Water Resources Research Act Program—Current Status, Development Opportunities, and Priorities for 2020–30

Circular 1488

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

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By Mary J. Donohue, Earl A. Greene, and Darren T. Lerner

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U.S. Geological Survey, Reston, Virginia: 2021

Suggested citation:
Donohue, M.J., Greene, E.A., and Lerner, D.T., 2021, Water Resources Research Act Program—Current status, development opportunities, and priorities for 2020–30: U.S. Geological Survey Circular 1488, 27 p., https://doi.org/10.3133/cir1488.

ISSN 1067-084X (print)
ISSN 2330-5703 (online)

ISBN 978-1-4113-4424-2

Preface

This Circular presents a vision for the U.S. Geological Survey Water Resources Research Act (WRRA) Program for the next 10 years (2020–30). It was produced at the request of the WRRA Program with input from the U.S. Geological Survey Water Resources Mission Area, an ad hoc vision committee convened by the Federal WRRA program coordinator, and the 54 associated State water resources research institutes and centers. The members of the ad hoc vision committee were directors of State WRRA institutes or centers and were selected for their disciplinary expertise in water resources, programmatic planning experience, and knowledge of stakeholder and partner relationships. Vision committee members also were selected to aid in achieving regional geographical representation indicative of the diverse hydrological, ecological, and socioeconomic circumstances of our Nation. This vision also was informed and guided by the "U.S. Geological Survey Water Science Strategy—Observing, Understanding, Predicting, and Delivering Water Science to the Nation" and the "U.S. Geological Survey Bureau Workforce Plan: 2015–2020." As a Federal-State partnership, The WRRA Program is authorized by the Water Resources Research Act of 1964, as amended in 1984 to (1) plan, facilitate, and conduct research to aid in the resolution of State and regional water problems; (2) promote technology transfer and the dissemination and application of research results; (3) provide for the training of scientists and engineers through their participation in research; and (4) provide for competitive grants to be awarded under the WRRA. The vision supports the legislative mandates of the WRRA for the next 10 years, recognizing opportunities available as a result of the network of 54 State and territorial water resources research institutes and centers established by the act at our Nation's premier universities and colleges.

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Flow rate	
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Abbreviations

USGS	U.S. Geological Survey
WMA	Water Resources Mission Area
WRRA	Water Resources Research Act

Water Resources Research Act Program—Current Status, Development Opportunities, and Priorities for 2020–30

By Mary J. Donohue,[1] Earl A. Greene,[2] and Darren T. Lerner[1]

Executive Summary

Liquid water has long been identified as fundamental to the habitability of our planet and life on Earth (Kasting and others, 1993). Availability of and access to safe, adequate freshwater supplies are critical to our Nation's prosperity and quality of life. Socioeconomics, geopolitical stressors, population growth, and climate variability, among other factors, provide challenges for management of water resources. The U.S. Geological Survey (USGS) is the primary agency tasked with serving our Nation through "…observing, understanding, predicting, and delivering water science to the Nation" (Evenson and others, 2013, p. 2). The USGS Water Resources Research Act (WRRA) Program connects our Nation's academic capital to the USGS mission by delivering university-based research, outreach, and education services to our citizens.

For more than 50 years, the WRRA Program has invested in local, State, and regionally focused water-related research; information and technology transfer; and workforce development through student training and professional internships. A true Federal-State partnership, the WRRA Program is administered in the Office of Planning and Programming of the USGS Water Resources Mission Area (WMA) and complements, but is distinct from, the WMA Science Centers and Divisions.

Unique to the WRRA Program are the congressionally established and mandated State water resources research institutes based at our Nation's universities and colleges (Water Resources Research Act of 1984; Public Law 88–379, Stat. 78). Institutes complete water-related research, outreach, and education activities to seek solutions to and resolve our Nation's water problems. The 54 State water resources research institutes (or centers) provide water-related services in the 50 States, the District of Columbia, and the territories of Puerto Rico, the U.S. Virgin Islands, and Guam. The WRRA Program has demonstrated success in serving our Nation, having funded hundreds of competitive research projects annually and trained nearly 11,000 students in a recent 16-year period (Donohue and Lerner, 2018).

In May 2018, the Federal program coordinator of the WRRA Program charged an ad hoc vision committee with developing a long-term (10-year) vision for the WRRA Program. This report fulfills that request. Vision committee members were directors of State WRRA institutes (or centers) and were selected for their disciplinary expertise in water resources, programmatic planning experience, and stakeholder relations. Vision committee members also were selected to include representation that reflected the diverse hydrological, ecological, and socioeconomic circumstances of different regions throughout the Nation. The vision committee worked in partnership with the WRRA Program coordinator and sought contributions from the 54 WRRA Program State institutes.

Water Resources Research Act Program Vision

The WRRA Program and its National Institutes for Water Resources are the premier university network instrumental in addressing State/territorial, regional, and national water issues by completing and applying research, sharing information and technology, and developing a diverse workforce.

Core Capabilities

This report identifies and describes four WRRA Program core capabilities that serve as a structural matrix for the program's thematic work. Core capabilities define the operational scope and distinctive character of the WRRA Program within the USGS WMA and reflect the mandates of the WRRA.

A University-Based National Network

The WRRA Program is unique among USGS programs in that it consists of an established network of diverse expertise embedded in our Nation's universities. The program's university-based institutes and centers bring to bear the capacity of our Nation's higher education enterprise on water-related issues.

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[2]U.S. Geological Survey.

Stakeholder-Driven Science (Research)

Discovering practical solutions and new technology to resolve our Nation's water resources challenges is the foundation of the WRRA Program research enterprise. The WRRA Program engages water users, managers, policymakers, and others to understand research needs and direct competitive funding, while maintaining a focus on USGS-relevant mission areas.

Outreach and Engagement

Providing evidence-based information and technology transfer as objective brokers defines the outreach and engagement role of the WRRA Program. The WRRA Program communicates research results and facilitates technology transfer among and between Federal agencies, localities, States, the public, and other users of water-related technology and information.

Education and Training

A foundational component of the WRRA Program is workforce development and, more broadly, water literacy of our Nation's citizens. This component is completed, in part, by training thousands of university and college students in water-related disciplines and through professional internships with the USGS Science Centers.

Vision Focus Areas

Seven focus areas are presented as a thematic framework around which to organize priorities and goals. Specific investment opportunities or strategies were developed for each goal. In total, 122 opportunities and strategies were identified in support of the vision; these opportunities and strategies were not prioritized to maintain flexibility of implementation.

Achievement of the goals articulated in this vision document will increase water available to users, water quality and safety, water supply reliability, a skilled U.S. workforce, and functioning ecosystems and drainage basins that support human and environmental health. Achievement of the goals articulated in this vision document will decrease waterborne threats to public health, socioeconomic water inequities, effects of flooding events, and water use conflicts.

Focus Area—Water Scarcity and Availability

Priority.—Drivers and outcomes of water availability and demand are understood and addressed to sustain human and environmental needs.

Goals.—The following goals have been set to address water scarcity and availability.

- Quantify agricultural water needs and opportunities for conservation and efficiency.
- Improve understanding of groundwater resources, including recharge, to achieve effective management and governance.
- Provide solutions, resources, and tools to mitigate competing uses for variable surface water supplies.
- Develop knowledge to manage drought risk and effects of climate variability.
- Advance science, outreach, and education to meet water, energy, and food needs.

Focus Area—Water-Related Hazards and Climate Variability

Priority.—Extreme hydrologic events and the effects of climate variability are understood and addressed to enhance community preparedness and resilience.

Goals.—The following goals have been set to address water-related hazards and climate variability.

- Increase outreach and engagement to communities, including underserved and vulnerable populations, to increase preparedness and recovery from extreme events.
- Mobilize scientific expertise of the USGS water resources research institute network to rapidly respond to hazards at local, State, and territorial levels.
- Understand infrastructure relations to acute and chronic hazards.
- Protect water security by ensuring water availability and sanitation.

Focus Area—Water Quality

Priority.—High-quality water that is safe and accessible is ensured to sustain humans and ecosystems.

Goals.—The following goals have been set to address water quality.

- Decrease incidence and severity of waterborne pathogens including harmful algal bloom events.
- Minimize human and environmental health risks from legacy and emerging water contaminants.

Focus Area—Water Policy, Planning, and Socioeconomics

Priority.—Policy, planning, and socioeconomics are integrated and applied toward the comprehensive management and governance of water resources.

Goals.—The following goals have been set to address water policy, planning, and socioeconomics.

- Enhance understanding and ramifications of the valuation of water.
- Investigate the human dimensions of water resources.
- Support sound public policy through evidence-based contributions, outreach, and effective science communications.
- Enhance effectiveness and robustness of water-related infrastructure planning.
- Complete multiple resource analysis.
- Complete informative, integrated water resource models.
- Increase transdisciplinary approaches incorporating economics in water-related issues.
- Assess the economic value of USGS water science and data.

Focus Area—Ecosystem and Drainage Basin Functions

Priority.—Ecosystem and drainage basin functions are conserved to support and revitalize ecosystem services.

Goals.—The following goals have been set to address ecosystem and drainage basin functions.

- Contribute to the development of a robust and informative National Water Model.
- Advance science, outreach, and education to improve/maintain the condition of ecosystem and drainage basin functions to ensure the provision of ecosystem services.

Focus Area—Water Technology and Innovation

Priority.—State-of-the-art water technology and innovation are advanced to meet societal and ecosystem needs.

Goals.—The following goals have been set to address water technology and innovation.

- Provide innovative educational and entrepreneurial programs.
- Advance research and development on water innovation, including innovation for urban areas.
- Advance water technology innovation to meet energy, food, and water needs.
- Transfer innovative water technology research to stakeholders.
- Explore industrial ecology to meet water-related needs.

Focus Area—Workforce Development and Water Literacy

Priority.—A diverse workforce equipped to address our Nation's need for water resources is achieved in concert with greater public understanding of water resources.

Goals.—The following goals have been set to address workforce development and water literacy.

- Increase experiential education opportunities for students, including students from underrepresented and underserved groups.
- Increase capacity and opportunities to share and translate research results with stakeholders.
- Cultivate and nurture an institutional culture that embraces diversity, equity, and inclusion.
- Enhance programmatic capacity in science communications.

Conclusions

The Federal legislative mandates and resulting activities, outcomes, and effects of the WRRA Program have demonstrated their utility and value to the Nation for more than 50 years. The WRRA Program's distributed reach, across all 50 States, U.S. territories, and the District of Columbia, via its university-based State institutes and centers, ensures that the needs and perspectives of all our Nation's citizens are acknowledged and addressed.

Nonetheless, the future facing our Nation is uncertain with regard to climate variability and its effects on water scarcity and availability. We also face increasingly common water-related hazardous events. Legacy and emerging contaminants pose a threat to our water resources and human and ecosystem health. These circumstances pose challenges in achieving adequate and safe freshwater for people and our Nation's agriculture and industry sectors. This vision document acknowledges the priorities and goals in the focus areas presented and offers paths forward, in the form of specific opportunities/strategies to implement now and in the coming decade in support of our Nation's prosperity.

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Introduction

Though safe, adequate freshwater supplies have always shaped humanity, perhaps at no time in humankind's experience have water resources been of greater interest. Increasing populations, socioeconomic and geopolitical stressors, emerging and legacy contaminants, and other factors affecting water resources are now compounded by climate variability—often resulting in too little, or too much, water regionally. Further, water resources and production are inextricably linked to food and energy production and security (Hoff, 2011; D'Odorico and others, 2018; Newell and others, 2019) and climate (Beck and Villarroel Walker, 2013); the complex interactions among these processes are known as the food-energy-water-climate nexus. Though such interactions are not always obvious, they form lifeline systems linked "…with the economic well-being, security, and social fabric of the communities they serve" (O'Rourke, 2007, p. 23).

Water resources support a hundred-billion-dollar economy in the United States. In 2005, surface water monitored by U.S. Geological Survey (USGS) streamgages totaled 270 billion gallons per day for irrigation, industry, thermoelectric power, and drinking water (Kenny and others, 2009) with an estimated instream economic value of more than $21 billion in 2010 dollars (Kauffman, 2010). Ecosystem services and wetland habitat in U.S. National Wildlife Refuges totaled $27 billion in 2008 dollars (Ingraham and Foster, 2008). Wildlife recreation that largely depends on clean water provided $122 billion in annual expenditures including fishing ($42 billion), hunting ($23 billion), and bird/wildlife watching ($46 billion) in 2006 (U.S. Department of the Interior, Fish and Wildlife Service, and U.S. Department of Commerce, U.S. Census Bureau, 2008). The outdoor recreation economy totals $140 billion nationally for water sports such as boating, paddling, and sailing (Outdoor Industry Association, 2017).

The Delaware River Basin alone contributes more than $22 billion in annual economic activity and more than 600,000 jobs (Kauffman, 2016), and the largest estuary in the United States, Chesapeake Bay, is estimated to support a trillion-dollar economy (Chesapeake Bay Watershed Blue Ribbon Finance Panel, 2004). The Colorado River is the foundation of a $1.4 trillion economy that provides 16 million jobs in California, Arizona, Nevada, Utah, Colorado, New Mexico, and Wyoming, or about 12 percent of the U.S. gross domestic product in 2012 (James and others, 2014). Further, the United States would gain $220 billion in economic activity annually and generate 1.3 million jobs by investing an additional $82 billion annually for the next 10 years in water and wastewater infrastructure (Value of Water Campaign, 2017).

Though positive economic opportunities associated with water resources are substantial, negative effects from extreme hydrologic events and the effects of climate variability pose risks to life and property (Adikari and Yoshitani, 2009; Jha and others, 2012). Effects to critical infrastructure are of key concern, particularly the interdependent lifeline systems as described by O'Rourke (2007), among them water supply. Elements of lifeline systems such as wastewater-treatment facilities, agriculture and food systems, water supply systems, and airports and other transportation are often susceptible to hydrologic events. Events and effects that result in too much—or too little—water may include floods, droughts, wildfire, land or mudslides and debris flows. Hydrologic events associated with weather and geologic events such as earthquakes and associated tsunamis also may affect key infrastructure such as port facilities and harbors (Wood and Good, 2004).

The USGS has a broad portfolio addressing water-related issues, including hazard science. Working collaboratively with partners, the USGS observes and monitors water and water-related properties, provides assessments, completes targeted research, and delivers information broadly to users. The Water Resources Mission Area (WMA), one of five mission areas around which the USGS is organized, encompasses the WMA Science Centers and oversees five divisions (Observing Systems, Laboratory and Analytical Services, Earth System Processes, Integrated Modeling and Prediction, and Integrated Information Dissemination) and four programs: the Water Availability and Use Science Program, Groundwater and Streamflow Information Program, National Water Quality Program, and Water Resources Research Act (WRRA) Program.

For more than 50 years, the USGS WRRA Program has invested in university-based local, State, and regionally focused water-related research; information and technology transfer; and workforce development through student training. A true Federal-State partnership, the WRRA Program includes a functional network of 54 State water resources research institutes or centers at our Nation's universities—connecting our Nation's intellectual capital to the USGS mission in the service of our citizens.

The vision of the WRRA Program is as follows. The WRRA Program and its National Institutes for Water Resources are the premier university network instrumental in addressing State/territorial, regional, and national water issues by completing and applying research, sharing information and technology, and developing a diverse workforce.

Background

History and Structure of the Water Resources Research Act Program

To address water issues at the State and regional level, the Water Resources Research Act of 1964, as amended in 1984 (Water Resources Research Act of 1984; Public Law 88–379, Stat. 78), established institutes in each State and territory to (1) plan, facilitate, and conduct research to aid in the resolution of State and regional water problems; (2) promote technology transfer and the dissemination and application of research results; (3) provide for the training of scientists and engineers through their participation in research; and (4) provide for competitive grants to be awarded under the WRRA Program.

Today, 54 WRRA Program institutes based at our Nation's universities and colleges provide water-related services in the 50 States, the District of Columbia, and the territories of Puerto Rico, the U.S. Virgin Islands, and Guam. Collectively, the institutes are organized as the National Institutes for Water Resources.

The WRRA Program was originally housed in the Department of the Interior Water and Science Division, and in 1984, the program was placed under the administration of the USGS. The WRRA Program is one of four programs in the USGS WMA, Office of Planning and Programming. Unique to the WMA programs, the WRRA institutes (or centers) are sited and administered at our Nation's universities. This Federal-State partnership of the WRRA Program and associated institutes and centers allows and facilitates the engagement of Federal water agencies with our Nation's universities on water issues of importance to our Nation.

The WRRA Program has broad authority to address water resources issues within the areas stated by the act inclusive of water supply/availability, water quality, infrastructure/engineering solutions, treatment technologies and efficiencies, economics and policy, and understanding aquatic ecosystems from a water-quality and quantity perspective.

There are four grant types through which the WRRA Program fulfills its legislative mandate in addressing water-related issues.

Annual base grants (104b).—The flagship element of the WRRA Program, annual base grants provide Federal support to the legislatively established institutes and centers in each State or territory to assist in developing solutions to hydrologic issues. This support is provided through funding competitive university-based research, disseminating results of research to water managers and the public, and providing hands-on training to students by supporting their participation in research. Across all institutes and centers, about 230 research projects are funded annually. From 2000 through 2015, an average of 678 students per year were supported and trained by the WRRA Program, nearly 11,000 over the 16-year period (Donohue and Lerner, 2018). Annual base grants (104b) are awarded under provisions of section 104 of the Water Resources Research Act of 1984, as amended, and require grant recipient institutes to provide $2 of non-Federal match for every $1 of Federal funding received.

National competitive grants (104g).—To address hydrologic issues of an interstate, regional, or national scope, national competitive grants provide opportunities for university scholars to collaborate with USGS scientists on research of the highest quality. National competitive grants also may be awarded to address a specific program priority identified by the U.S. Secretary of the Interior and the water resources research institutes or centers. Like annual base grants, dissemination of associated research results and training of scientists in water resources are elements of national competitive grants. These highly competitive, merit-based awards are typically large, multiyear and multi-institute projects that engage several USGS scientists and multiple university faculty. Any investigator at an accredited institution of higher learning in the United States is eligible to apply for a grant through a water research institute or center established under the provisions of the WRRA. Grant recipients are required to match each dollar of Federal funding awarded with $1 from non-Federal sources.

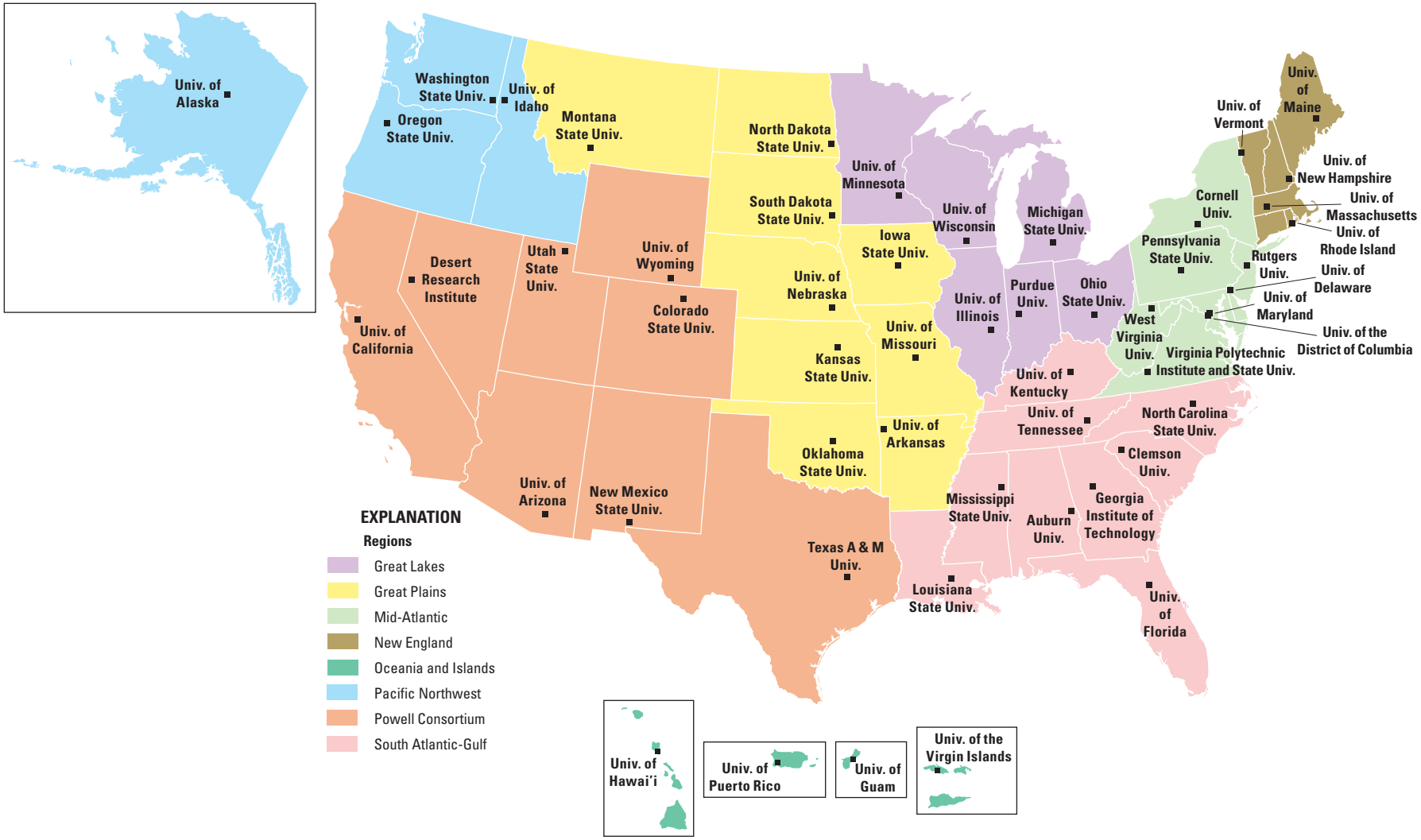
Coordination grants.—Coordination grants provide additional opportunities for the USGS and other U.S. Federal agencies to access and benefit from the expertise of our Nation's university faculty and students through the network of institutes and centers established by the WRRA. Coordination grants are established when a Federal agency or program of the U.S. Government, including those within the Department of the Interior, provides funding to the USGS to "pass through" to an institute or center established by the WRRA to complete hydrologic research. Although coordination grants fund research related to the missions of Federal programs concerned with water resources, research must fall within the provisions of the WRRA, advance the science of hydrology or related disciplines, and be of interest to the Nation.

National student internships.—As part of a formal internship program established by the WRRA, interns participate in USGS activities that include field and laboratory-based research in association with USGS Science Centers. The USGS Science Centers fund interns who are hired by WRRA Program institutes or centers. Interns are employees of host universities and colleges and may be students from any accredited postsecondary institution in the State of a WRRA institute or center. Students commonly work alongside Federal scientists in a USGS Water Science Center. Unlike

Water Resources Research Act Program

The Water Resources Research Act (WRRA) Program is a unique research, education, and outreach program of the U.S. Geological Survey that includes an established network of 54 institutes or centers embedded in our Nation's universities. Established in 1964 by the U.S. Congress, the WRRA Program is structured to connect our Nation's university enterprise to the U.S. Geological Survey mission, and vice versa, and provides a mechanism for university researchers to rapidly respond to emerging water-related issues of national concern. Located in each State, three U.S. territories, and the District of Columbia, institutes and centers operate and engage locally, at the State and territorial level, and regionally and nationally. The WRRA Program supports workforce development and water literacy through training water-resources students and professionals, completing stakeholder-driven science and policy, and translating research results and transferring technology through evidence-based outreach to users.

The U.S. Geological Survey research vessel Kaho was christened and commissioned on August 6, 2014, in Oswego, New York. The vessel was designed with state-of-the-art navigation and scientific capabilities, giving the U.S. Geological Survey modern scientific resources for research into Lake Ontario's coastal and deep-water ecosystems. Photograph by U.S. Geological Survey.



Map of the 54 Water Resources Research Act Program institutes and centers by State, territory, or district location; university partner; and geographic region. The institutes and centers were established by the Water Resources Research Act of 1964, as amended in 1984 (Public Law 88–379, Stat. 78). The U.S. Geological Survey began administering the Water Resources Research Act Program in 1984. Map generated using data from the National Institutes for Water Resources (2014).

coordination grants, only the USGS can establish an intern within this program; that is, no "pass-through" funding of interns occurs through other Federal agencies or programs.

In fulfilling its mandates, the WRRA Program has trained or supported tens of thousands of students and funded thousands of research projects addressing water resources. Critically, institutes connect university expertise on water-related issues to water users and managers at local, regional, and national levels. Institutes achieve this success in part by leveraging their Federal investment through non-Federal dollars from partnerships; an arrangement that ensures a good value for the U.S. investment. The local and State focus of the WRRA Program is distinctive within the USGS's primarily national focus. The structure of the WRRA Program also promotes institute flexibility and agility in addressing emerging water resources issues adaptable to local cultures, institutions of governance, and regional socioeconomic and physical conditions.

Water Resources Research Act Program Visioning Process

In May 2018, the WRRA Program began a collaborative visioning process to guide the program and activities of its 54 university-based State institutes and centers over the next 10 years (2020–30). The purpose of the visioning was to (1) determine the WRRA Program's most appropriate roles over the next 10 years and (2) identify priority research, outreach and engagement, and education strategies leading to reliable, sustainable quantities of quality water in support of sustainable economic development, environmental health, water-related hazard resilience, and social equity and well-being.

This report presents a vision for the USGS WRRA Program for the next 10 years. It was produced at the request of the WRRA Program with input from the USGS WMA, an ad hoc vision committee convened by the Federal coordinator of the WRRA Program, and the 54 associated State water resources research institutes and centers. The members of the ad hoc vision committee were directors of State WRRA institutes or centers and selected for their disciplinary expertise in water resources, programmatic planning experience, and stakeholder relations. Vision committee members also were selected toward achieving regional geographical representation indicative of the diverse hydrological, ecological, and socioeconomic circumstances of the Nation.

The visioning process also was informed and guided by the USGS Science Strategy, "Facing Tomorrow's Challenges—U.S. Geological Survey Science in the Decade 2007–2017" (U.S. Geological Survey, 2007) and the "U.S. Geological Survey Water Science Strategy—Observing, Understanding, Predicting, and Delivering Water Science to the Nation" (Evenson and others, 2013). This vision document broadly supports the priority actions and water science goals and objectives identified and described in the water science strategy (Evenson and others, 2013) but interprets and translates the water science strategy appropriate to a Federal-State partnership program inclusive of the mandates of the WRRA; for example, workforce development. This document also develops specific priorities and goals and associated investment opportunities/strategies scalable to the WRRA Program and its university-based State institutes and centers. These elements and the seven vision focus areas developed herein, are imbued with, and reflect, the Federal-State partnership of the WRRA Program and university-based water institutes and centers.

Core Capabilities

Four core capabilities that create the distinctive character of the WRRA Program within the USGS WMA were recognized in the visioning process. Core capabilities reflect the structure of the WRRA Program that results from specific language in the WRRA. Core capabilities provide a structural matrix that transcends the thematic work of the WRRA Program. The core capability, a university-based national network, facilitates the achievement of the remaining three core capabilities, stakeholder-driven science (research), outreach and engagement, and education and training.

A University-Based National Network

The WRRA Program is unique among USGS programs in that it consists of an established network of diverse expertise embedded in our Nation's universities. The program's university-based institutes and centers bring to bear the capacity of our Nation's higher education enterprise on water-related issues. This structure (fig. 1) facilitates additional features defined here as core capabilities: stakeholder-driven science (research), outreach and engagement, and education and training.

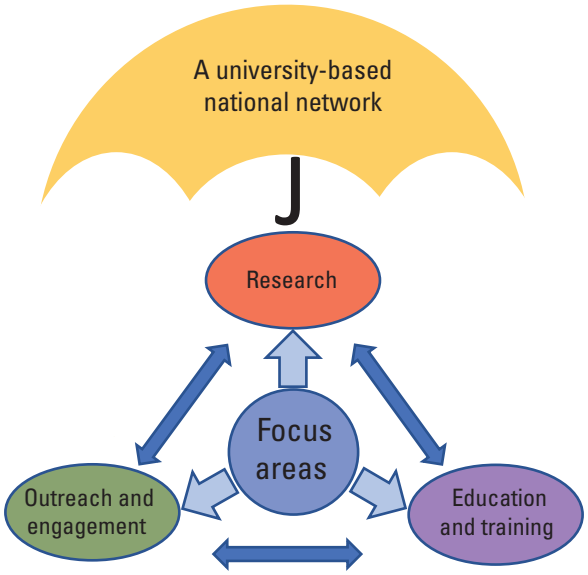


Figure 1. The core capabilities of research, outreach and engagement, and education and training reflect the Federal legislative mandate of the Water Resources Research Act Program and shape activities completed at the State level. A fourth core capability, "a university-based national network" provides an overarching operational programmatic framework. Relations among core capabilities and focus areas are dynamic and iterative.

Stakeholder-Driven Science (Research)

Discovering practical solutions and new technology to resolve our Nation's water resources challenges is the foundation of the WRRA Program research enterprise. The WRRA Program engages water users, managers, policymakers, and others to understand research needs and direct competitive funding, while maintaining a focus on USGS-relevant mission areas. Using this integrated "bottom up" and "top down" approach ensures research results are relevant at multiple scales and to diverse users.

Outreach and Engagement

Providing evidence-based information and technology transfer as objective brokers defines the outreach and engagement role of the WRRA Program. The WRRA Program communicates research results and facilitates technology transfer among and between Federal agencies, localities, States, the public, and other users of water-related technology and information. This engagement is achieved through traditional outreach and extension models and emerging models, such as the coproduction approach.

Education and Training

A foundational component of the WRRA Program is workforce development and, more broadly, water literacy of our Nation's citizens. This is achieved, in part, by training thousands of university and college students in water-related disciplines and through professional internships with the USGS Science Centers.

Vision Focus Areas

Focus areas provide a thematic framework around which to organize priorities and goals. An interpretation of each vision focus area is provided as a refined vision statement, or priority, from which the associated goals were developed. For each goal, one or more investment opportunities/strategies are identified. Where multiple investment opportunities/strategies are identified, they are listed for organizational clarity but are not prioritized or ranked. These opportunities/strategies may be addressed and implemented individually or in multiple variations in response to national need inclusive of the hydrological, ecological, and socioeconomic circumstances of specific stakeholders and constituents. Further, the opportunities/strategies identified are not intended to be exhaustive, and adaptive planning may be necessary to address emerging issues including hazards.

Achievement of the goals articulated in this vision document will increase water available to users, water quality and safety, water supply reliability, a skilled U.S. workforce, and functioning ecosystems and drainage basins that support human and environmental health. Achievement of the goals articulated in this vision document will decrease waterborne threats to public health, socioeconomic water inequities, effects of flooding events, and water use conflicts.

Water Scarcity and Availability

Priority.—Drivers and outcomes of water availability and demand are understood and addressed to sustain human and environmental needs (table 1).

Water-Related Hazards and Climate Variability

Priority.—Extreme hydrologic events and the effects of climate variability are understood and addressed to enhance community preparedness and resilience (table 2).

Water Quality

Priority.—High-quality water that is safe and accessible is ensured to sustain humans and ecosystems (table 3).

Water Policy, Planning, and Socioeconomics

Priority.—Policy, planning, and socioeconomics are integrated and applied toward the comprehensive management and governance of water resources (table 4).

Ecosystem and Drainage Basin Functions

Priority.—Ecosystem and drainage basin functions are conserved to support and revitalize ecosystem services (table 5).

Water Technology and Innovation

Priority.—State-of-the-art water technology and innovation are advanced to meet societal and ecosystem needs (table 6).

Workforce Development and Water Literacy

Priority.—A diverse workforce equipped to address our Nation's water resources needs is achieved in concert with greater public understanding of water resources (table 7).

Table 1. Water scarcity and availability—priority, goals, and investment opportunities/strategies.

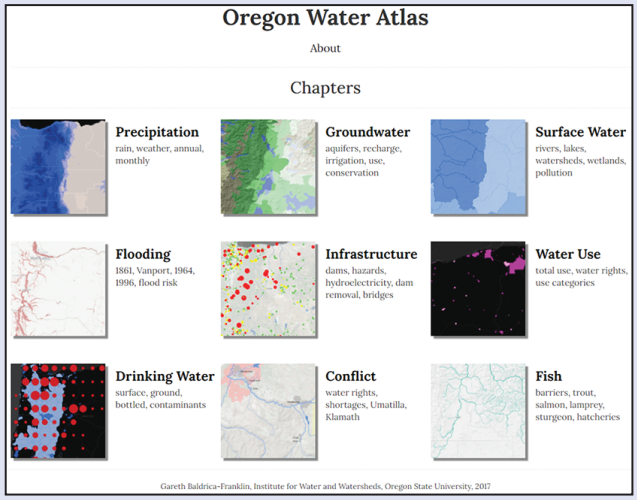
[USGS, U.S. Geological Survey]

Priority	Goal	Investment opportunity/strategy
Drivers and outcomes of water availability and demand are understood and addressed to sustain human and environmental needs.	1. Quantify agricultural water needs and opportunities for conservation and efficiency.	1.a. Complete remote sensing of crop evapotranspiration. 1.b. Define energy needs and applications to agricultural systems to increase efficiency and resilience. 1.c. Complete irrigation technology integration including "internet of things" and big data applications.
	2. Improve understanding of groundwater resources, including recharge, to achieve effective management and governance.	2.a. Advance integrated modeling that links hydrology to economics and policy/decision making.
	3. Provide solutions, resources, and tools to mitigate competing uses for variable surface water supplies.	3.a. Complete inventory of spatial and temporal environmental flows needed to support aquatic systems. 3.b. Develop white papers to evaluate policy options and economic effects of environmental flow programs.
	4. Develop knowledge to manage drought risk and effects of climate variability.	4.a. Complete inventories, hydrologic characterizations, monitoring, modeling, and drought assessments. 4.b. Complete predictions of drought for local, regional, and national models and stakeholders. 4.c. Complete stakeholder need and perception assessments, and aquatic habitat needs assessments, to clarify drought risks and climate variability effects. 4.d. Investigate effects of drought on water supplies and hydrology. 4.e. Investigate linkages between water scarcity and economic growth. 4.f. Complete economic and social effect assessments of drought risk and climate variability. 4.g. Improve understanding of snowpack dynamics and surface water hydrology under climate variability. 4.h. Link university extension and outreach with USGS resources to improve stakeholder response to drought risks. 4.i. Invest in data poor regions such as rural areas, the U.S. Virgin Islands, and other Pacific territories to bolster our understanding of drought risk and climate variability effects.
	5. Advance science, outreach, and education to meet water, energy, and food needs.	5.a. Invest in food-energy-water systems research and modeling. 5.b. Complete outreach and education on innovative food, energy, and water systems, including aquaculture and aquaponics. 5.c. Establish connectivity among local, State/territorial, and national organizations and entities to coordinate constituent service and leverage investments. 5.d. Build capacity in systems thinking through professional development within and outside USGS water resources research institutes.
	6. Protect water security by ensuring water availability and sanitation.	6.a. Secure access to water through institutional strategies for coping with drought and water scarcity. 6.b. Advance innovative technology for onsite, community, and municipal sanitation infrastructure, technologies, and services. 6.c. Improve the research-policy-action cycle for securing and improving sanitation.

Focus Area—Water Scarcity and Availability

Our vision.—Understanding and addressing drivers and outcomes of water availability and demand are key to sustaining human and environmental needs.

A fundamental aspect of water resources is water availability to sustain human and environmental needs. Scarcity develops when needs are unmet and may result from a lack of quality water, an inability to access or use water, or inefficient use of available water. Water scarcity and availability will continue to be a principal focus of the Water Resources Research Act Program. Key to this focus is improving understanding of our Nation's groundwater resources to achieve effective management and governance. Developing knowledge to manage drought risk and effects of climate variability also will be necessary. Quantifying agricultural water needs and opportunities for conservation and efficiency represent additional key goals. Through such work, the Water Resources Research Act Program will continue to provide solutions, resources, and tools to mitigate competing uses for variable water supplies. These efforts will advance the science, transfer technology to water users and managers, and support education and training needed to meet our Nation's linked water, energy, and food needs.



The "Oregon Water Atlas" has digitally aggregated Oregon's water data and created a dynamic online visualization tool allowing users to directly access and manipulate data on multiple water-related topics. This tool was developed by a student intern supported by the State water resources research institute known as the Oregon Institute for Water and Watersheds through the Water Resources Research Act Program's flagship annual base grants (104b awards). Outreach, including developing tools and technology transfer, is a core capability of the Water Resources Research Act Program. [Image from Baldrica-Franklin, 2017]

Rogue River Canyon in southwest Oregon. Photograph by Ruth Jacobs, U.S. Geological Survey.

Table 2. Water-related hazards and climate variability—priorities, goals, and investment opportunities/strategies.

[USGS, U.S. Geological Survey; NOAA, National Oceanic and Atmospheric Administration]

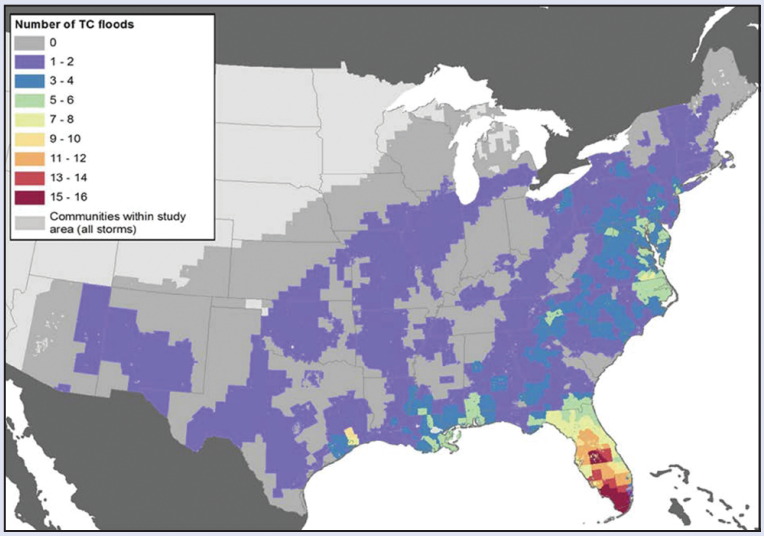
Priority	Goal	Investment opportunity/strategy
Extreme hydrologic events and the effects of climate variability are understood and addressed to enhance community preparedness and resilience. Events and effects may include floods, droughts, hurricanes, sea-level rise, debris flows, tsunamis, and wildfire.	1. Increase outreach and engagement to communities, including underserved and vulnerable populations, to increase preparedness and recovery from extreme events.	1.a. Train students, including underrepresented and underserved students, in hazard science relevant to community-level application. 1.b. Engage local communities to complete local needs assessments and determine community priorities for increasing preparedness inclusive of the coproduction method. 1.c. Translate USGS data and fact sheets for underserved communities (for example, Spanish language). 1.d. Enhance hazard literacy to communities using USGS research and other resources and local USGS water resources research institute expertise. 1.e. Identify interagency synergies, adapt to make hazards communications context specific and culturally relevant.
	2. Mobilize scientific expertise of the USGS water resources research institute network to rapidly respond to hazards at local, State, and territorial levels.	2.a. Develop and deploy rapid response research and outreach teams to hazard or effect events. 2.b. Generate actionable science and outreach to address hazards in response to national needs. 2.c. Generate actionable science and outreach in response to USGS needs. 2.d. Identify synergies and develop collaborations with the NOAA National Sea Grant College Program related to coastal hazards. 2.e. Collect hazard data during and after events to enhance future prediction capabilities.
	3. Understand infrastructure relations to acute and chronic hazards.	3.a Investigate the built environment as it relates to hazard susceptibility, resilience, and recovery. 3.b. Investigate ecological engineering/green infrastructure, such as green roofing systems, swales, holding ponds, wetland and mangrove coastal buffering, and so on to mitigate hazards, such as those associated with stormwater. 3.c. Complete a national synthesis of green infrastructure innovations. 3.d. Integrate the natural and social sciences in hazard-related training and outreach. 3.e. Envision and promote critical policy and technology for water infrastructure; applications include wastewater and water-treatment plants, airports, hospitals, energy generation sites, and so on and susceptibility to hazard-related effects including those resulting from climate variability such as sea-level rise, stormwater, and inundation.
	4. Protect water security by ensuring water availability and sanitation.	4.a. Secure access to water through institutional strategies for coping with drought and water scarcity. 4.b. Advance innovative technology for onsite, community, and municipal sanitation infrastructure, technologies, and services. 4.c. Improve the research-policy-action cycle for securing and improving sanitation.

Focus Area—Water-Related Hazards and Climate Variability

Our vision.—Extreme hydrologic events and the effects of climate variability are addressed.

The U.S. Geological Survey has a long history of service in water-related hazard science. The Water Resources Research Act (WRRA) Program contributes through basic and applied research, outreach to managers and users, and training our next generation of water resources professionals. Climate variability is increasing the challenge of predicting, preparing for, and recovering from water-related hazards such as floods, mud and debris flows, and even wildfire, among many others. Understanding and mitigating hazard effects on critical infrastructure such as water supply systems and treatment facilities, airports and other transportation hubs, and agriculture and food systems is paramount. Water resource decision-makers would benefit from an improved understanding of the relationship of infrastructure to acute and chronic hazards. Unique to the WRRA Program is the ability to mobilize the scientific expertise of the program's 54 university-based institutes and centers to rapidly respond to hazards at local, State, and territorial levels. Key to this response is increased outreach and engagement with communities, including underserved and vulnerable populations, to increase preparedness and recovery from extreme events. Fundamental to this vision is protecting water security by ensuring water availability and sanitation before, during, and after hazardous events.

The WRRA Program national competitive grant program (104g awards) connects university scholars and U.S. Geological Survey scientists on hydrologic issues of an interstate, regional, or national scope such as developing methods to assess residential damage associated with inland flooding from North Atlantic tropical cyclones. Completed in collaboration with the WRRA Program's Iowa Water Center, this research recognizes the most severe effects from heavy rainfall and freshwater flooding are often far removed from the center of these storms, as much as hundreds of kilometers away, with associated societal and economic losses. Characterizing areas of increased risk, characterizing the extent and magnitude of these events, and developing statistical models relating flood magnitude to the number of insurance claims can provide insight on levels of exposure and vulnerability and predict future claims and losses from public and private insurance and Federal disaster relief (Czajkowski and others, 2017; Aryal and others, 2018).



Map of areas at increased risk from inland flooding from North Atlantic tropical cyclones (TCs) east of the Rocky Mountains between 2001 and 2014. [Image unmodified from Czajkowski and others (2017), licensed under the Creative Commons Attribution 4.0 International License]

Table 3. Water quality—priority, goals, and investment opportunities/strategies.

[HAB, harmful algal bloom; USGS, U.S. Geological Survey]

Priority	Goal	Investment opportunity/strategy
High-quality water that is safe and accessible is ensured to sustain humans and ecosystems.	1. Decrease incidence and severity of waterborne pathogens including HAB events.	1.a. Increase understanding of formation, severity, and prediction of waterborne pathogens and HABs using modeling and other tools. 1.b. Evaluate socioeconomic effects of waterborne pathogens and HABs. 1.c. Create a national, spatial-temporal inventory and database of types of HABs. 1.d. Increase knowledge of toxin production that results from HABs. 1.e. Develop technology to mitigate HABs. 1.f. Promote interagency HAB event coordination. 1.g. Accelerate outreach and engagement to reduce sources and effects of waterborne pathogens and HABs, including to agricultural communities. 1.h. Link university extension and outreach with USGS resources to improve stakeholder response to waterborne contaminants including HAB events. 1.i. Provide training for underrepresented minorities.
	2. Minimize human and environmental health risks from legacy and emerging water contaminants.	2.a. Promote innovative technology to monitor water quality. 2.b. Create undergraduate, graduate, and postdoctoral internship and research programs to address water quality. 2.c. Increase community-science efforts that contribute to robust water-quality monitoring. 2.d. Explore water-treatment alternatives to ensure safe water. 2.e. Investigate contaminant transport and degradation in the environment. 2.f. Investigate contaminants associated with water-related infrastructure; for example, aging piping, rainwater harvesting, and so on.
	3. Protect water security by ensuring water availability and sanitation.	3.a. Secure access to water through institutional strategies for coping with drought and water scarcity. 3.b. Advance innovative technology for onsite, community, and municipal sanitation infrastructure, technologies, and services. 3.c. Improve the research-policy-action cycle for securing and improving sanitation.

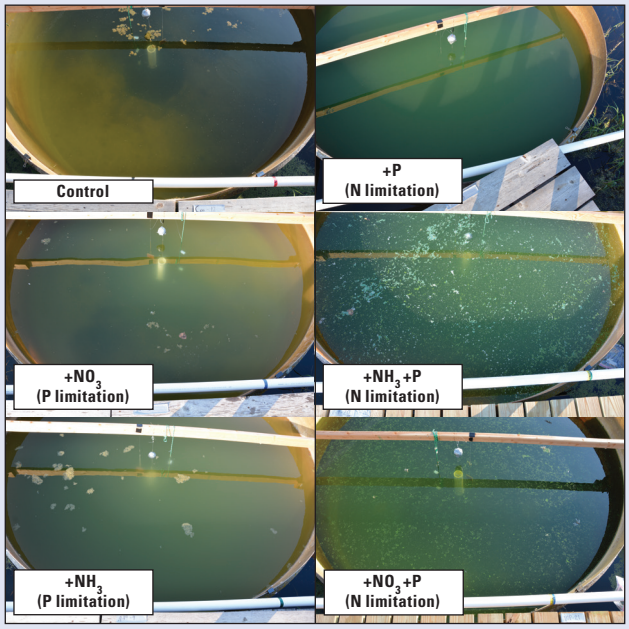
Focus Area—Water Quality

Our vision.—High-quality water that is safe and accessible for humans and ecosystems is ensured.

Immortalized in "The Rime of the Ancient Mariner" by poet Samuel Taylor Coleridge "…Water, water, everywhere, nor any drop to drink…," water quality, irrespective of quantity, is imperative to users. Water quality will remain a focus of the Water Resources Research Act (WRRA) Program in the coming decade. This focus includes water for direct human use and for sustaining functioning ecosystems and the services they provide, upon which humankind relies. Primary goals for the program will include minimizing human and environmental health risks from traditional, legacy, and emerging water contaminants and decreasing the incidence and severity of harmful algal bloom events.

The WRRA Program's Kansas Water Resources Institute, University of Kansas researchers, University of Missouri Limnology Laboratory, and U.S. Environmental Protection Agency Region 7 are investigating the causes of cyanobacterial (blue-green algae) blooms and associated cyanotoxin production through large-scale field experiments. Unlike smaller laboratory experiments, this work approximates real-world conditions and improves understanding of ecosystem-scale processes.

With funding from the WRRA Program's flagship annual base grant (104b), an experiment was performed in 18 large tanks by University of Kansas researcher Ted Harris and colleagues. Initially, clear water tanks were inoculated with water from Milford Reservoir in Kansas—a reservoir with near-annual cyanobacterial blooms—and treated with nitrogen, phosphorous, or both to drive phytoplankton communities into nitrogen or phosphorus limitation.



After 21 days, blooms were present in tanks with added phosphorus (P) but the largest blooms and poisonous cyanobacteria surface scums only formed on tanks where nitrogen (NO_3 or NH_3) and P were added (nitrogen limitation; T. Harris, University of Kansas, unpub. data, 2019). Tank phytoplankton counts, bioavailable nutrients, and cyanotoxins are now under analyses to better understand what triggers harmful algal bloom events and how to prevent them. Photographs by Theodore Harris, Kansas Water Resources Institute, University of Kansas, used with permission.

Table 4. Water policy, planning, and socioeconomics—priority, goals, and investment opportunities/strategies.

[USGS, U.S. Geological Survey; WRRA, Water Resources Research Act]

Priority	Goal	Investment opportunity/strategy
Policy, planning, and socioeconomics are integrated and applied toward the comprehensive management and governance of water resources.	1.Assess economic value of USGS water science and data.	1.a. Develop economic models and frameworks with applications within and beyond water-related issues. 1.b. Estimate the magnitude of economic and (or) societal effects associated with key water-related issues. 1.c. Survey and compile information on use, users, and benefits of scientific information for each mission area from expert scientists, economists, decision makers, data users, and stakeholders. 1.d. Identify and evaluate one or more high-value water science data or information products from each USGS mission area.
	2. Enhance understanding and ramifications of the valuation of water.	2.a. Evaluate the relation between economic development and water availability. 2.b. Evaluate economic costs of poor water quality including treatment costs and adverse effects on various economic sectors such as agriculture, fisheries, and recreation. 2.c. Analyze water cost trends in different use sectors. 2.d. Examine and improve understanding of water pricing and markets. 2.e. Complete cost-benefit analyses of different resource management/optimization strategies.
	3. Investigate the human dimensions of water resources.	3.a. Investigate water-related attitudes, perceptions, beliefs, values, decision making, and behavior change including those of underserved, under-represented, and vulnerable populations with attention to place-based and culturally relevant foci. 3.b. Incorporate and integrate USGS water resources research institute science and outreach with local and traditional ecological knowledge to couple human-hydrologic system models. 3.b.i. Collect, translate, and interpret oral histories to inform current science. 3.b.ii. Invest in historical ecology through student and fellow support, language translation, and national and international archives research, among other efforts. 3.c. Develop and implement new community-science applications.
	4. Support sound public policy through evidence-based contributions, outreach, and effective science communications.	4.a. Translate USGS and university science to inform water-related policy. 4.b. Link university extension and outreach with USGS resources to enhance stakeholder capacity to engage in water-related policy. 4.c. Expand programmatic capacity in science communications, inclusive of the social and natural sciences. 4.d. Develop scientific mediation capacity to serve scientist-scientist and researcher-public spheres. 4.e. Develop a legal analysis component to research, outreach, and education in support of solutions to water-related issues.
	5. Enhance effectiveness and robustness of water-related infrastructure planning.	5.a. Complete assessments of infrastructure condition. 5.b. Complete cost-benefit analyses of infrastructure revitalization and related water costs. 5.c. Complete preplanning assessments of water resources and associated infrastructure.
	6. Complete multiple resource analysis.	6.a. Examine interrelations among multiple demands for resources and how to assess competing broader issues. 6.b. Incorporate multiple scenarios into all goals of policy, planning, and socioeconomics research.
	7. Complete informative, integrated water resource models.	7.a. Integrate physical/biological/socioeconomic elements in all research. 7.b. Integrate economic data with USGS products.

Table 4. Water policy, planning, and socioeconomics—priority, goals, and investment opportunities/strategies.—Continued

[USGS, U.S. Geological Survey; WRRA, Water Resources Research Act]

Priority	Goal	Investment opportunity/strategy
	8. Increase transdisciplinary approaches incorporating economics in water-related issues.	8.a. Sponsor USGS WRRA seminar/webinar series regarding the economics of water. 8.b. Assess opportunities for increased use of USGS water data by local, State, and national users. 8.c. Explore and identify current program research not directly using socio-economic data that could incorporate such data. 8.d. Complete seminar to foster collaborations among economists (Flagstaff, Arizona; Fort Collins, Colorado; and Reston, Virginia), USGS economists, and water resources research institutes with strong economics research capacity and portfolios. 8.e. Establish an economics advisory group/liaison to connect WRRI/USGS researchers.

Focus Area—Water Policy, Planning, and Socioeconomics

Our vision.—Policy, planning, and socioeconomics are integrated and applied toward the comprehensive management and governance of water resources.

Although the physical and natural sciences provide information on water resources themselves, the access, distribution, and use of water resources are informed by human dimensions and behavior addressed by the social sciences. The integrated application of water policy, planning, and socioeconomics is an emerging focus of the Water Resources Research Act (WRRA) Program. This focus area supports advancements in understanding and serving our stakeholder community. Additional efforts will focus on the substantial data and expertise within the U.S. Geological Survey and the application of these assets toward effective, equitable management and governance of our Nation's water resources. A better understanding of the valuation of water and associated ramifications will be key, as will assessing the multiple demands for water resources. Increased transdisciplinary approaches incorporating economics in water-related issues and achieving informative, integrated water resource models represent additional goals. Among the many benefits of such approaches is enhanced effectiveness and robustness of water-related infrastructure planning.

Drinking water contamination is an ongoing issue nationwide, as is tracking water-quality violations and notifying residents—because no systematic approach exists for prioritizing assistance once a violation is detected. The WRRA Program's California Institute for Water Resources is assessing bottled water sales toward improvements in identifying drinking water violations and notifying and aiding residents (Allaire and others, 2019).

Short-term violations, often caused by pathogens, requiring immediate public notification were correlated with a 14-percent increase in bottled water sales (Allaire and others, 2019). This research also identified strategies to improve decades-old modes of public notification using modern communication tools to improve public awareness and residents' ability to respond to contamination risks. Application of the social sciences to water governance and management, such as community water system performance nationwide, represents an area of future growth for the WRRA Program.

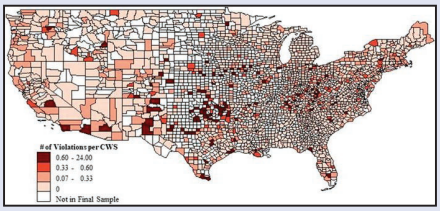


Image unmodified from Allaire and others, 2019, licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives license.
[#, number; CWS, community water system]

Table 5. Ecosystem and drainage basin functions—priority, goals, and investment opportunities/strategies.

[USGS, U.S. Geological Survey]

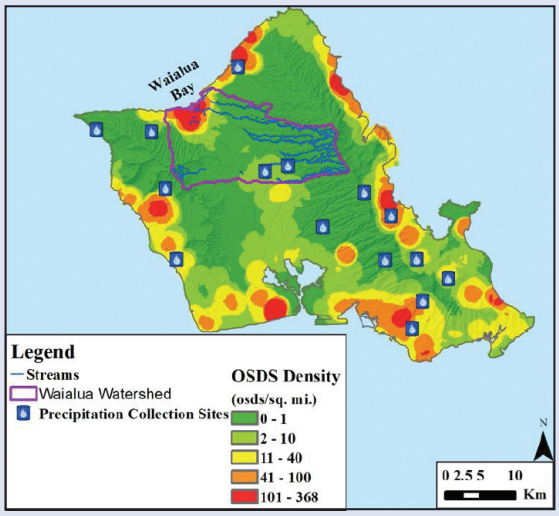
Priority	Goal	Investment opportunity/strategy
Ecosystem and drainage basin functions are conserved to support and revitalize ecosystem services.	1. Contribute to the development of a robust and informative National Water Model.	1.a. Establish a postdoctoral fellowship program focused on research of ecosystem and drainage basin functions to improve the National Water Model (for example, temperature and sediment models). 1.b. Complete an inventory and metadata analysis of instrumented drainage basins, including longitudinal datasets, to identify gaps/needs and opportunities to inform models. 1.c. Fund longitudinal ecological research and similar longitudinal datasets for synthesis into the National Water Model. 1.d. Use and support innovative technologies in ecosystem and drainage basin research such as remote sensing and unmanned aerial vehicle data collection and analysis. 1.e. Establish an undergraduate research internship program focused on research of ecosystem and drainage basin functions.
	2. Advance science, outreach, and education to improve/maintain the condition of ecosystem and drainage basin functions to ensure provision of ecosystem services.	2.a. Create new visualization tools to help communities explore drainage basin scenarios under various time scales. 2.b. Incorporate and integrate USGS water resources research institute science and outreach with local and traditional ecological knowledge to couple human-hydrologic system models. 2.b.i. Collect, translate, and interpret oral histories to inform current science. 2.b.ii. Invest in historical ecology through student and fellow support, language translation, and national and international archives research, among other efforts. 2.c. Develop and implement new community-science applications. 2.d. Link university extension and outreach with USGS resources toward enhanced stakeholder engagement in maintaining ecosystem and drainage basin functions. 2.e. Advance development of criteria and indicators to assess ecosystem and drainage basin function.

Five tule white-fronted geese take off from Summer Lake Wildlife Area in southern Oregon, on the edge of the Great Basin drainage, the primary stopover site for this species on its fall migration. Photograph by Andrea Mott, U.S. Geological Survey.

Focus Area—Ecosystem and Drainage Basin Functions

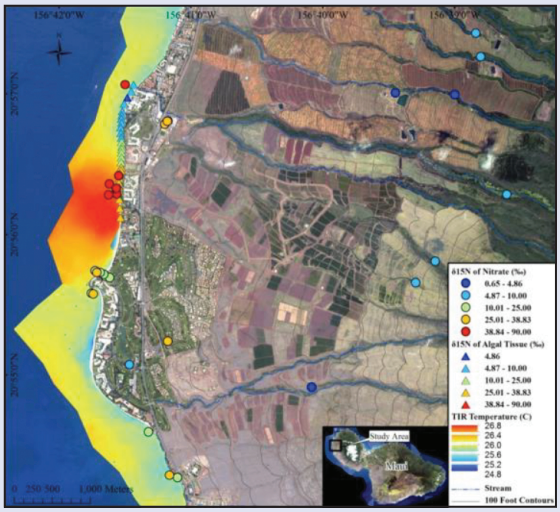
Our vision.—Ecosystem and drainage basin functions are conserved to support and revitalize ecosystem services.

Growing human populations, increased standards of living, climate variability, and other factors are placing resources, including water resources, under pressure. Conserving and revitalizing ecosystem and drainage basin functions is critical to ensure our Nation's prosperity. The Water Resources Research Act (WRRA) Program will focus on completing science and outreach to maintain, and where possible improve, the condition of ecosystem and drainage basin functions including development of a robust and informative National Water Model. An inventory and metadata analysis of instrumented drainage basins is needed to inform models, as is the synthesis and integration of longitudinal ecological research datasets.



Map of O'ahu, Hawai'i, showing onsite sewage disposal systems (OSDS) density and the Waialua drainage basin. More than 1,900 OSDS (1,400 of which are cesspools) are estimated to be in this drainage basin adjacent to Waialua Bay (unmodified from C.R. Glenn and others, University of Hawai'i, unpub. data, 2019, adapted from Whittier and El-Kadi, 2009). [osds/sq. mi., onsite sewage disposal system per square mile; km, kilometer]

Using and supporting innovative research represents additional opportunities. Engaging students at all levels will be integrated in research and outreach. Enriching traditional outreach, the WRRA Program also will promote community-science applications and historical ecology in support of achieving and maintaining functioning drainage basins.



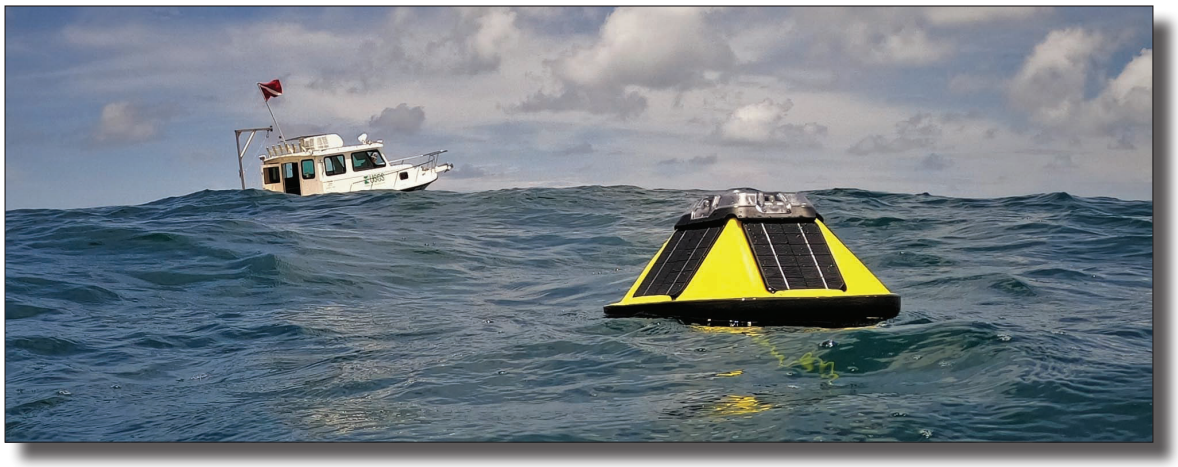
Aerial view of a warm wastewater effluent plume near Lahaina, Maui, showing the correspondence of high values of the ratio of the two stable isotopes of nitrogen, ^{15}N:^{14}N ($\delta^{15}N$), in algal tissue (triangles) and high $\delta^{15}N$ values of dissolved nitrate (circles) with high sea surface temperatures of the effluent also shown. More than 1.5 million gallons per day of injected municipal wastewater effluent resurfaced within this coastal ocean setting (unmodified from Glenn and others, 2013; and compare to Fackrell and others, 2016). [‰, per mil; TIR, thermal infrared; C, degree Celsius]

The WRRA Program partners to leverage U.S. Geological Survey investment, such as research projects cofunded by the University of Hawai'i Water Resources Research Center and Sea Grant College Program on ecosystem and drainage basin functions. These projects explore the hydraulic and geochemical connectivity between land use, such as injected wastewater and onsite sewage disposal systems (that is, septic systems and cesspools) and nearshore Hawaiian waters (for example, Amato and others, 2016; Fackrell and others, 2016; Bishop and others, 2017).

Table 6. Water technology and innovation—priority, goals, and investment opportunities/strategies.

[R & D, research and design; USGS, U.S. Geological Survey]

Priority	Goal	Investment opportunity/strategy
State-of-the-art water technology and innovation are advanced to meet societal and ecosystem needs.	1. Provide innovative educational and entrepreneurial programs.	1.a. Develop community-science applications. 1.b. Support and develop innovative water education programs (for example, blue business ecosystems and Blue Planet).
	2. Advance R & D on water innovation.	2.a. Support R & D in membranes, sensors, subsurface storage, and biofouling. 2.b. Support R & D in legacy and emerging contaminant detection and treatment. 2.c. Support R & D in water reuse technology. 2.d. Support R & D in water-to-energy technology (for example, microbiological fuel cells, wave energy, aquifer recharge and recovery, among others). 2.e. Support R & D on innovative water infrastructure including green infrastructure.
	3. Advance water technology innovation to meet energy, food, and water needs.	3.a. Advance desalination technologies. 3.b. Advance technologies to minimize crop water use and optimize irrigation practices. 3.c. Support development of new crop varieties and cultivars to minimize water use. 3.d. Investigate aquaculture and aquaponics water-related technologies to advance food availability and security.
	4. Transfer innovative water technology research to stakeholders.	4.a. Identify water-related technology needs using the coproduction approach. 4.b. Expand programmatic capacity in science communications at State, regional, and national levels. 4.c. Strengthen programmatic outreach capacity. 4.d. Link university extension and outreach with USGS resources to improve technology transfer to stakeholders.
	5. Explore industrial ecology to meet water-related needs.	5.a. Advance understanding of the energy-food-water nexus. 5.b. Develop industrial ecology infrastructure and technologies. 5.c. Complete economic and legal analyses of industrial ecology water-related applications.



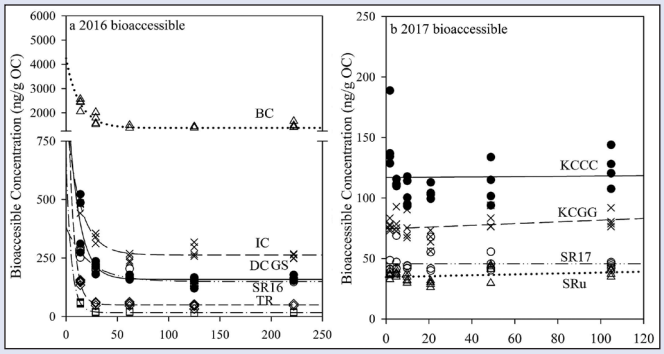
A solar-powered Sofar spotter buoy floats in the water next to the research vessel Sallenger. This instrument, along with an additional instrument on the seafloor, will deliver high-fidelity, real-time wave, water level, and wind data to scientists at the U.S. Geological Survey St. Petersburg Coastal and Marine Science Center. This buoy, along with other instruments further inshore and a camera on the beach, will be used to collect data to track how waves and water level transform as they travel towards the beach. This information is used to assess the skill and improve models used in the Total Water Level and Coastal Change Forecast Viewer. These forecasts help inform coastal communities about potential coastal hazards. Photograph by BJ Reynolds, U.S. Geological Survey.

Focus Area—Water Technology and Innovation

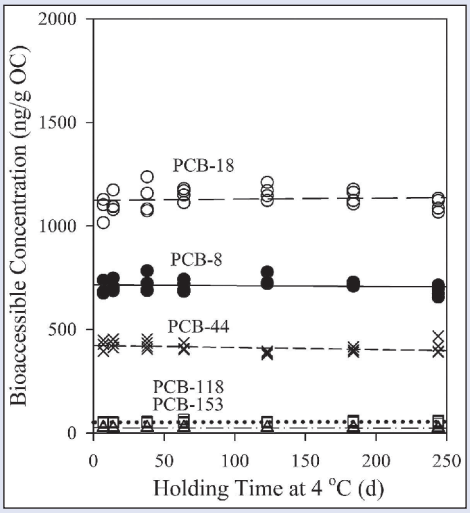
Our vision.—State-of-the-art water technology and innovation are advanced to meet societal and ecosystem needs.

The Water Resources Research Act (WRRA) Program recognizes that advancements and innovations in water-related technology will be required to meet the needs of society and the ecosystems that sustain us. Among the goals for this focus area is advancing research and development on water innovation. The complex interdependent systems that produce our energy, food, and water will require new technologies to sustain our Nation's growth. Exploration of the role of industrial ecology to meet water-related needs is an additional goal. Water technology and innovation represent not only opportunities for research but also key areas in which the transfer of research results to stakeholders can advance our Nation's security and prosperity. As such, providing innovative educational and entrepreneurial programs in water technology and innovation also is a key goal of the WRRA Program.

The WRRA Program national competitive grants program (104g awards) connects university scholars and U.S. Geological Survey scientists on hydrologic issues of an interstate, regional, or national scope; for example, using an innovative testing method to indicate that storing sediment samples before testing may bias toxicity estimates for recently deposited contaminants (Huff Hartz and others, 2018). The single-point Tenax extraction method estimates bioaccessible concentrations with sufficient temporal resolution to track changes in concentrations during recommended sediment holding times. Completed in collaboration with the WRRA Program's Illinois Water Resources Center, this research determined exposure to pyrethroid insecticides may be underestimated pending sample storage time (Huff Hartz and others, 2018).



Bioaccessible concentrations of bifenthrin, a pyrethroid insecticide, with sediment holding time from six California sites in 2016 showing first-order loss with half-lives from 3 to 45 days of holding, or slower; linear decreases are as much as 14 percent over 220 days (shown in graph a). Bioaccessible concentration declines were likely due to the timing of pesticide application. Recently applied compounds are more susceptible to differences in bioaccessibility (shown in graph a) than compounds that have had time to reach steady state in field sediments (shown in graph b). [Images unmodified from Huff Hartz and others, 2018, used with permission; ng/g OC, nanogram per gram organic carbon; °C, degree Celsius; d, day; BC, IC, DC, GS, SR16, TR, KCCC, KCGG, SR17, and SRu refer to sample sites in the California study area]



Bioaccessible concentrations of five polychlorinated biphenyls (PCBs) sampled in 2017, but deposited decades before, in sediments at a Superfund site in Michigan seem to have achieved steady state and do not change with sediment holding time. [Image unmodified from Huff Hartz and others, 2018, used with permission; ng/g OC, nanogram per gram organic carbon; °C, degree Celsius; d, day]

Table 7. Workforce development and water literacy—priority, goals, and investment opportunities/strategies.

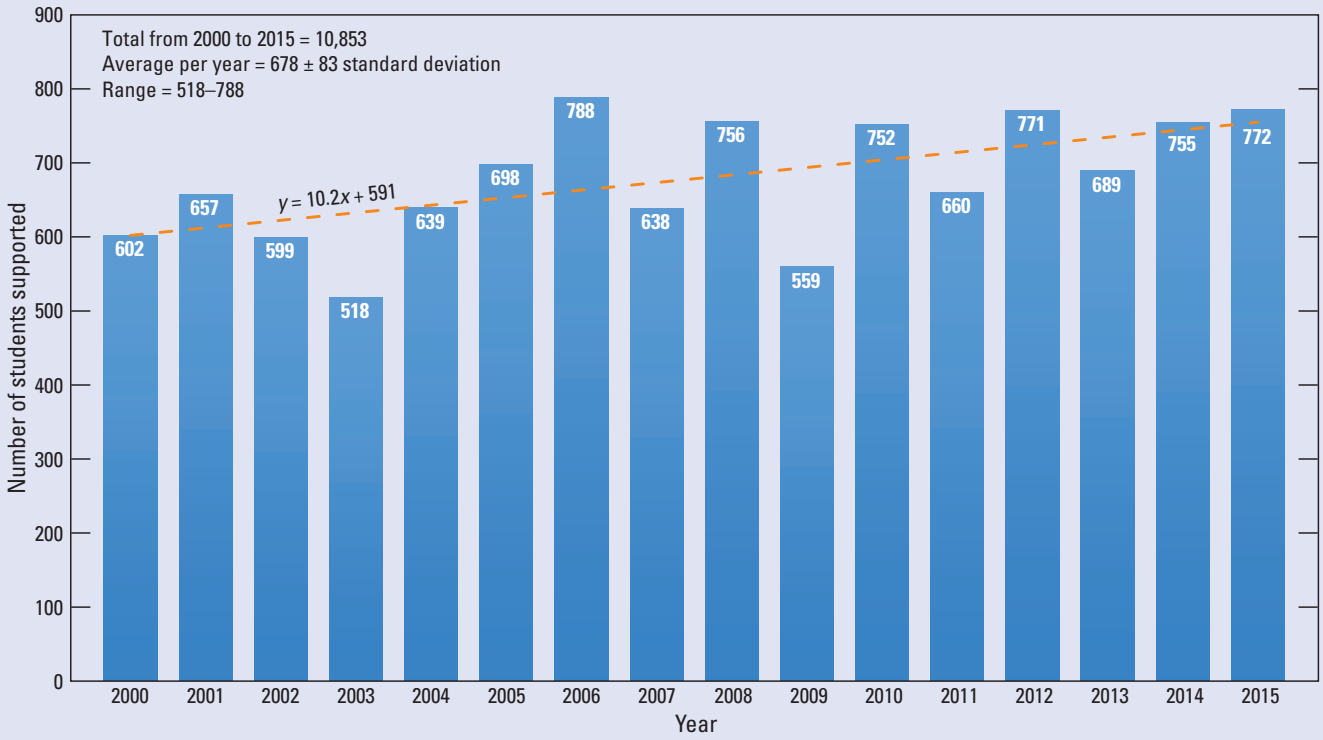
[NIWR, National Institutes for Water Resources; USGS, U.S. Geological Survey; STEM, science, technology, engineering, and mathematics; AGU, American Geophysical Union; NOAA, National Oceanic and Atmospheric Administration; DEI, diversity, equity, and inclusion; UCOWR, Universities Council on Water Resources]

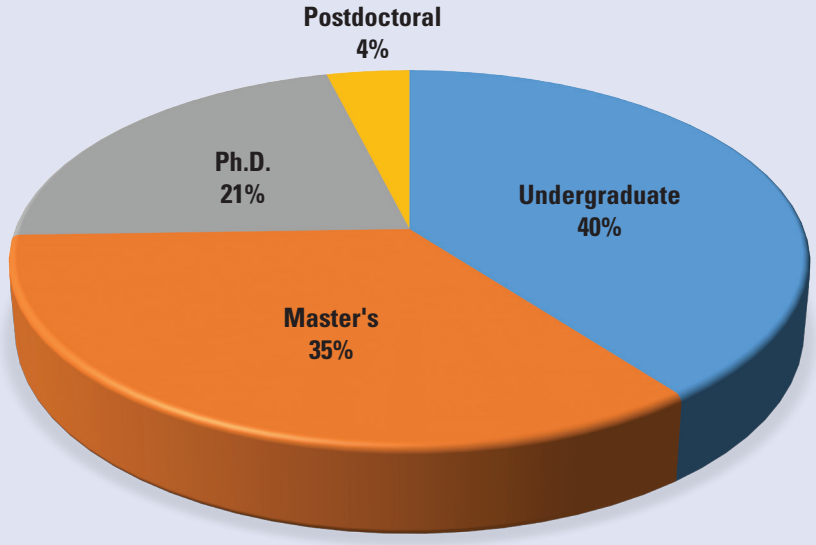
Priority	Goal	Investment opportunity/strategy
A diverse workforce equipped to address our Nation's water resources needs is achieved in concert with greater public understanding of water resources.	1. Increase experiential education opportunities for students, including those from under-represented and underserved groups.	1.a. Increase participation in the NIWR-USGS Student Internship Program. 1.b. Create a national mentorship program for students underrepresented in STEM that links them with USGS water resources research nstitute mentors. 1.c. Update and enhance information and metrics collected on student training. 1.d. Increase support for undergraduate student participation in funded research, especially those from underrepresented and underserved groups, as well as students in the first or second year of college/university. 1.e. Develop and implement context-specific and culturally relevant strategies to increase engagement of underrepresented and minority groups. 1.f. Create a USGS Congressional Fellow program, modeled after other fellowship opportunities (AGU, NOAA Knauss), or partner with existing opportunities, to support career development of students with water-related interests. 1.g. Create a State-level legislative or executive fellow program.
	2. Increase capacity and opportunities to share and translate research results with stakeholders.	2.a. Develop and support inquiry-based outreach activities at the national, regional, State, and local levels for all ages. 2.b. Establish faculty positions in professional extension at USGS water resources research institutes. 2.c. Identify, develop, and incentivize nontraditional, including interagency, partnerships to address water resources issues. 2.d. Link university extension and outreach with USGS resources to improve delivery of research results to stakeholders. 2.e. Require and support an outreach component in all funded 104b research projects. 2.f. Update and enhance information collected on program outreach.
	3. Cultivate and nurture an institutional culture that embraces DEI.	3.a. Complete a national synthesis to examine diversity within USGS water resources research institutes at administrative, faculty, staff, and participant levels. 3.a.i. Identify, prioritize, and invest in opportunities for increased DEI informed by national synthesis. 3.b. Include diverse speakers as plenary presentations at annual NIWR meetings and the UCOWR/NIWR conferences to increase DEI. 3.c. Establish NIWR award(s) to recognize individuals/institutes that advance DEI. 3.d. Establish a DEI NIWR subcommittee.
	4. Enhance programmatic capacity in science communications.	4.a. Develop and implement a programmatic communications plan. 4.b. Establish a programmatic communications position. 4.c. Create a new postdoctoral program, perhaps regionally implemented at USGS water resources research institutes, focused on data synthesis and (or) science communications.

Focus Area—Workforce Development and Water Literacy

Our vision.—A diverse workforce equipped to address our Nation's water resources needs is achieved in concert with greater public understanding of water resources.

Student training and workforce development and enhanced community literacy in water-related issues, contribute to our Nation's economic, social, cultural, and environmental well-being. A diverse and skilled workforce will position the United States to remain competitive worldwide while providing water needed by key sectors of our society. A principal component of the U.S. Geological Survey Water Resources Research Act (WRRA) Program is the training of water scientists and engineers through participation in research. Training occurs through WRRA Program university-based institutes and centers and national fellowships and internships. In fulfilling its legislative mandate, the WRRA Program has supported more than 50,000 students in its 55-year history.





From 2000 through 2015, the WRRA Program supported nearly 11,000 students at all levels of study, from undergraduate students through postdoctoral fellows. More than 80 percent of students from 2000 through 2015 were supported by the program's flagship annual base grants (104b) to university-based State institutes and centers. The WRRA Program has increased student training each year by about 10 students during this time frame, in large part because of leveraging Federal dollars with non-Federal dollar matching by State institutes and centers. [Modified from Donohue and Lerner, 2018]

The Water Resources Research Act Program—Training the Next Generation of U.S. Geological Survey Water Professionals

> "I can't express enough how valuable the [water resources research institute] program in Wisconsin has been for me through my graduate career and beyond…"
>
> —A USGS WMA scientist

The Water Resources Research Act (WRRA) Program serves as a critical pipeline through which water professionals are trained and ultimately recruited to the U.S. Geological Survey (USGS) workforce. The USGS anticipates a shortage of science and technology professionals needed to serve our Nation and stay competitive in today's global economy (U.S. Geological Survey, 2015). As we experience climate variability, understanding and protecting our Nation's precious water resources will require the best trained minds our Nation can produce now and in the future. The WRRA Program's institutes and centers combine the innovation and technology of our Nation's premier universities with practical experience in water resources. This "on-the-job" training is critical for the success of our new graduates.

> "This program is very important to address State-specific water resources research…and support graduate students that may continue their careers with the USGS."
>
> —A USGS WMA scientist

A 2018 survey[1] of USGS Water Resources Mission Area (WMA) professional personnel documented one in 10 survey respondents are alumni of a WRRA institute or center.

More than 1,000 USGS WMA employees completed the survey, 80 percent of which were permanent Federal employees, the core of the USGS workforce. Most survey respondents were supported as students (69 percent), followed by researchers (20 percent). An investment in our Nation's USGS WRRA Program is an investment in our future science and technology workforce.

> "…an excellent opportunity for student training and building USGS collaborations with academic institutions for enhancing USGS science…"
>
> —A USGS WMA scientist

One in 10 USGS WMA survey respondents in professional positions were alumni, supported or trained at some point in their career by a USGS water resources research institute.

Nearly 80 percent of USGS water resources research institute alumni say their institute training or support positively influenced their professional development and achievements.

More than 7 of 10 survey respondents who were supported or trained by a USGS water resources research institute say their institute training or support helped them get their USGS job.

[1]The internal 2018 workforce survey was developed and completed by the USGS WRRA Program in collaboration with the National Institutes for Water Resources, the USGS WMA, and the University of Hawai'i Water Resources Research Center.

Hydrologist measuring on the Holston River. Photograph by Dennis Adams, U.S. Geological Survey.

Conclusions

The Federal legislative mandates and resulting activities, outcomes, and effects of the Water Resources Research Act (WRRA) Program have demonstrated their utility and value to the Nation for more than 50 years. The administrative framework of the WRRA Program provides a structure through which our Nation's best Federal and university scientists address not only the challenges but also the opportunities related to our freshwater resources. The WRRA Program has successfully operationalized the research, technology transfer and information delivery, and workforce training mandates of the Water Resources Research Act of 1984 to meet the evolving water resources-related needs of our citizens at local, regional, and national scales. Critically, the program's notable Federal-State/university partnership and administrative grant structure imbued the program with the flexibility required to adapt to the changing and unprecedented environmental, demographic, and socioeconomic conditions experienced by our Nation in the last 50 years. The WRRA Program's distributed reach across all 50 States, U.S. territories, and the District of Columbia, via its university-based State institutes and centers, ensures that the needs and perspectives of all our Nation's citizens are acknowledged and addressed. This is anchored further through the non-Federal to Federal dollar matching requirements for most grants awarded through the WRRA Program, ensuring that work funded is relevant and valued "on the ground" by U.S. Geological Survey stakeholders.

Nonetheless, the future facing our Nation is uncertain with regard to climate variability and its effects on water scarcity and availability. Uncertainty also surrounds increasingly common water-related hazardous events. The ability to provide adequate and safe freshwater for the more than 300 million people residing in the United States remains a challenge. Water is also necessary for the agriculture and industry that support our Nation. Legacy and emerging contaminants pose a threat to our water resources and the ecosystems on which they and we depend. Enhanced planning and policy will necessarily be required in concert with science-based technology and innovation to sustain our Nation's interests and quality of life. This vision document acknowledges the priorities and goals in the focus areas presented and offers paths forward, in the form of specific opportunities/strategies to implement now and in the coming decade in support of our Nation's prosperity.

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https://www.usgs.gov/water-resources/water-resources-research-act-program

Publishing support provided by the
Reston and Rolla Publishing Service Centers

Donohue and others—**Water Resources Research Act Program—Current Status, Development Opportunities, and Priorities for 2020–30**—Circular 1488

ISBN 978-1-4113-4424-2

ISSN 1067-084X (print)
ISSN 2330-5703 (online)
https://doi.org/10.3133/cir1488

Printed on recycled paper