U.S. DEPARTMENT OF AGRICULTURE

United States
Department of
Agriculture

**Agricultural
Research
Service**

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WATER RESEARCH VISION 2050

USDA Agricultural Research Service Water Research Vision

The Agricultural Research Service, USDA's intramural scientific research agency, is a leader in agricultural water research locally, nationally, and internationally, with a focus on landscapes that produce food, fiber, fuel, and forage, as well as their source-waters and receiving-waters.

- **ARS water research** focuses on societal-level outcomes that build global food, fiber, and water security.
- **ARS water researchers** innovate cutting-edge, systems-level science, decisions support tools, and solutions.
- **ARS water researcher teams** value partnerships and collaboration with a wide range of communities including producers, stakeholders, Federal, State, and local agencies, and the public.
- **ARS water research impacts** lead to lasting, sustainable change in water use, management, productivity, and quality.
- **ARS water research outreach** will share our exciting science and research findings with everyone and reach all corners of the globe.

The ARS Water Research Vision 2050 provides a roadmap and guide that describes where we have been, where we are going, how we would like to get there, who we would like to travel with, and what we would like to accomplish together toward solving the most important water issues of the next three decades and beyond.

USDA Water Research Vision 2050

Productive, Appropriate, Sustainable Water Use

USDA will pursue a long-term, national-scale, transdisciplinary approach to solve complex water challenges in agricultural systems and support sustainable decisions under increasing water costs, limitations, and vulnerabilities.

One of the greatest challenges facing agriculture is stewardship of our Nation's water resources – reliably provisioning and maintaining sufficient quantity and quality of water to meet the Nation's many needs. Growing populations, climate change, resource competition, and pressures on the Nation's ecosystems simultaneously increase the need for, and threaten availability of, water used by agriculture.

Agricultural Research. The Agricultural Research Service (ARS) is the United States Department of Agriculture's (USDA) chief scientific in-house research agency tasked with finding solutions to agricultural challenges affecting all Americans. The work of USDA-ARS is critical for maintaining and improving quality of life, positively impacting individuals, communities, our Nation, and the world. ARS supports a vision of agriculture as a primary steward of the Nation's water resources, delivering clean and abundant water to society over the long-term (Fig 1). We develop practices and technologies that are environmentally sound and sustainable to ensure water quality and quantity are maintained while providing abundant food, fiber, fuel, and forage.

ARS research priorities are pursued through a diverse portfolio of research projects with 2,000 scientists and post-doctoral fellows at over 90 locations globally that rely upon a variety of networks bringing together many partners. ARS research develops solutions to a full range of water challenges facing agriculture, from models that assess and forecast the consequences of climate and management changes on water resources and ecosystem health, to innovative technologies that provide options to the Nation's farms and ranches, to strategies that balance the services expected of our agroecosystems.

To accomplish this, ARS scientists coordinate and collaborate across disciplines, regions, and other scientific organizations to ensure that research outcomes are comprehensive and address not only the symptoms, but also the root causes of, the challenges facing agriculture. These expanded efforts will integrate biophysical and socioeconomic factors affecting sustainable water use to inform policymakers.

Hydrologic Extremes and Water Supply. Changing climatic conditions are causing an increase in drought and flooding events that affect the hydrologic cycle. However, these changes differ by region, and uncertainty remains about climate projections of extreme events at the local scale. ARS continues to carry out nationally networked research with local, national, and international collaborators to understand the fundamental processes of hydrologic extremes, to mitigate the risks and buffer their impact on agricultural and non-agricultural systems, and to share information and data.

This fundamental information underpins models that extrapolate the outcomes of management change, as well as decision support systems that integrate weather forecasts with predictions of water availability and ecosystem vulnerability, sustaining water resources on and off farms. Recognizing that any single technology presents trade-offs, ARS innovates a suite of new technologies supporting irrigation, watershed, and aquifer management and conducts systems-level research. This ensures agriculture can more efficiently use or reuse available sources of water, while delivering clean water to downstream end users.

Water Quality. Agriculture contributes to water quality concerns in major watersheds across the country from the San Francisco Bay, to the Mississippi River Basin, to the Great Lakes, to the Chesapeake Bay, to the Everglades. However, the interaction of rural and urban communities and the diversity and complexity of the Nation's landscapes affect water quality. Interdisciplinary approaches are required to develop solutions for agriculture's water quality concerns. ARS's research improves the understanding of potential contaminant sources and their fate. ARS develops water quality management innovations to protect water resources that are cost-effective and can contain, trap, and/or treat possible contaminants. Decision support tools will help communities envision, co-design,and implement water quality mitigation strategies.

Societal and Economic Impacts of Water Supply and Quality. The transdisciplinary research of ARS extends beyond the biophysical sciences and engineering and improves the stewardship of the Nation's water resources. However, these science-proven methodologies must be adopted and used to realize the positive impacts. By engaging with social science disciplines, ARS is ensuring that its solutions are adopted and used. Broad social science research includes a variety of disciplines, such as geography, rural sociology, ethnography, participatory methods, and more. Incorporating these approaches enables ARS to supply stakeholders and policymakers with systems-based tools for complex water decisions that are not only environmentally sound but are also socially acceptable and economically viable.

USDA-ARS Water Research Vision 2050

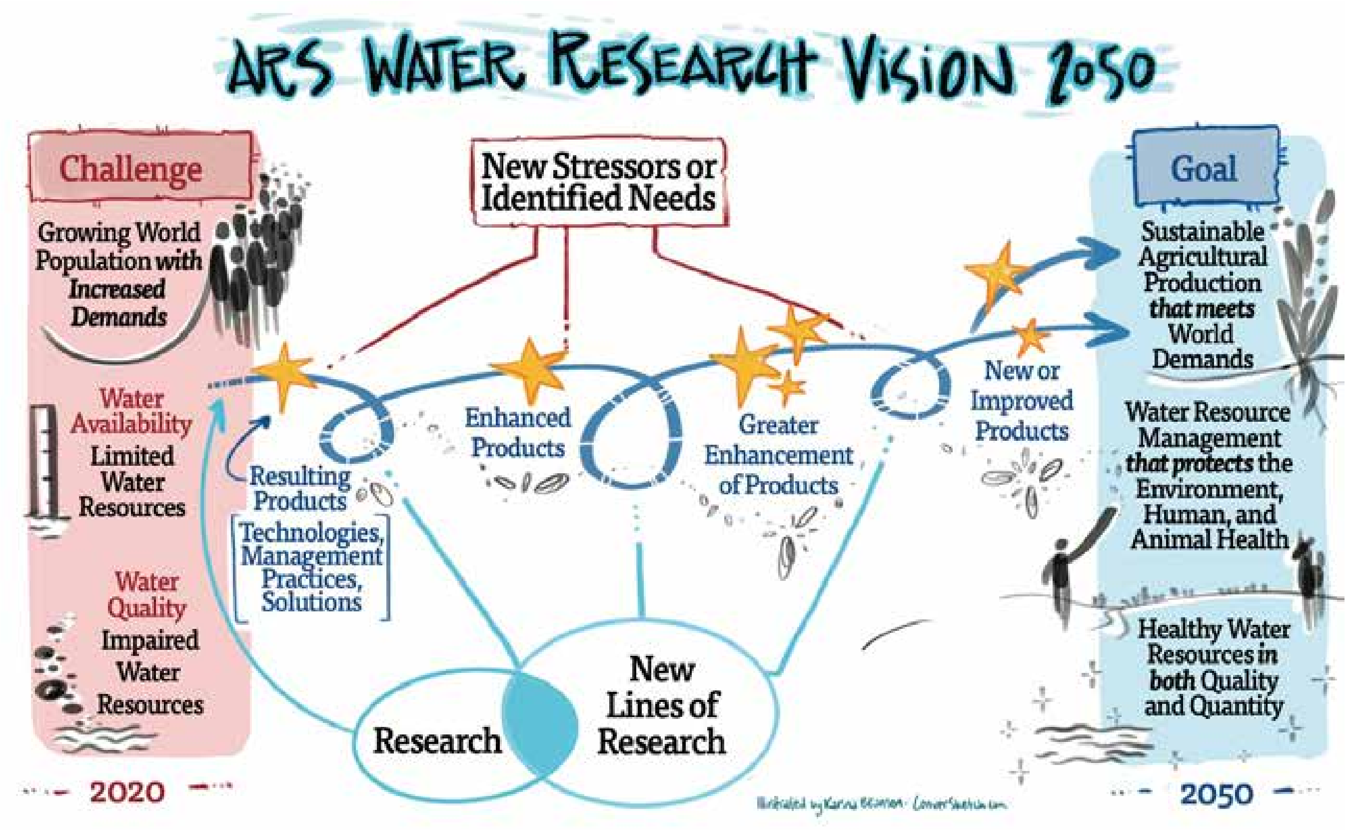


Figure 1. *ARS water research vision addresses current and anticipated challenges for sustainable, healthy landscapes and communities by 2050.*

Water Resource Challenges in the Continental United States

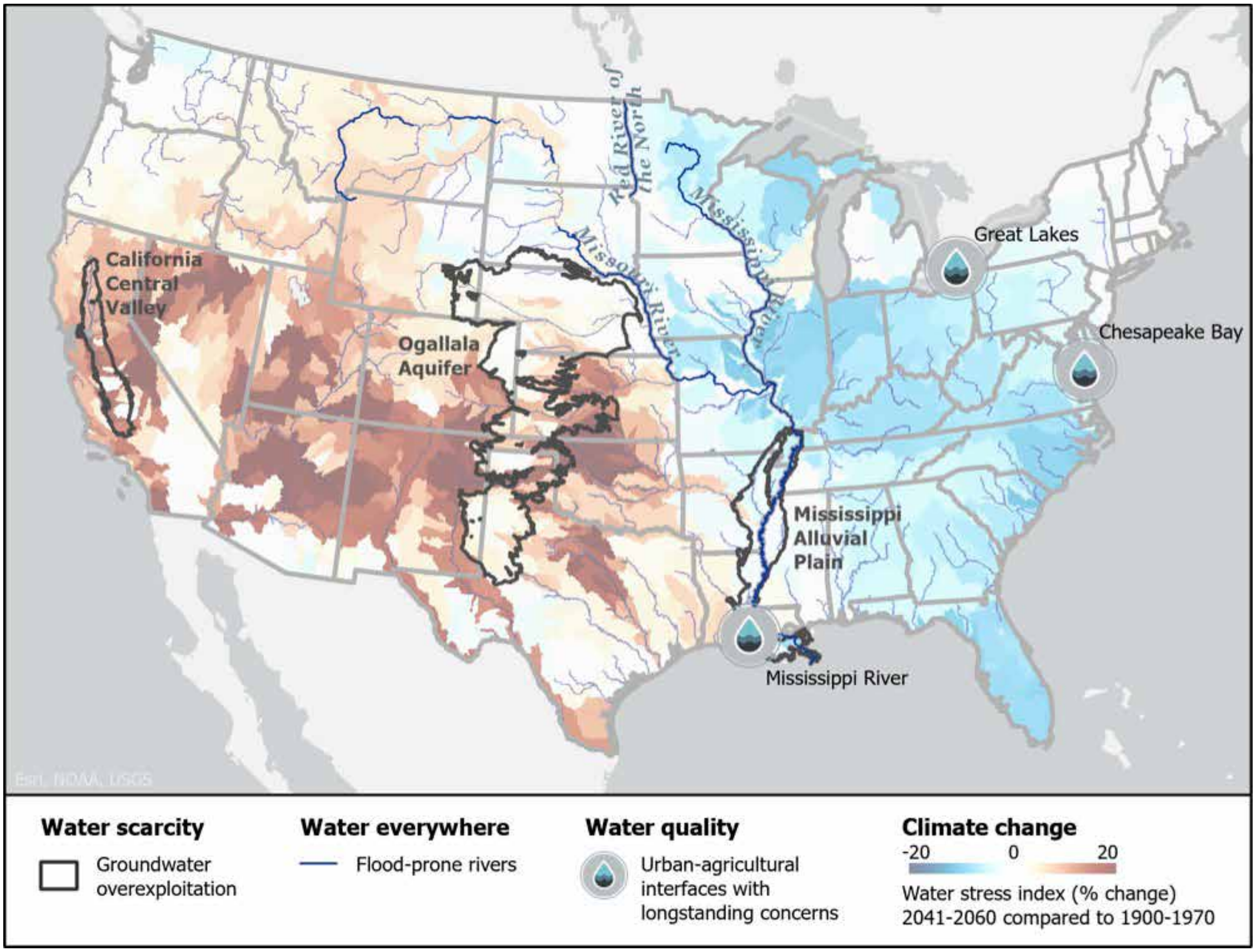


Figure 2. *Map depicts water challenges in different regions based on climate change impact on the water stress index and longstanding areas with water quality issues.*

Challenges of Today and the Future

The two most significant challenges facing agricultural production, and placing enormous pressures on the world's water resources, are climate change and the increasing global population.

The dual challenges of climate change and increasing global population are affecting the world's water supply and resources. Climate change is altering precipitation patterns and increasing air and water temperatures globally which is disrupting agricultural production locally. These changes are causing more intense drought and heat waves, while heavier down-pours and flooding occur more frequently. At the same time, growing populations are competing for water resources traditionally used by agriculture.

Furthermore, these challenges have complex consequences for water availability, quality, and distribution when combined with other biophysical and ecological stressors, changing economic conditions, and societal values and expectations. National, regional, and local solutions to these challenges must address the climate, soil management and characteristics, agricultural practices, food systems, agroenvironmental programs and policies, and the role of water in the local cultures, and economies.

USDA Research Network. Although these challenges have persisted over many decades, they will continue to evolve through 2050 and beyond. The complexities of water systems and their associated challenges require experts from many disciplines. Transdisciplinary and multi-disciplinary teams learn from each other and work collaboratively to blend their diverse knowledge and experiences into new, path-breaking approaches, insights, and solutions. The USDA-ARS research network is uniquely positioned to bring scientists from many diverse disciplines together with producers and community members to discuss, to question, and to explore our Nation's and the world's most pressing water challenges.

Water Supply. All U.S. regions face water supply shortages that will only worsen with time as the climate changes and as populations and agricultural intensification grow. Integrity of storage reservoirs is threatened with dwindling inflows and increasing sedimentation, reducing the ability of these systems to mitigate drought effects. For example, continued development of irrigated agriculture in the drier High Plains and western regions exacerbates surface water availability and significantly draws down the midwestern Ogallala and California Central Valley Aquifers. In the East, despite a humid climate, patterns of rainfall and crops grown can sometimes require extensive irrigation. In other locations seasonal flooding results in excess soil moisture causing crop failures. Decades of irrigation have depleted the Mississippi River Valley Alluvial Aquifer, the second most productive aquifer in the United States.

Water Everywhere. Throughout the Midwest, Mid-South, and Northern Plains, excess precipitation and runoff in the spring leads to localized flooding and delays in fieldwork, resulting in yield losses. Extreme rainfall events in the Missouri and Mississippi River Basins contribute to flooding, causing extensive damage to infrastructure, agricultural production, personal property, and even the loss of life. Flooding occurs not only along the main rivers, but also along all major tributaries and in small streams. Reduced water storage capacity, due in some cases to sedimentation or changes in reservoir management policies or objectives, can increase the risk of flooding and lead to significant damages to crops, and major losses of very fertile topsoil. This challenge will require many professions and disciplines to develop innovative cropping and drainage water management systems and improved watershed models for flood forecasting.

Water Quality. From the Gulf of Mexico to the Chesapeake and San Francisco Bays to the Great Lakes and beyond, critically important water bodies are negatively affected by hypoxia (zones of low or no oxygen), harmful algal blooms, and habitat devastation which are typically caused by increases in sediment, nitrogen, and phosphorus in stormwater runoff and groundwater exfiltration. However, pesticides, metals, and pharmaceuticals are also emerging concerns and can lead to aquatic impairment, affect aquatic diversity, and render the water unusable for human consumption, fishing, and recreation. ARS leads the development of strategic solutions to minimize harmful algal blooms, but complex ecosystem-level events that deliver contaminants to sensitive water bodies are expected to occur more frequently, further complicating mitigation and management strategies.

Culture, Society, Economy, and the Urban and Agriculture Interface. The challenges outlined above will require USDA to continue engaging in transdisciplinary research. Land use changes, urban expansion into agricultural areas, and other complex social and cultural challenges necessitate creative approaches and solutions. Increased interest in urban community gardens, large vertical farming facilities, building retention ponds, and establishing artificial wetlands are a few novel opportunities needing creative water use and water quality solution.

Research Approach

USDA maintains global leadership in water and agroecosystem science advancement by focusing on research that is diverse, adaptive, collaborative, targeted, and integrated.

The challenges of today and tomorrow to ensure a plentiful supply of high-quality water for agriculture and the Nation must be addressed with a vision and research agenda that leverages new technologies and integrative approaches. The water vision 2050 research approach is shaped by our history and builds upon our rich research capital.

Perform Multiple Metric Assessment. Agroecosystem decision making does not often involve simple problems. Decisions must consider producers, water and other natural resource managers, and the surrounding communities because outcomes have greater impacts than just at the point of the decision. For instance, minimum waterflow rates for aquatic habits must account for upstream agricultural producers who make decisions on irrigation withdrawals or on the selection of crops that require more or less water. Scientists will develop multiple metrics to assess agroecosystem performance, communicate the interdependencies of these decisions, and coordinate the decision processes from the different sectors. These metrics will weigh the different perspectives and outcomes and will be communicated to the public with both thoroughness and sensitivity.

Integrate and Develop New Technology. New technologies will emerge in diverse domains such as *in situ* and real time sensors (e.g., soil and plant property sensors, water quality, aerial imagery), bioengineering (e.g., wastewater treatment and reuse), and informatics and computer science (e.g., artificial intelligence and machine learning). With the development of more advanced sensor technologies and telemetry, research methods will rely on greater amounts of measured real-time data at refined spatial and temporal scales. Because the human resources will likely not increase with these needs, ARS scientists will continuously work with industry leaders to develop and to evaluate new monitoring technologies that require less human intervention for equipment calibration, maintenance, and data collection, and processing techniques for data quality analysis and control, ultimately leading to higher-quality, actionable information, and decision support systems. For problems such as waste management and reuse, water treatment, and pesticide and bacteria removal from agricultural runoff, scientists will invest resources toward the development of bioengineering technologies to develop creative solutions.

Artificial intelligence and machine learning techniques will provide new collaboration and research opportunities to solve problems that have remained intractable and to address important system components. These techniques could propel modeling science to a new level by

- creating maps of the agroecosystem modeling universe,
- managing data streams for individual model operation,
- iterating among individual modeling platforms to provide holistic simulations of ecosystem services,
- and forecasting cumulative impacts resulting from decision options across multiple spatial and temporal scales and sectors for informed policy development.

Quantify and Reduce Uncertainty. Uncertainty specification will be needed for any data point whether measured or obtained from computational models. Uncertainty quantification will allow moving away from replicated experiments and toward the use of data collected across multiple sites for large meta-analyses. It will provide modelers more insight in the data they use for model calibration and validation. Ultimately, it will provide experimentalists and modelers a stronger basis for comparing the simulated or measured effects of treatment, biophysical parameters, or climate on water quantity and quality. To reach this goal, scientists will need to develop research methods and statistical analyses that incorporate and reduce field measurement and model prediction uncertainty.

Produce Scalable Results. ARS is a producer of knowledge grounded in measured data often collected at local scales. Yet, future research must be able to apply results at a larger scale, at other locations, and allowing for a changing climate. In addition, farming processes rely on mechanization and are becoming more automated. Thus, scientists need to understand and to communicate how local solutions can be interpreted and implemented at

USDA Water Research Vision Process

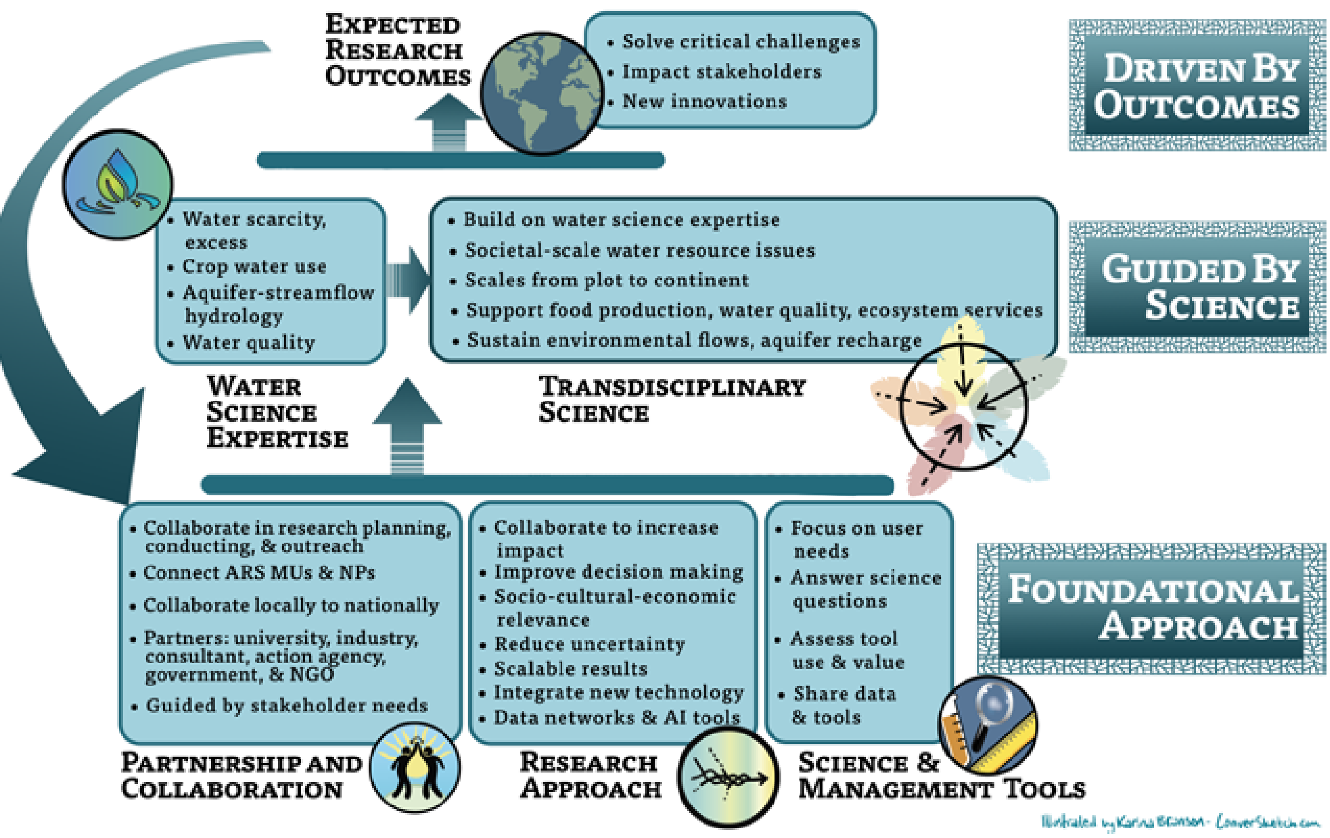


Figure 3. *Innovations, research, and actions needed to achieve vision.*

a larger scale and in an automated process, thus improving agricultural management practices. Scientists will develop methods, likely including machine learning and artificial intelligence processes, to scale results up to broader areas and increase the impact of ARS research.

Share Data and Tools. Understanding complex processes and developing advanced technology requires that data be available for others to use and share. Creating a viable data sharing strategies will not only lead to improvements in current research and development of technology and practices but will enable productive and vital collaborations aimed at solving complex scientific problems. Effective communication is also critical for technology delivery and adoption. Thus, the Water Research Vision will create robust data sharing plans and faster data networks for researchers and stakeholders enhancing research communications.

Translate Research into Decision Support Tools. The result of the stakeholder-driven research approach described above is often the development of science-proven tools that guide real-world decision making. ARS envisions a fluid process of translating multi-metric, technologically advanced, scalable research into user-friendly decision support tools that accurately reflect decision uncertainty or risk.

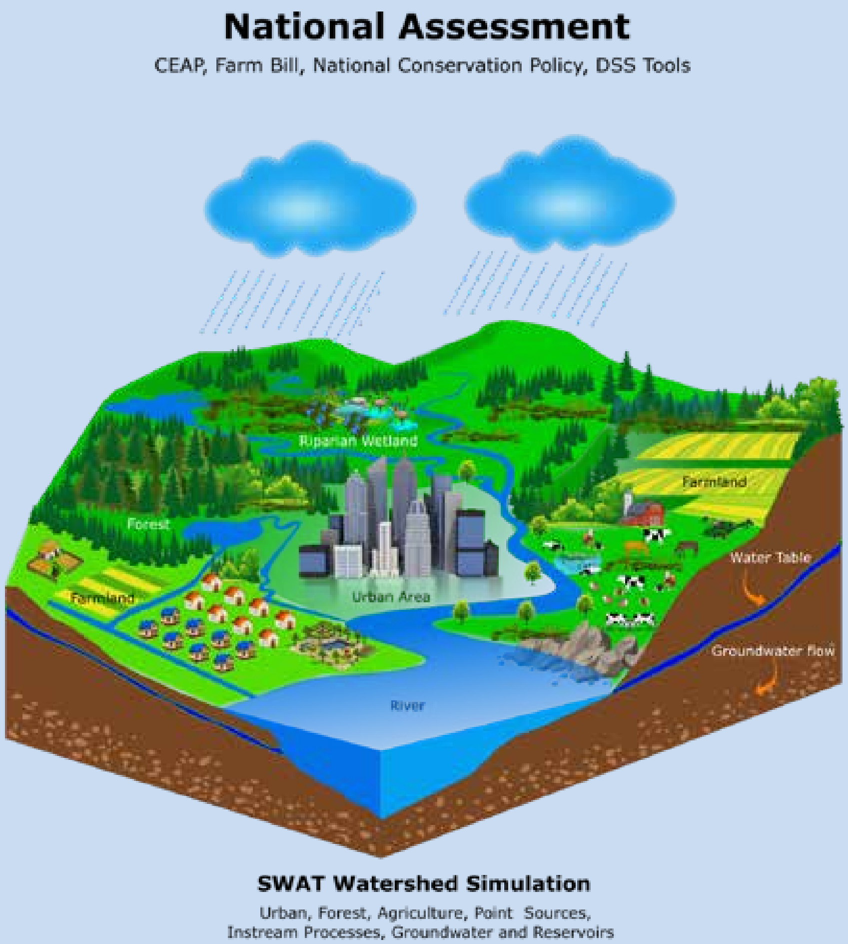
Maintain Ability to Respond to Change. We do not know what will come about in the next 30-50 years in terms of problems, possibilities, and research technologies. But ARS needs to have the capacity and flexibility to address upcoming problems as well as long-term research questions. Thus, ARS will maintain its ability to adapt staff, skill sets, and land resources to those required for solving urgent issues identified by ARS or stakeholders. Simultaneously, ARS will cooperate with stakeholders to implement long-term experiments. To ensure relevance to current issues, ARS will re-evaluate long-term programs regularly.

Demonstrate the Value of Science. Often it seems that a large fraction of the public sees little value in scientific and research investment, except when there is an urgent problem to solve. Press releases have great value but are often limited in scope to a single study or a few studies. Scientific popularization has the potential to help the public understand the long-term benefits of water resources research and how it connects to the critical questions stakeholders may have. Scientists will collaborate with experienced science writers to ensure accurate representation and interpretation of water resources research findings.

Achieving Research Goals. To achieve these goals, ARS will strive to foster engagement and connections among researchers, industry partners and the public, responding to critical knowledge and skill gaps in water resources. ARS will foster strong connections between researchers and the public to communicate the importance of water research, not only for agriculture, but include in which water science has an impact. With an improvement in water science acceptance will come consideration of water research in decision making, helping to move the focus from purely economic decisions to broad agroecosystem sustainability, considering intensification and production demands. Gaps that remain are the skills to communicate efficiently and effectively to the public and not relying on solely research journal publications, which are not generally accessible by the public. Current efforts to generate interpretive summaries may be expanded to encourage novel outreach via mobile interfaces tailored to user interests, along with more traditional communications such as trade publications, popular magazines, social media, and public/stakeholder meetings.

The full impact of research accomplishments occurs after publication, when they are integrated into real-world applications and practice. This requires engagement with industry partners and action agencies through regular dialogue and listening sessions as well as incorporation of end user input throughout the research cycle. There is currently little incentive for scientists to complete this process. Strategies need to be developed, along with personnel and financial resources, to help scientists accomplish this task, which requires different skills than those needed for scientific discovery and managing research projects. Technological transfer personnel need to go beyond protecting the legal and financial interests of ARS and its scientists to help them make their data and scientific results more findable, understandable, interoperable, and reusable (FAIR). (https://www.go-fair.org/fair-principles/).

Soil and Water Assessment Tool (SWAT+) and the National Agroecosystem Model (NAM)



The Soil and Water Assessment Tool (SWAT+) is a river basin scale, continuous time model designed to predict the effects of land management and climate on water, sediment, nutrients, and agricultural chemical yields in gauged and ungauged watersheds. Led by ARS scientists, SWAT code and associated software development is a collaboration of U.S. and international universities and Federal laboratories.

SWAT+ has proven to be an effective tool for assessing water resource and nonpoint source pollution problems for a range of scales and environmental conditions worldwide, including North American, Europe, Asia, and other regions. In the U.S., SWAT+ is used to develop strategies for water quality challenges in the Chesapeake Bay, Western Lake Erie, and the Gulf of Mexico hypoxic zone. The National Agroecosystem Model (NAM), developed using SWAT+ as the modeling engine, is being used for future conservations and environmental assessments.

Partnership and Collaboration

ARS engages collaborators and partners in research that has long-term focus, is both place-based and at a national scale, and solves complex agroecosystem water issues using a transdisciplinary approach.

In the face of growing challenges such as climate change, human population growth and environmental impacts, agricultural production systems will need to evolve over the next 30 years to address emerging issues. In turn, ARS will innovate and build strong partnerships to achieve the complex research objectives required to address the up and coming issues constraining sustainable intensified agricultural production systems. Partnerships with shared values strengthen ARS capacity by adding expertise, supplying additional data, and allowing ARS to inform water policies and decisions. Successful partnerships support all partners, conserve resources, and lead to more effective communication, maintaining ARS' leadership, and enhancing adoption and transformation of new technologies.

Technology Impacts on Collaboration. Today, mobile devices, email, videoconferencing, cloud data storage, and web-based decision support systems are just a few of the ways technology is changing the way to collaborate. It is difficult to predict how technology will affect collaboration over the next 30 years. To advance a vision for 2050 and beyond, ARS will work with technology futurists who are best positioned to project how advances in this area will drive the nature of future collaboration.

Partnerships and Collaborations. ARS has engaged in partnerships with diverse institutions, including government agencies, producers, industry researchers, manufacturers, non-governmental organizations, and citizen groups. Partnering across units or entities outside of ARS has enabled units to expand in expertise, impact, and geographic scope. ARS will continue to seek new, creative partnerships and collaborations to address future challenges, including work with international partners on joint solutions to common problems.

GRAPEX and OpenET
A Public Private Partnership for Water Use

Annual production from wine grape vineyards in California (300,000 ha) is valued at $6.5B and supports an industry generating nearly $120B in economic activity nationally, with $57B in California alone. At the same time, water resources in the state are rapidly decreasing due to increased demand from a growing population, expanding agricultural production, and more frequent and severe droughts. **E. & J. Gallo Wineries** recognized the critical need to improve irrigation water management in commercial vineyards and reached out to ARS scientists to develop satellite-based techniques for mapping daily crop water use (evapotranspiration or ET) and stress.

This partnership led to the Grape Remote sensing Atmospheric Profile and Evapotranspiration eXperiment **(GRAPEX)** project, supported by ARS, E. & J. Gallo, and the **NASA Applied Sciences Program.** Through GRAPEX, ARS scientists collaborate with industry and university researchers to create geospatial tools and ET information to assist in irrigation scheduling. Satellite maps of daily water use will be widely accessible to growers through the **OpenET** platform, a unique public-private partnership developed by NASA with philanthropic support.

University Partnerships. ARS has a long history of collaborating with university partners. This is an integral part of effective research. Co-location of units within or very near university campuses provides access to researchers, facilities, and students and provides benefits for both ARS and the collaborating university. ARS benefits from expertise that extends beyond the limits of the agency to include the expertise of university collaborators. Students, staff, and faculty benefit from exposure to more opportunities to get involved with a broader research portfolio. ARS and universities benefit from a pooling of resources, both infrastructural and intellectual, toward accomplishing common research objectives. Co-locating new units or re-locating units to university settings may prove beneficial. Remote collaboration tools may also provide new opportunities to reduce barriers for collaboration with non-co-located universities.

Building Collaboration to Strengthen Partnership Outcomes. Stakeholders in the agricultural community will benefit from the outcomes of ARS partnerships. This approach will ultimately lead to end-to-end pilot programs that disseminate innovative technologies. ARS will continue to:

- Encourage agreements with private industry to transfer ARS-developed technologies into the marketplace and simplify intellectual property arrangements.
- Encourage new scientists to collaborate with industry, university, State, and Federal scientists and with farmers.
- Build partnerships with researchers outside of ARS, especially those with expertise in the social sciences and science communication.
- Identify key groups needed to implement new technologies.
- Encourage involvement with innovation support schemes.
- Develop consortia of Federal/State government agencies, non-governmental organizations (NGOs), and private industry partners that can champion needed outcomes.
- Strongly leverage and support government networks.
- Increase engagement/outreach activities with underrepresented communities.
- Make targeted investments in research resources and partnerships that emphasize synergies of collaboration and communication strategies leading to effective solutions.
- Engage with NRCS to gain understanding of relevant issues farmers, growers, ranchers, and producers face and to identify potential collaborators.

Science and Management Tools

ARS ensures its water research has societal relevance by integrating socio-cultural and economic values at all phases, incorporating appropriate technologies, and disseminating user-focused decision tools.

ARS Maintains a Focus on User Needs. ARS places science and management user needs at the forefront of tool and technology development to ensure that decision-support tools are effective and used. Thus, ARS scientists have developed hundreds of widely used and recognized tools to answer fundamental scientific and management questions locally and globally.

The involvement of end-users provides a deeper understanding of their needs and increases the likelihood of meeting those needs. Focus on user needs begins with identifying the relevant users and involving them in tool development as an extension of the entire research process. Scientists are use these tool-users in their own research to answer fundamental scientific questions. With complex decisions involving multiple stakeholders, effective application of tools includes facilitating learning processes among groups of stakeholders and supporting practices that foster social involvement.

ARS prioritizes tested, credible tools with user-friendly and efficient tool design. Tools that assist producers with decision making by providing information tend to be adopted over those that simply prescribe actions. ARS assesses existing tools with users to determine how well they are meeting needs and what improvements are required. An important part of building credible tools is demonstrating their use and value in applied science settings. ARS has established transparency and two-way communication between model developers and users. ARS scientists will continue to develop experiments and engage partners and stakeholders to provide necessary calibration and validation and will conduct demonstrations and training in applied tool use.

ARS Identifies Gaps, Needs, and Barriers Related to Management Tools. ARS the identifies needs for additional tools and issues with existing tools. This effort includes assessing whether management tools demonstrate future interrelationships as a function of changing external impacts, climate change, shrinking land for crop and animal production, and limited water resources. ARS will assess the need for tools to inform emerging agricultural systems such as vertical farming, urban agriculture, smart agricultural systems, and the integration of solar farms and agriculture. Decision support tools are among the most successful management applications. However, accurate decision support requires the establishment of local and regional networks for real-time monitoring for multiple variables. Real-time micrometeorological, plant, and soil water sensing networks at farm and watershed scale will better inform irrigation strategies, and short- and long-term water policies.

Water issues and their solutions are complex and often involve other sectors. Therefore, science management tools should be holistic and address the complexities that exist across sectors. ARS ensures that models have an intentional science-to-management interface so that they produce sustainable management strategies for water and agroecosystems.

With complex decisions involving multiple stakeholders, effective application of tools includes facilitating learning processes among groups of stakeholders.

ARS will continue efforts and seek additional partners for near-real-time mapping of agricultural water resources, water use monitoring, near-term forecasting and modelling of irrigation scheduling and quantifying accuracy, and improved forecasting of rainfall and snow melt. The studies will be conducted at the field and watershed scales using established agrometeorological networks across regions, and results will inform integrated decision support systems.

ARS Builds Capacity to Share Data and Technologies. Tools to manage scientific data are just as important as tools to make scientific measurements. This is especially relevant because big data is a rich resource for smart technology advancements and will continue to facilitate improvements in all areas of agriculture. Big data analytics are a major component in many agricultural projects. ARS will continue to explore new approaches using machine learning (ML) and artificial intelligence (AI) techniques. Secure, but feasible access to databases, will support model input, strengthen AI algorithms, and provide useful products driven by data analytics. Public/private data partnerships will facilitate broader data availability. Modular design and establishing open-source repositories will facilitate quicker prototyping and solutions for hard-tools (e.g., plant and soil sensors) and soft-tools (models) and will allow tools to be updated as technology improves.

ARS Maintains a Repository of Existing Tools. Existing tools include sensors and models that inform scientific research and end-user decision making. Sensors range from *in situ* soil and water sensors to proximal ground-based, and remote aerial- and satellite-borne sensors. Analytical tools range from models of specific processes such as heat, water, or solute movement to complex biophysical models that integrate multiple processes and provide estimates of multiple outputs at multiple scales. Many of the ARS models are cataloged and publicly available in one location (https://www.ars.usda.gov/research/ software/). ARS will build upon this framework to develop and maintain a complete, categorized, and updated catalog to help users access available tools.

Water Science Expertise

ARS develops fundamental and applied disciplinary research on all agroecosystem facets and related scales to support ecosystem and human health along with global food security and safety.

ARS has a team of globally-recognized scientists and a network of long-term research stations and laboratories that will facilitate future research into the most critical water challenges.

Water Scarcity and Excess. Sustainable water management requires reliable forecasts of water availability and demand and novel methods to monitor water use at multiple scales. Research efforts will include improving algorithms of hydrologic processes in integrated land-surface and hydrologic models; leveraging new high resolution (spatial and temporal) remote-sensed data sources, open modeling platforms linked to cloud computing, and high-resolution forecast data; and developing alternative water sources.

Weather extremes have become more prevalent with more intense and longer drought conditions and overly excessive rainfall in many regions. This will exacerbate challenges in managing traditional water stores, such as snowpack and reservoirs, and will necessitate new management strategies and alternative storage. These weather extremes require more knowledge of our changing climate and the processes controlling current water sources.

ARS employs new satellite data sources with expanded ground-based measurement networks to supply information at finer spatiotemporal scales and greater accuracy. These new diagnostic datasets will improve representation of physical processes in integrated modeling systems. ARS will continue to lead agricultural water decision-making frameworks that merge new geospatial datasets with high-resolution forecasts tailored to specific growing regions that meet producer needs.

Crop Water Use. Optimal water use at the field scale is critical to water conservation. Knowledge gaps exist in basic plant physiology and the effects of shifting management strategies to address the new realities of increased CO_2 and climate change. ARS scientists will continue to lead research in crop response to higher temperatures and CO_2 and in modeling this response under different climate scenarios. Transdisciplinary research will be conducted concerning crop water stress which will be facilitated by the extensive network of experimental farms and large datasets at multiple ARS sites including LTAR Network and CEAP locations.

Use of more sophisticated modeling and precise management requires commensurate and new instrumentation development. High-resolution soil and canopy moisture status signatures derived from imagery collected by in-field, drone, aircraft, or satellite-based platforms will be linked directly to autonomous variable rate drip or micro-irrigation systems. Improvements in agricultural forecasts at the microclimate level allow adjustment of current water applications to meet future demands more effectively. New developments will include remote sensed data about crop condition, water use, 3D geophysical measurement of soil properties, and spatially and temporally extensive monitoring of soil water at field and sub-field scales.

Research will link agronomic practices and soil carbon management and will investigate critical questions, such as the effects of irrigation water composition and carbon sequestration on ground-water quality, the potential for microbiological interactions with crops to increase crop resilience, and agronomic effects on soil carbon dynamics.

Groundwater-Surface Water Connections. Much of U.S. irrigated agriculture is dependent on ground-water. While we have historically treated surface and groundwater separately, this division fails to recognize the effects on water tables, streamflow, and irrigation water supply. Effective management of surface water and groundwater resources requires a better understanding of the subsurface pathways linking the two; however, accurate experimental determination and modeling of water and contaminant flows remain problematic due to the complex sub-surface environment. Improved characterization of subsurface soil properties and water flows at multiple spatial and temporal scales will be developed, and new models will improve water and contaminant flows estimates to, from, and within agricultural fields and watersheds. This will lead to enhanced groundwater recharge and sustainability of irrigated agriculture, improved water quality, minimized groundwater depletion, and restoration of ecosystem function.

Water Quality. Agricultural activities can alter the quality of water entering the water supply leading to serious impairments and affecting human and environmental health. Multiple constituents will require different treatments. ARS will examine preventive measures and remediation strategies to address these challenges in a holistic approach. Previous results concerning the effects of water quality on human and ecosystem health will be used to inform new research efforts.

- Ensure the viability of irrigated agriculture by preventing salt accumulation in soils by developing novel, advanced desalinization methods from source and drainage waters.

- Develop technological solutions, including sensors to detect crop nutrient deficiencies or pest infestations and the real-time application of fertilizers and pesticides, to improve the efficiency of agrochemical use by crops and minimize environmental degradation.

- Improve soil erosion management by broadening understanding of the factors that control and inhibit erosion, including the use of no-till practices and soil conditioners.

Prevent agricultural contaminants, such as particulate matter, sediments, fertilizers, agro-chemicals, and new and emerging contaminants, e.g., pathogens, pharmaceuticals, and microplastics, from entering waterways by developing treatment technologies for manures and wastewater.

Managed Aquifer Recharge

Managed aquifer recharge (MAR) is the purposeful recharge of water to aquifers for subsequent recovery or environmental benefit and includes surficial infiltration to subsurface injection. A MAR pilot project combining riverbank filtration and aquifer storage in the Mississippi Delta is underway where the system captures river water through induced infiltration, using natural processes during flow through sandy riverbank and aquifer sediments, to yield high quality groundwater. The withdrawn water is injected into an area of groundwater depletion and stored in the aquifer. Full-scale implementation has the potential to reverse regional groundwater depletion in the Delta, supporting irrigated agriculture and sustaining natural ecosystems.

Transdisciplinary Science in Water Solutions

ARS innovates transdisciplinary integration of water research into societally relevant, sustainable, systems-level science and solutions.

Water governs life on earth. As such, no resource is more fundamental to both agricultural and natural systems than water. Agricultural production and sustainability can only be realized when the water use is balanced among production optimization, agroecosystem services, and other societal needs. However, decisions that optimize water for one purpose may hamper the optimization for other uses. Large, societal-scale issues must find solutions that optimize water utilization across many competing issues, scales, and purposes (Fig. 4).

The ARS portfolio of historical and active research addresses the full range of water issues in agricultural and land resources. Since establishing a coordinated water program in 2000, ARS water research has evolved toward increasing complexity and transdisciplinary teams to develop innovative science tools to solve challenges. Even with this focus, however, many critical water issues remain unresolved. ARS will broaden transdisciplinary research approaches that build on shared discovery to address society's water resource issues and transform water stewardship.

Transdisciplinary Science Begins with Partner Needs. High-quality, within-discipline research is foundational to addressing the complex, multifaceted challenges facing water and agriculture now and in the future. Actionable, transdisciplinary science is designed around stakeholder needs. ARS strives to solve problems at the interface of agriculture and water resources examining the effects of agriculture on water and the effects of water availability, quality, and distribution on food production and agroecosystem health.

Major water challenges are rarely discrete, single-discipline issues. Groundwater depletion in regional aquifers, water scarcity and competition, shifting precipitation intensity, infrastructure integrity, flooding, and hypoxia in near shore environments all exemplify challenges requiring transdisciplinary research approaches. ARS will continue as the most responsive network of scientists addressing these broad challenges that impact society and connect agricultural water uses with competing, vital water demands.

Socially relevant solutions often incorporate science from multiple, interconnected challenges, leading to decision and policy relevant information. However, implementation often requires engagement and adoption by key stakeholders. ARS scientists will work closely with stakeholders to identify needs, engage interdisciplinary research teams, and mobilize multi-agency collaborative efforts to develop, test, implement, and refine solutions in concert with decision-makers and stakeholders.

The nimble and responsive solutions envisioned in the future to address our societal grand challenges include attending to infrastructure integrity and needs.

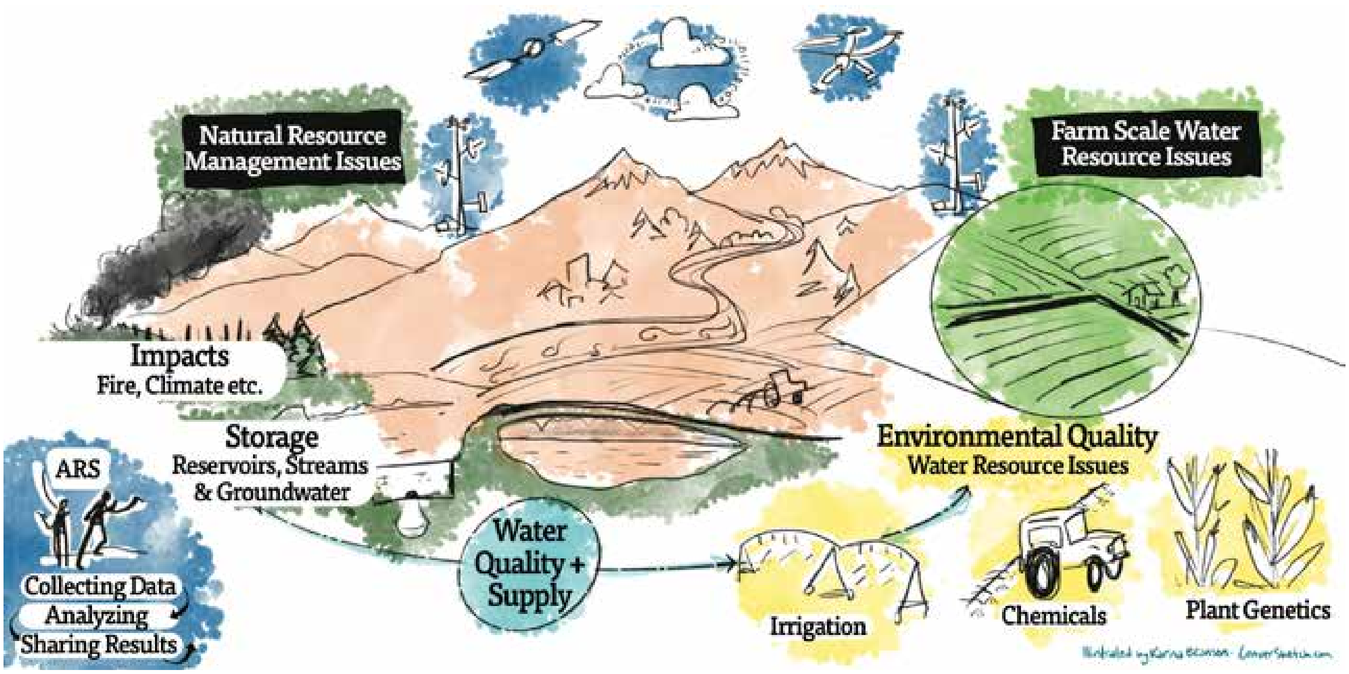


Figure 4. *Transdisciplinary approaches address:*

1) ***societal-level water resource issues*** *(e.g., agricultural production, source-water availability, water storage and transport),*

2) ***scales*** *(e.g., plant, field, farm, region, continent, and global),*

3) ***purposes*** *(e.g., food production, environmental flows, ecosystem services, recreation),*

4) ***agencies and jurisdictions*** *(e.g., local, State, Federal, international),*

5) ***socioeconomic constraints*** *(e.g., user adoption behavior, urban-ag competition, regulations, water rights, intra-and interstate and international compacts),*

6) ***data availability*** *(e.g., on-site, edge of field, remote sensing, internet/ cloud services, data networks), and*

7) ***decision support tools*** *(e.g., web-based services, models).*

Supporting Future Transdisciplinary Research. Historically, ARS research has followed a disciplinary focused approach with research linked to defined programmatic areas. At present, research activities are allocated across 4 programmatic areas and 16 national programs. However, many of the environmental processes and agricultural practices, which influence water use, availability, and quality, bridge multiple national programs. Thus, ARS will re-envision how to maintain the strengths of the disciplinary culture while fostering a culture that facilitates transdisciplinary research spanning national programs. In conjunction with other USDA agencies, ARS has put in place mechanisms that enable transdisciplinary research, such as the Grand Challenge Initiative, the LTAR Network, and the USDA Climate Hub.

Although these platforms are typically aimed at large-scale projects that extend across multiple locations and research avenues, support is needed augment interdisciplinary research within individual ARS projects and within projects focused at multiple sites. ARS will also create mechanisms that encourage research activities to reach across all national programs and disciplinary boundaries.

Ensuring future transdisciplinary research requires foresight to encourage coordination and partnerships. As science and technology advance over time, humanity's sum knowledge has increased exponentially, yet the cognitive ability of the individual scientist to grasp this knowledge is unchanged. As a result, scientists and researchers have become specialized in an ever-increasing number of sub-divided fields of study. Future transdisciplinary research will require coordination between and increasing number of individuals and integration of information from across contributing disciplines. Novel approaches to enable these interactions will ensure success in these high risk, transdisciplinary projects.

The ability to establish successful partnerships between research teams hinges on developing a shared vision and building trust among scientists and stakeholders. A shared vision provides a unity in purpose that embraces the breadth of perspectives needed to fully recognize constraints and available resources required for robust solutions. It also provides the foundation to bridge cultures. Different research organizations and disciplines have different histories, perspectives, and epistemo-logical foundations. ARS will continue to provide individual scientists with experiences and training to encourage inclusiveness between disciplines, foster communication using shared terms and language, and develop skills needed to overcome our Nation's greatest agricultural challenges.

Appendix 1

USDA Agricultural Research Service
Water Research: A Retrospective 2000 – 2020

The Agricultural Research Service (ARS) was created in 1953 as the USDA's primary scientific research agency and is distributed across more than 90 communities globally (https://www.ars.usda.gov/people-locations/find-a-location/). Water-related topics have been a major component of the agency's research portfolio from its inception, focusing on landscapes producing food, fiber, feed, and fuel. The ARS role in water research is unique and necessary because consistent funding enables development of research infrastructure, collection of long-term data sets, and the consequent development of simulation models able to represent the effect of management on water-related processes in agricultural systems over time.

A core strength of ARS is the ability to develop and participate in long-term national research projects and networks allowing greater scientific impact and development of practical resources for stakeholder use including the Conservation Effects Assessment Project (CEAP), The Long-Term Agroecosystem Research (LTAR) Network and the USDA's Climate Hubs network. Through our strong and diverse network and working group activities, ARS communicates our research findings to producers, growers, ranchers, consumers, and communities.

ARS's long-term water datasets are invaluable products of public investment in ARS research. Almost 14,000 station years of storm hyetographs and hydrographs from field to watershed scales are available in the ARS Water Data Base in the Ag Data Commons. A later hydrologic database, STEWARDS (Sustaining the Earth's Watersheds—Agricultural Research Data System), contains 16 million records from 11 states. Many other datasets (MANAGE water quality dataset, AgCROS) focus on aspects of the water cycle. Few countries have invested as much in data collection over decades. These datasets are a foundational source of long-term hydrologic information worldwide that can be used to answer questions that were not contemplated when the data were initially collected.

Perhaps the best example of this is the conversion of datasets into ARS erosion simulation models including the Universal Soil Loss Equation, which synthesized over 10,000 plot years of natural and simulated rainfall to become the first soil erosion model that could be applied throughout the United States. As science and technology advanced, ARS scientists used technology to advance hydrologic modeling. Revised and updated models developed by ARS include: the Revised Universal Soil Loss Equation (RUSLE), the Water Erosion Prediction Project (WEPP) model, the Rangeland Hydrology and Erosion Model (RHEM), the Soil Water Assessment Tool (SWAT), and the Agricultural Non-Point Source (AGNPS) Pollution Model. These models are now used worldwide to assess effects of management on water resources in watersheds.

Establishment of the Office of Scientific Quality Review (OSQR) in 1999 led to the first ARS water resources research strategy, including 5-year peer-reviewed plans that have been informed by stakeholder input. Referred to as Action Plans, the components have changed somewhat from 2000 to 2020 (Fig. 5), reflecting changes in research needs. However, the overall mission has been consistent: to develop new and improved practices, technologies, and strategies for managing the Nation's agricultural water resources.

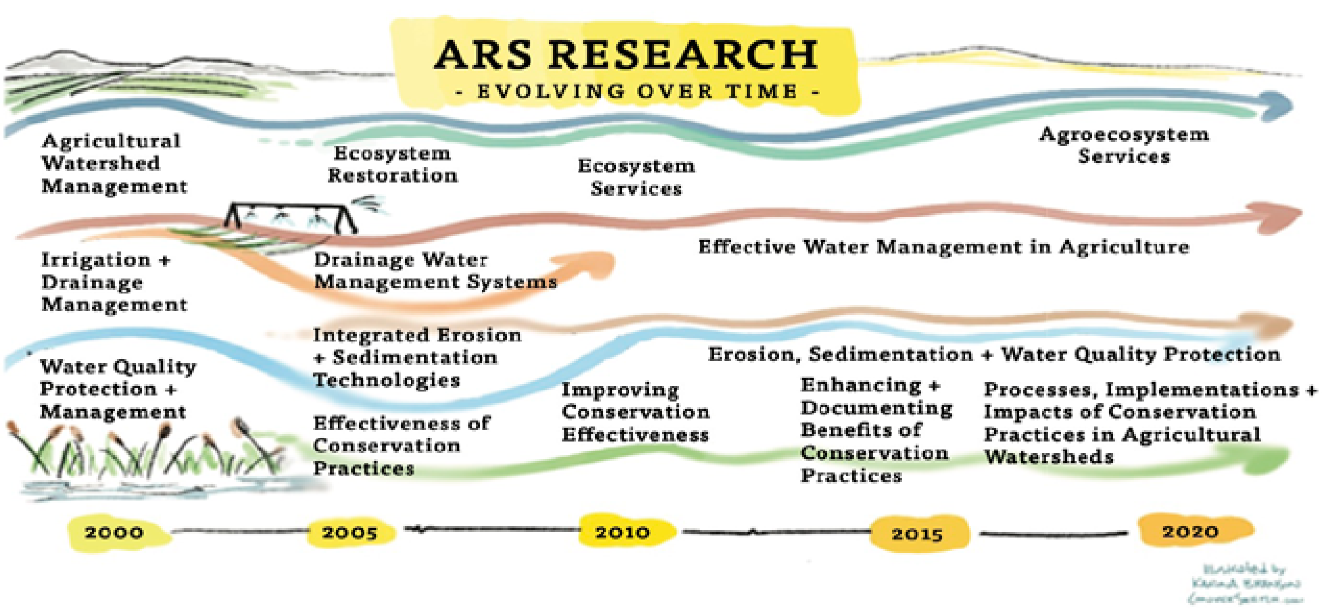


***Figure 5**. History of themes included in ARS action plans.*

USDA Agricultural Research Service Water Research Vision 2050 Feedback Workshop

ARS developed the USDA Water Research Vision by conducting a facilitated year-long, virtual workshop with nearly 40 ARS scientists from nearly all U.S. regions and water science related disciplines. Participants spanned early to senior level career ARS scientists, with special attention paid to diversity. This extended workshop was followed by several months of writing and synthesis from which the above vision was composed. A facilitated 3-day workshop garnered feedback from partners and stakeholders, including Federal and State agencies, policymakers, and commodity groups.

DAY 1 – GATHERING FEEDBACK ON THE VISION

ARS scientists shared an overview presentation on the Water Resource Vision 2050 which was followed by participants engaging in three separate breakout sessions to discuss six sections of the vision document. The goals of this workshop were to elicit input and feedback on the Water Resource Vision 2050 and for participants to explore potential alignments and mutual interests, to ask questions, and to consider gaps in the vision document. Participants were also invited to review the Water Resource Vision 2050 document and provide specific written comments over the next week.

DAY 2 – BRAINSTORMING COLLABORATION

Participants were asked to engage in four rounds of randomly selected, small group conversations exploring what are the collaborative opportunities and what will help ARS get there by considering these three questions?

1. What's possible? Where is collaboration possible in water research? What scientific questions can you help each other understand better?

2. What are the risks and rewards of collaborating on water research?

3. What's needed to do this well? What will strengthen multi-agency, cross-discipline scientific collaboration? Who are the missing stakeholders? Voices? Perspectives? How do we engage with them?

The fourth round was designed to produce specific topic questions for discussion on Day 3. Specifically, participants were asked to consider what themes or patterns were they noticing? They were also asked to identify their top three topics or questions that should be explored further.

DAY 3 – YOUR TOPICS, YOUR CHOICE

Topic areas from Day 2 conversations were organized into two sessions, and participants self-sorted into their topic of interest in each session. The questions considered on Day 3 were grouped into five general areas: important and emerging water issues, collaborations, incentives, challenges, and big data. Common themes emerged when examining the comments from all categories together: communication, active engagement with all parties affected, support of underserved communities, engagement of early career scientists, and project support from data management and basic administration to challenges in addressing agency requirements.

LIST OF REGISTERED ORGANIZATIONS

Federal Agencies

Executive Office: Council on Environmental Quality
National Aeronautics and Space Administration (NASA)
National Oceanic and Atmospheric Administration (NOAA)
National Science Foundation (NSF)
United States Agency for International Development (USAID)
United States Center for Disease Control and Prevention
United States Department of Agriculture
- Agricultural Research Service (ARS)
- Economic Research Service (ERS)
- Foreign Agricultural Service (FAS)
- Forest Service (FS)
- National Agricultural Statistics Service (NASS)
- National Climate Hub Office
- National Institute for Food and Agriculture (NIFA)
- Natural Resources Conservation Service (NRCS)
- Office of the Chief Economist
- Office of the Secretary

United States Department of Energy (DoE)
United States Department of the Interior
Bureau of Reclamation
United States Geological Survey (USGS)
United States Environmental Protection Agency (US EPA)
United States Food and Drug Administration (US FDA)
United States Trade and Development Agency

National Research Laboratories

Lawrence Berkley Laboratories
Pacific Northwest National Lab

Colleges and Universities

College of the Muscogee Nation
Colorado State University
Kansas State University
Michigan State University
New Mexico State University
Texas A&M University
University of California at Irvine
University of Cincinnati

Other

Colorado Agricultural Water Alliance
Field to Market
Lower Mississippi River Sub-basin Committee on Hypoxia
New Mexico Department of Agriculture
Upper Mississippi Basin River Association

USDA Agricultural Research Service
Water Research Vision 2050 Feedback Workshop
Summary of Feedback

Stakeholders were very engaged in the discussions and provided useful input to the Water Research Vision 2050 crafted by ARS scientists. Much of this feedback will be utilized as collaborations and projects are developed.

Water Challenges. Stakeholders would have liked to have seen more information about the following topics:

- water laws and policies discussed as these vary from State to State;
- recognition of international research ties with respect to water problems and climate change which are transboundary;
- water and environmental justice; the connections between agrovoltaic energy production and water conservation and agricultural production;
- assessment of economic impacts and opportunities related to water resources challenges;
- a brief description of ongoing watershed assessment and restoration research;
- and more emphasis on climate intensification and its impacts.

Water supply. Both water scarcity and water everywhere are issues associated with water supply, and stakeholders suggested that we combine them. Related to this was a suggestion to recognize water supply issues in the eastern United States, not just the West because both flood and drought can asynchronously affect yearly production in many regions. The vision needs to emphasize uncertainty associated with supply – exploring the shifting trends in snowmelt/runoff and water arrival and timing, which could mean that optimal operating rules for dams/reservoirs for purposes of supply may need to change. The writing team rewrote this section to address these concerns.

Water quality. Stakeholders requested further discussion and details on water quality ties with climate change, changes in aquatic diversity, reduced vegetative cover, fire and post-fire runoff and flooding, and water treatment for reuse in crop production or groundwater recharge. In addition, more focus should be given to the long-term impacts of poor groundwater quality. The vision should also include conjunctive water use impacts to water quality, discussions on salinity intrusion, and changes to nutrient availability due to ecosystem changes.

Water as culture. ARS should engage more with social scientists to understand the cultural importance of water and access issues particularly to native communities and their water rights. Stakeholders reiterated the importance of researchers understanding water policies and laws for individual states to implement solutions in a way that works with the local people. Furthermore, ARS should engage, expand, and closely work with socially disadvantaged, low-income, minority, and rural populations including American Indians, Alaska Natives, and sovereign Tribal governments on water resource research challenges and issues.

Research Approach. Participants were willing to collaborate with the ARS to realize the vision, however, a strategy to do so has not yet been defined. Development of a combined vision with other USDA agencies, NOAA, NASA, USGS, EPA, USACE, DoS, and others was suggested. NSF organized 2019 workshop on Integrated Hydro-Terrestrial Modeling (in which ARS participated) could serve as a foundation. Real cross agency collaboration would require funding.

Partnership and Collaboration. Non-ARS participants encouraged the agency to look beyond Federal partnerships towards state-level expertise driving policy and regional partnerships and towards NGOs or private sector groups that are leading efforts to quantify environmental impacts of farming. Such entities could be tapped for collaborative tool development and adoption and are usually better connected and trusted by consumers and stakeholders throughout a product chain. ARS was strongly encouraged to get more scientists directly engaged to identify and rapidly respond to water resource challenges.

Among Federal participants, discussion was focused on the nuts and bolts of research partnership to accomplish project goals, and how ARS could improve collaboration with other Federal research entities. ARS leadership was encouraged to create a database of subject matter experts within the agency and throughout the Federal government to facilitate cross pollination and leverage resources. Universities were consistently acknowledged as current, integral, and effective partners, but work could be done to reach out to those not typically involved in agricultural research.

More projects and funding priorities involving several agencies are needed to solve large over-arching challenges. This will need to include development of common communication infrastructure to help make it easier to share documents when collaborating with others outside ARS; open access data, software, and code; and clearer common funding pathways or shared support infrastructure across organizations. Several agencies are interested in collaborating to address water insecurity, while others would like to consider irrigation water use. A possible way to address water resource needs for agriculture is to locate agriculture relative to the local area's resources, e.g., growing water-intensive crops in areas with larger water supplies. Another suggestion to address water needs was to evaluate possibilities of vertical or urban agriculture for some crop types.

Science and Management Tools. Participants outside of ARS were interested in working cooperatively to solve national water issues and named several common topics towards which science and management tools could be applied, such as, climate change impacts on snowpack and water supplies, modernizing irrigation conveyance systems to use less energy and water, and improving technologies for water conservation and water treatment for reuse. However, it is imperative that agencies be deliberate in their collaborations. Notably, ARS must make their tools known and accessible to other agencies.

Formulating partnerships between agencies to develop specific tools to help stakeholders would have impact, but there must be mechanisms in place to share and disseminate tools, funding to hold workshops to teach end-users how to use the tools and support to sustain tools, e.g., updating, algorithms, code, and datasets. Industry members voiced that tools should offer compatibility so that they could be adapted and integrated with different agricultural systems or applications. Internal customers stated that linkage to real-time sensor networks is needed to improve tool robustness and tools for the public must be off-the-shelf for usability.

Water Science Expertise. The Water Research Vision 2050 is aligned well with the goals and vision of other Federal agencies. However, additional details of some topics are needed, so that state and local governments can be more intentional in addressing water resources, availability, and use and to conduct the economic research required to quantify the results of applying the developed tools and management changes. These include linkages between water use, drought, and water quality (including water borne diseases, nitrogen deposits, fertilizer management, and aquatic diversity), global application of tools, and policy focused initiatives.

Transdisciplinary Research. The complexity of water issues, the mosaic of stakeholder needs, and the patchwork of overlapping local and national regulations across the country present significant challenges. Workshop participants strongly agreed that transdisciplinary research was critical to addressing these issues and that ARS, with its range of disciplines is uniquely suited and national scope, to facilitate transdisciplinary research and has a strong record of doing so. However, one of the greatest challenges to transdisciplinary research is identifying and engaging the diverse group of scientists and stakeholders that are needed to achieve success. As one participant noted, “I know integrating the social sciences into my research is important, but I don’t know enough about natural resource sociology or economics to know who to reach out to.” Several participants suggested creating a cross-agency forum or database to address this need.

Participants also identified several internal challenges to transdisciplinary research including the need for: greater administrative support to coordinate the disparate cultures and policies among different government agencies and research organizations; more flexibility within the National Program structure to accommodate projects that bridge several National Programs and span multiple 5-year research cycles; and broader criteria of evaluating scientists that recognize that transdisciplinary research can be high risk and may take many years to bear fruit and show impacts. Transdisciplinary research offers the ground-breaking high impact means by which ARS research can move forward. Groups undertaking these research projects should be strongly encouraged to seek out collaborations across agencies and institutions, especially seeking opportunities to enhance equity and inclusion in their research process.

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