined as “the water required for production of commodities” (Yang and Zehnder, 2007) or the “the amount of water used in growing, producing, packaging and shipping” products and goods (Allan, 2011). Virtual water is also sometimes referred to as ‘embedded water’, and is related to the ‘water footprint’ (Chapagain and Hoekstra, 2004). In the past 10 years, many studies have looked at transfers of virtual water through trading commodities amongst countries throughout the world. The movement of virtual water is sometimes referred to as virtual water flow. Since food production is one of the largest uses of water, much of the literature focuses on virtual water flow related to food commodities (Yang and Zehnder, 2007).

There is much debate on the applicability of virtual water for resource management, and the appropriateness of using virtual water estimates for policy and decision-making. For water scarce regions, importing virtual water through importing food commodities can be an alternative to using scarce water resources for agricultural practices, potentially allowing for the available water resources to be used for other domestic needs. Virtual water flows, related to commodity trading, also involve economic, environmental, ecological, and political issues that are difficult to quantify and factor into virtual water estimates.

Many groups have and continue to develop methods to estimate virtual water, virtual water flows, and water footprints at various regional and global scales. Limitations in these estimates are related to the lack of detailed data input to these models. Allan, 2011, suggests that we need more, “observation and monitoring of actual resources, of actual trends in use, of actual levels of resource-use efficiency and of trends in such efficiencies”. Chapagain and Hoekstra, 2004, state that, “an important shortcoming is that the estimates of virtual water content of crops are based on crop water requirements, which leads to overestimates in those cases where actual water availability is lower than the crop water requirement”. Agricultural water use is an important component for calculation of water footprints, and(or) virtual water imports and exports. Increasing the temporal and spatial resolution of estimates of withdrawals and consumptive use for agriculture could improve the virtual water estimates for states and/or counties in the U.S. Yang and Zehnder, 2004, note the need to estimate the contribution of green water (water stored in the soil, i.e. from precipitation) and blue water (water in lakes, rivers, reservoirs, and aquifers, i.e. irrigation water) contributions of consumptive use for agriculture. Additionally, increased temporal and spatial resolution of estimates of withdrawals and(or) consumptive use for other categories, such as commercial, industrial, and livestock categories could further improve the virtual water estimates. The Panta Rhei Working Group, titled "Water Footprint of Cities", is working to "examine the virtual water in both the consumption and production of goods and services to better incorporate the complex trade dynamics of cities". They will also be identifying data gaps at various scales (local to global). There is potential for the NWC to work with the Panta Rhei workgroup to determine a method for filling the data gaps.

Current virtual water estimates focus on the quantity of virtual water, rather than the quantity and quality of virtual water. This is an area that the NWC could work to advance the science of incorporating water quality data into virtual water estimates, by developing a series of "weighting" factors.

The NWC could work to estimate the effects of climate change on future virtual water imports and exports, both at a national scale and within the U.S. Dang and others, 2015, identified several states with high agricultural virtual water importance that could be affected by climate change (Illinois, Pennsylvania, California, Massachusetts, Washington, New York, and Texas). Research could be done to incorporate virtual water (flow) into water budgets, and then determine how changes to virtual water flows affect the sustainability of water resources in the U.S.

Information Management and Delivery

Information management and data integration for a program the magnitude of the NWC presents major technical and resource challenges, this section identifies key challenges and the suggested approaches to address these challenges. In order to maximize the utility of the information, the design and development of the NWC must be closely coordinated with the ACWI. Although it is beyond the scope of this document to detail the requirements of a cyber infrastructure, it is worth noting that this initiative will require significant coordination of information and observational data, sophisticated and high-performance computing, large data storage capacity, and data management and communication services in a distributed network. In any data management and delivery system deployment approach, the number of qualified human resources needed for system administration and application technical support as well as continued application research development is often severely underestimated, and would need to be evaluated in depth.

USGS Databases – Preserving Information for Future Generations

The types of data USGS collects are varied, but generally fit into the broad categories of surface water, groundwater, water use, and ecological data and are publically available through multiple web-based databases. Surface water, groundwater, and water use data are served through a web-based application USGS Water Data for the Nation, which is the web interface for the National Water Information System (NWIS; *http://waterdata.usgs.gov*). NWIS Web provides water-resources data from approximately 1.5 million sites in all 50 States and US territories. Water-quality data are available for both surface water and groundwater. Examples of water-quality data collected include field measurements of temperature, specific conductance, pH, nutrients; and laboratory analyses of pesticides and volatile organic compounds. NWIS Web serves current and historical data that can be retrieved by data type or geographic area. Subsequent pages allow further refinement by selecting specific information and by defining the output desired.

USGS ecological data is served on the newly released BioData website (*https://aquatic.biodata.usgs.gov/*). BioData provides access to aquatic community and physical habitat data collected by USGS scientists across the nation since 1991. BioData retrieval filters based on data type, location, date, or taxonomy; personalized retrieval criteria can be saved to a computer desktop for future queries. Requested data can be downloaded in several formats.

National Water Census Data Platform

A major component of the NWC is the NWC Data Platform, which is currently under development in collaboration with the USGS Center for Data Analytics. Much of the data served has either been collected by USGS and is available as a stand-alone product through the appropriate database (NWIS Web, BioData, etc.) or has been provided through cooperation with other Federal agencies (EPA, NOAA, NPS, FWS, USDA, state agencies, etc.). The NWC will organize its databases and tools in anticipation of continued cooperation with external data sources to provide stakeholders with greater connectivity between hydrologic and ecological data and thus, greater opportunities for the development of predictive flow-ecology response models.

The NWC Data Platform relies on a series of new data management practices to enable integration and delivery of water budget information alongside other data of interest to managers, such as water use data or ecological assessment criteria. Eventually, end users of water budget data (i.e. management agencies and decision-makers) will be able to access an integrated online database in a form that will enable them to construct local and regional water budgets.

A web interface is being developed that allows the user to click on a location, watershed, or polygon to download data available for that selection. Surface water information, data, and model results served include; stream flow, stage, storage, precipitation, evaporation, water use, and water quality data and predictions. Groundwater data served includes groundwater levels, aquifer hydraulic properties, well discharge, groundwater use and quality. In addition to hydrologic data, ecological measures and predictions will be used to validate water quantity and quality assessments. Fish species status and trends data made available from multiple state and federal agencies and non-governmental organizations and macroinvertebrate species data available through NWIS and also by the EPA will help serve this need. It should be noted that ecological data are not always available for sites having data describing hydrologic alteration, consequently, the capacity to serve ecological data simultaneously with hydrologic data will be limited by the disparate and disaggregated nature of ecological data.

In addition to serving data, the NWC Data Platform will host a database of hydrologic indicators (table 2) and a program for assessing ecological flow needs. The database of hydrologic indicators will be served on a web-based platform that provides nationally consistent data at the HUC-12 scale for a series of hydrologic indicators developed as part of the national ecological flow needs study.

An Installation IT Security Officer will be appointed to handle security matters related to the IT resources managed under the NWC. All DOI and USGS security policies, guidelines, and best practices will be followed to ensure the IT security. NWC data will be managed and maintained to preserve all data while making it accessible for current and future generations. Long term data management and maintenance is difficult and expensive because of the dynamic nature of information; in order to minimize cost and maximize effectiveness the NWC will:

- adhere to open standards and meta data documentation to enable a broad range of tools to be used;
- leave source data in its native location, when possible, and access it through web services and XML; and,
- communicate with stakeholders on a regular basis about future needs and changes.

Table 2. Indicators of water availability

Hydroclimatic indicators	**Units**
Precipitation, P	Inches/day/HUC-12
Potential Evapotranspiration, PET	Inches/day/HUC-12
Evapotranspiration, ET	Inches/day/HUC-12
ET Ratio, ETR	dimensionless
Aridity Index, AI	dimensionless
Timing of snowmelt, Ssnow-ice	TDB
Groundwater indicators	
Recharge rate, Rgw	Inches/day/HUC-12
Baseflow, SW-base	Inches/day/HUC-12 & cf-day at the pore point of HUC-12
Groundwater movement	Cf-day per specified aquifer unit
Total groundwater storage, Sgw	Feet per specified aquifer unit
Seasonal change in storage, dSgw/dt	Feet per specified aquifer unit per quarter
Longterm change in storage, dSgw/dt	Feet per specified aquifer unit per year
Water Quality indicators	
Proportion of groundwater resource with water quality above human-health benchmark(s)	TBD
Proportion of surface water resource with water quality above aquatic life or human-health benchmark(s)	TBD
Surface-water indicators	
Total Runoff, Qsw	Inches/day/HUC-12 & cf-day at the pore point of HUC-12
Surface Storage indicators	
Total SW storage (glaciers and snowpack)	Inches of water equivalent/unit time/HUC-12
Seasonal changes in ice and snowpack storage	Inches of water equivalent /quarter/HUC-12
Long-term change in ice and snowpack storage	Inches of water equivalent /year/HUC-12
Total SW storage (reservoirs and managed lakes)	MG/unit time/ HUC-12 (alternate in acre-feet)
Seasonal changes in reservoirs and managed lakes storage	MG/quarter/ HUC-12 (alternate in acre-feet)
Long-term change in reservoirs and managed lakes storage	MG/year/ HUC-12 (alternate in acre-feet)
Water-Use indicators	
Withdrawals (Thermoelectric)	MG/month/HUC-12
Return flows (Thermoelectric)	MG/month/HUC-12
Consumptive use (Thermoelectric)	MG/month/HUC-12
Withdrawals (Public Supply)	MG/month/HUC-12

Return flows (Waste Water Treatment Plant)	MG/month/HUC-12
Consumptive use (Public Supply)	MG/month/HUC-12
Withdrawals (Irrigation)	MG/month/HUC-12
Return flows (Irrigation)	MG/month/HUC-12
Consumptive use (Irrigation)	MG/month/HUC-12
Withdrawals (Industrial)	MG/month/HUC-12
Return flows (Industrial WWTP)	MG/month/HUC-12
Consumptive use (Industrial)	MG/month/HUC-12
Withdrawals (Aqua-Livestock-Mining)	MG/month/HUC-12
Return flows (Aqua-Livestock-Mining)	MG/month/HUC-12
Consumptive use (Aqua-Livestock-Mining)	MG/month/HUC-12
Withdrawals (Domestic-Self)	MG/month/HUC-12
Return flows (Domestic-Self)	MG/month/HUC-12
Consumptive use (Domestic-Self)	MG/month/HUC-12
Relative Net Demand	dimensionless
Water-use Intensity	dimensionless
Ecological-Flow indicators	
Streamflow characteristics *(ie. IHA, HIP/HAT)*	variable units
Streamflow timing	Centroid of flow - Julian Day
Streamflow characteristics relative to thresholds of ecological function	

Data Delivery

Standard operating procedures for data providers will be developed to implement a system that will ease the challenges of data integration at the national level. Establishing metadata standards is also necessary to manage a data exchange system with cataloging, query, and retrieval capabilities. Establishing multiple portals, both public and internal,will require establishing a protected network with various permission levels to access and manage the information and data.

Federal Geographic Data Committee (FGDC)-compliant searchable metadata will be made available for all NWC data products. A national catalog of NWC data will be developed to provide information for discovering, assessing, and accessing NWC data sets. The NWC national catalog will consist of three levels of data objects, national scale conglomerate data resources, distinct geospatially-oriented databases, and where possible feature / sample level metadata.

USGS commonly uses web based map applications to serve data. Most map viewers allow identify sampling or monitoring locations on a digital map base, plus allow for the display and/or download of data records from selected sites. NWC will supplement visualization of and access to data, by performing robust analysis or modeling of the data and displaying the results via a web map viewer interface. This capability will be particularly useful for those who wish to use the output of a web analytic function as an input for their own application.

Assessment Tools

The ability of the USGS to integrate hydrologic, geologic, chemical, geographic, and biological data into new science-based management tools and models at multiple scales provides important new opportunities to translate the best interdisciplinary science into useful approaches and usable information to address important water availability/use management issues. Following is a limited summary of hydrologic and ecologic assessment tools that will be served on the NWC Data Platform.

Hydrologic Models

To achieve the objectives of the NWC a wide variety of models will be used. Watershed models provide insight into the routing of water through a catchment, simulate watershed processes, and can be used to assess the hydrologic and water-quality effects of land-use change, climate change, and water control structures. Groundwater models and coupled groundwater-surface water models provide a means to simulate groundwater flow and transport and the interactions between surface water and groundwater. Ecological models provide a means to scientifically assess a wide variety of habitat management issues related to water availability and quality. Land use change models are used to assess the impacts of human activities on a watershed. Integration of the various models will provide a means to better understand the complex relationships between human activities, ecological communities, and the availability and quality of water in a hydrologic system.

Statistical Analysis Tools

A variety of statistical techniques will be used to extract information from large data sets and to distinguish between variations caused by real effects as opposed to those resulting from random chance. Statistical analysis will also provide a means to summarize information in a way that helps resource managers make decisions where variability obscures the answers.

Repository to archive models

The NWC model archive will contain comprehensive model documentation, input files, source code, code version, output files, and output analysis approaches. Archiving NWC data and models will provide the ability to reproduce results and perform additional analyses while saving the cost of redundant data collection activities. Archived models will provide the methodological detail of numerical modeling studies to recreate published modeling results, enabling the synthesis of results across modeling studies and the investigation of new hypotheses. In addition, archived models will allow determination of uncertainties for comparison with results from other models.

Scenario development

Future hydrologic/ecologic assessment tools will require scenario-building and multiple-scale visualization tools to evaluate the complex interactions between competing water demands and hydrologic/ecologic responses, the uncertainty involved with climate change impacts and other hydrologic/ecologic drivers; and, to synthesize the large amounts of available information within a framework that explicitly recognizes this complexity and uncertainty. With adequate tools to model these complex uncertain systems, decision-makers will be able to assess consequences of specific policies and decisions within appropriate scenarios. The integrated, science-based tools can be used to inform local, State, and Federal decisions by helping stakeholders visualize the effects of alternative futures on valued ecological and socioeconomic endpoints. Ultimately, the wealth of information made possible by sophisticated national-scale linked-databases and associated forecasts will require interpretation within a conceptual framework based on scenarios that can be understood by decision makers and their stakeholders.

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