FEATURE

A vision for integrated, collaborative solutions to critical water and food challenges

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More than 40 leading US agricultural and water scientists developed a water research vision designed to address the most critical water and agricultural challenges in a changing climate to sustain agricultural production and natural systems. Water sustainability can only be realized by balancing the needs of agriculture, society, and ecosystems (Pastor et al. 2019) (figure 1). To address these competing demands, USDA Agricultural Research Service (ARS) scientists worked with a broad group of partners to develop a national Water Research Vision (*Vision*) for the next 30 years (Tsegaye et al. 2022).

The *Vision* emphasizes transdisciplinary approaches to water sustainability that enhance resiliency in agricultural systems that are increasingly vulnerable to climate change. A draft of the *Vision* was presented to external peers and stakeholders to ensure it reflects their perspectives. The final *Vision* represents a deep understanding of the role of water in agriculture, the importance of food and water security, and water's interconnection with other sociocultural values. It also includes recommendations for research and management actions to address pressing water needs across the United States. This article provides our *Vision* to support collaboration and resource sharing.

WATER CHALLENGES OF TODAY AND THE FUTURE

Fresh water supplies are facing increasing pressure globally from both climate change and growing populations (Immerzeel et al. 2020; Milly and Dunne 2020). Altered precipitation patterns and warmer temperatures associated with climate change are disrupting agricultural systems and water sources (Elias et al. 2021), while growing populations compete for water supplies. These challenges, in combination with other stressors, have complex consequences for water availability, quality, and distribution. We see these challenges falling into three main categories: supply shortages, flood risk, and water quality.

The US faces water supply shortages that will worsen as the climate changes and population grows (Overpeck and Udall 2020). Fire and shifting climate patterns threaten forested source waters. Reservoirs face dwindling inflows and are filling with sediment, increasing flood risk and reducing their capacity to respond to drought. Continued development of irrigated agriculture to mitigate the impacts of drought and rising temperatures is diminishing critical aquifers (figure 2). Limited water supplies will face increasing demand under higher temperatures, including management practices that use irrigation to mitigate crop damage during heat waves.

Throughout the Midwest, Mid-South, and Northern Plains, flooding along main stem rivers, tributaries, and small streams is forcing farmers to delay fieldwork, reduc-

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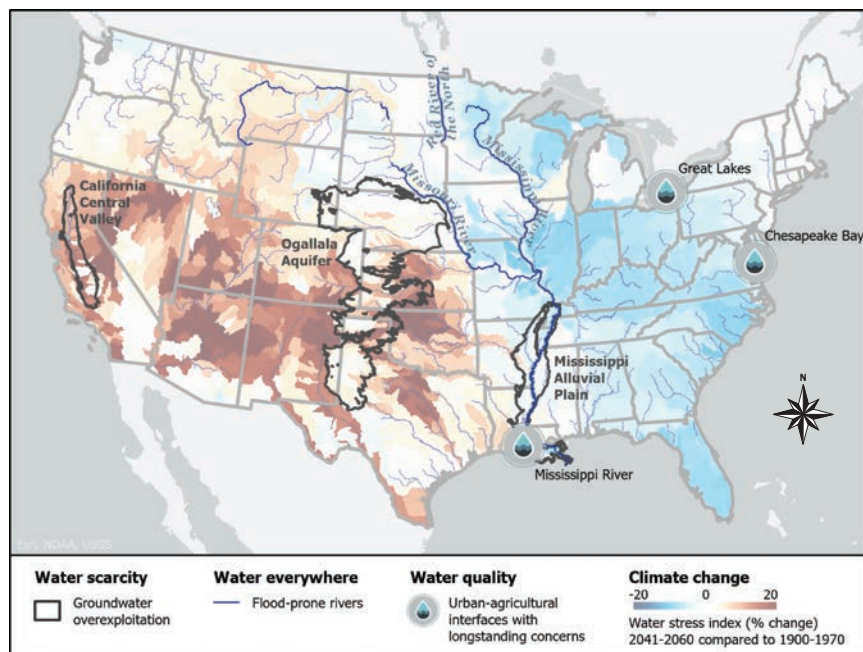
Figure 1

Water issues connect across agroecosystems and require transdisciplinary solutions (figure from Tsegaye et al. [2022]; concept by Kyle Mankin).
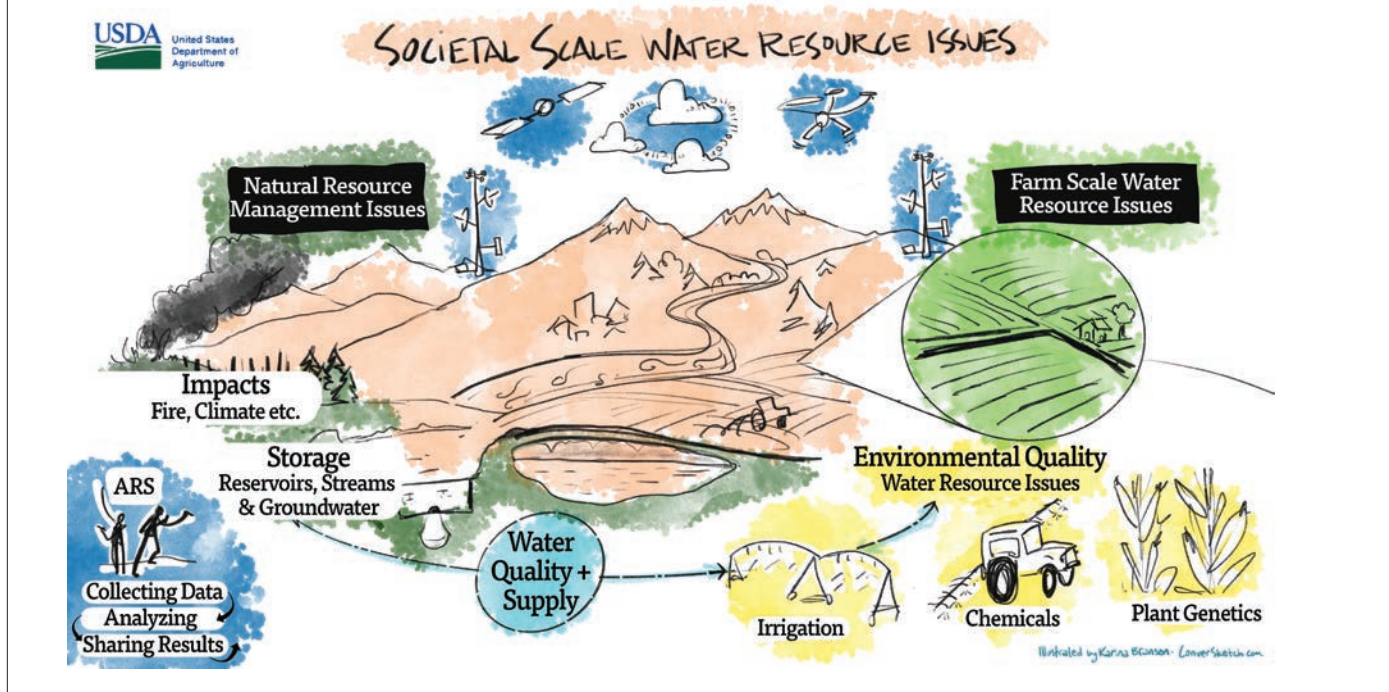
Figure 2

Water resources in the Continental United States are threatened by climate change, groundwater overdraft, and longstanding water quality issues (Tsegaye et al. 2022).

ing yields, damaging infrastructure, and even causing loss of life. Excess water at the wrong time limits yield and production in many areas, adding to the societal cost of the Federal Crop Insurance program.

Critically important water bodies, from the Gulf of Mexico to Chesapeake and San Francisco Bays to the Great Lakes, are experiencing habitat devastation caused by hypoxia (zones of low or no oxygen [O_2]) and algal blooms resulting from increased inflows of sediment, nitrogen (N), and phosphorus (P) (Chen et al 2020). Pesticides, metals, and pharmaceuticals impair aquatic ecosystems, reducing biodiversity while rendering water unusable for human consumption, fishing, and recreation. Heavy downpours and other events that deliver contaminants to sensitive water bodies are expected to occur more frequently, further complicating mitigation and management efforts.

SOLUTIONS AND OPPORTUNITIES

While the future is beset with challenges, the *Vision* also identifies opportunities. For example, growing cities and the urban–agriculture interface create opportunities for creative solutions to water scarcity

and quality challenges, including urban community gardens, vertical farming, and green infrastructure such as retention ponds and constructed wetlands.

The challenge of ensuring a plentiful supply of high-quality water requires a novel research agenda. Solutions must be guided by the needs of producers, resource managers, and surrounding communities, recognizing that decisions made in one location ripple outward. Our agenda calls for agroecosystem assessment tools co-created with users and informed by sociocultural-economic factors. This requires partnership and collaboration, grounded in sound disciplinary and transdisciplinary science to leverage technological advances, creating impactful outcomes.

We present a foundational approach guided by science and driven by outcomes (figure 3). Three critical components supporting the *Vision* are (1) partnership and collaboration; (2) a sound research approach designed to improve decision-making, reduce uncertainty, and scale beyond test sites; and (3) decision support through sharing data and developing tools tied to user needs. These foundational elements lead to development of a cadre of leading water experts with strong disciplinary expertise, which is necessary for the effective transdisciplinary science required to solve our societal-scale water resource issues to support food production, high-quality water, and ecosystem services (Pastor et al. 2019). The expected outcomes of this approach are to solve critical challenges, develop new innovations, and support people and communities despite a changing climate and population growth. We expand on the critical elements to realize the *Vision* below.

Partnership and Collaboration. Research to address these challenges requires collaboration grounded in mutual support, effective communication, and shared leadership. Effective collaboration can help conserve research resources and enhance adoption of new technologies. This will require scientists to engage stakeholders and agencies to cooperate across jurisdictions including with industry to develop public-private partnerships.

Grape Remote sensing Atmospheric Profile and Evapotranspiration eXperiment (GRAPEX) and OpenET (Kustas et al. 2018) exemplify public-private partnerships that could be replicated. Amid rapidly decreasing water supplies, California wine grapes (*Vitis vinifera* L.) support an industry valued at US\$120 billion. Recognizing the need to improve vineyard irrigation management, E. & J. Gallo Wineries contacted USDA scientists to develop satellite-based techniques for mapping crop water use and stress. This partnership led to the GRAPEX project. GRAPEX provides geospatial tools for improved irrigation scheduling, which will be accessible through the OpenET platform, another public-private partnership developed by the National Aeronautics and Space Administration (NASA) with philanthropic support.

Figure 3

Innovations, research, and actions needed to achieve vision (figure from Tsegaye et al. [2022]; concept by Kyle Mankin).
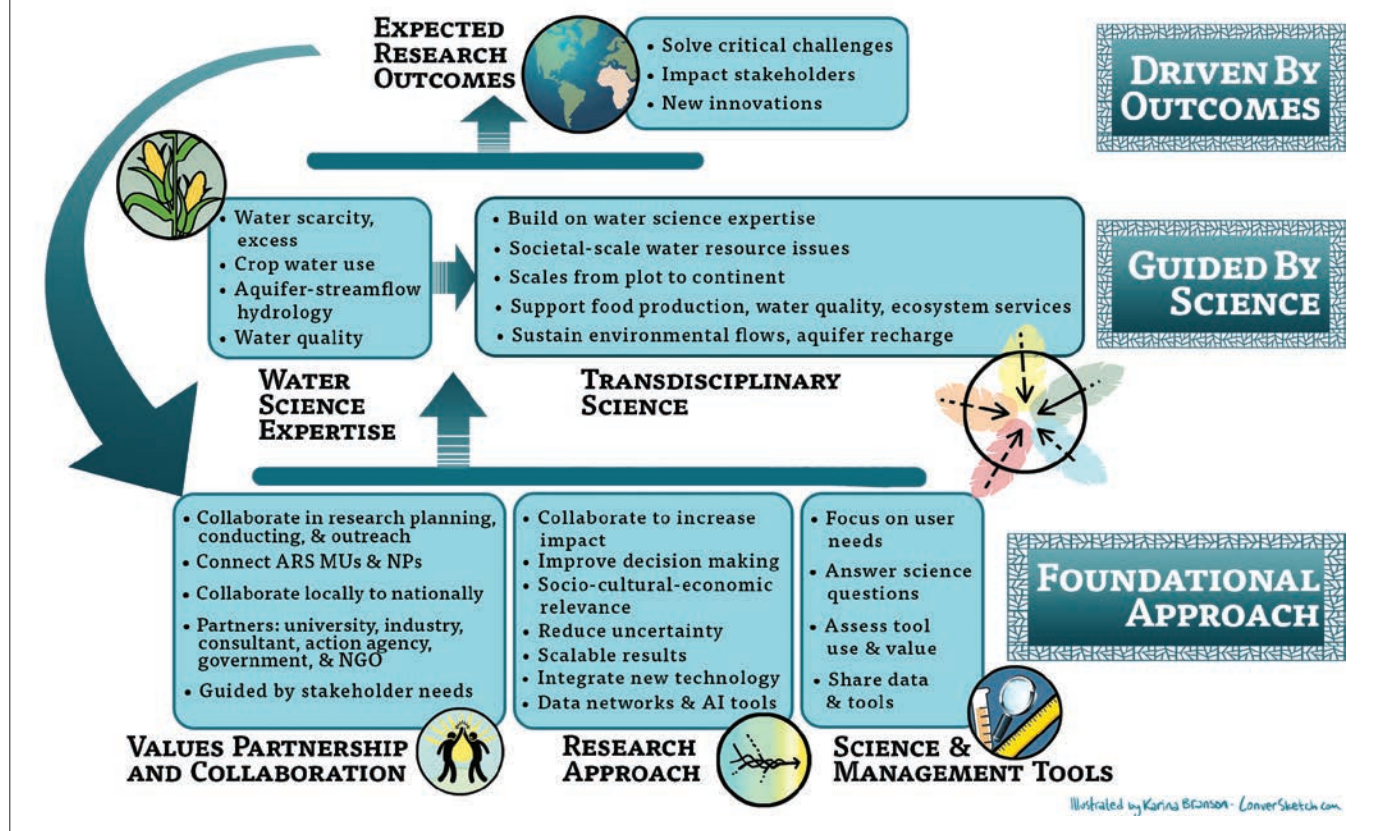
Research Approach. The *Vision* recognizes that "challenges of today and tomorrow to ensure a plentiful supply of high-quality water…must be addressed with a vision and research agenda that leverages new technologies and integrative approaches" (Tsegaye et al. 2022). The research approach is "shaped by our history (figure 4) and builds upon our rich research capital" (Tsegaye et al. 2022). Given the integrated nature of hydrologic systems, scientists must develop multiple metrics to assess agroecosystem performance, communicate the interdependencies of different decisions, and coordinate the decision processes from different sectors. Future research will both integrate and develop new technologies. We anticipate that new technologies will emerge in bioengineering, informatics and computer science, and in situ and real time sensor technology (Capalbo et al. 2017). Efforts will continue to quantify and reduce uncertainty, share data and tools, and to produce scalable results. Maintaining the ability to respond to change is a critical element of the research approach. The result of the stakeholder-driven research approach herein is the development of science-proven tools to guide decision-making.

Science-Management Tools and Technological Advances. Building credible tools requires demonstrating their value in practice. Tools that provide information tend to be adopted over those that simply prescribe an action. Participation of end users in tool development increases the likelihood of meeting producer needs (Meadow et al. 2015). We envision user-friendly tools that translate technologically advanced, multimetric, scalable research in a way that accurately communicates uncertainty and risk. One successful example is the Soil and Water Assessment Tool (SWAT+), which assesses pollution problems worldwide (Gassman et al. 2014). In the United States, SWAT+ is being used to develop strategies for water quality challenges in Chesapeake Bay, Lake Erie, and the Gulf of Mexico.

Technological advances, such as real-time sensors for measuring soil and plant conditions, can create both challenges and opportunities. Emerging sensor technologies generate robust data, but also create data management challenges that will require new ways of automating data collection and analysis. These tools can be used to improve management decisions, for example, by linking high-resolution soil moisture data to autonomous variable-rate drip irrigation that provides water to crops exactly where and when it is needed.

Water Science Expertise: Discipline-Specific Knowledge Gaps. While the *Vision* emphasizes transdisciplinary collaboration, single-discipline agroecosystem research is also critical to addressing water sustainability. Further research in plant physiology is needed to address gaps in knowledge about how crops respond to changing climate conditions and increasing carbon dioxide (CO_2). This requires sophisticated instrumentation to measure soil, canopy, and topographic characteristics sensed from perspectives that stretch from farm fields to orbiting satellites. Tools that merge geospatial datasets with high-resolution localized forecasts and autonomous irrigation systems will allow for adjustment of water applications to maximize technical efficiency and crop water productivity. Likewise, sensors to detect crop nutrient deficiencies or pest infestations could improve the efficiency of agrochemical use on crops while minimizing impacts on water quality. Other critical areas of research will include questions about the effects of irrigation water composition on groundwater quality, the potential for microbiological interactions with crops

Figure 4
History of themes included in Agricultural Research Service action plans (figure from Tsegaye et al. [2022]).

to increase crop resilience, and agronomic effects on soil carbon (C) dynamics. Much of US irrigated agriculture depends on groundwater. While we have historically treated surface and groundwater separately, they are often closely linked. Effective management of water resources requires a better understanding of these relationships. Advances in this area can make irrigated agriculture more sustainable by minimizing groundwater depletion, enhancing recharge, improving water quality and restoring ecosystem function.

Transdisciplinary Science in Water Solutions. As science has advanced, humanity's sum knowledge has increased exponentially, yet the individual scientist is often incentivized to specialize in one among the ever-increasing fields of study, making it challenging to integrate new developments. Future research will require coordination between individuals, integration of information across disciplines, and a new paradigm of data and informatics approaches, including artificial intelligence (Liu 2020).

Collaborative, participatory transdisciplinary research is fundamental to effectively responding to water-related challenges. Implementation of scientific solutions requires working closely with stakeholders to identify needs and mobilizing multiagency collaborative efforts to develop, test, implement, and refine ideas. Successful partnerships between research teams hinge on developing trust and a shared vision that provides unity in purpose, embraces diverse perspectives, and bridges disciplinary cultures and other ways of knowing (including traditional ecological knowledge) to create robust solutions.

SUMMARY

Our *Vision* relies on partnership and collaboration in a user-driven, decision-focused framework. We believe that, collectively, we can mobilize scientific expertise along with emerging technologies codeveloped with partners to provide enough water for thriving agroecosystems while minimizing detrimental impacts of agriculture on water resources and aquatic ecosystems (figure 5). Maintaining the capacity and flexibility to adapt to changing conditions over the next three decades is critical, as are continued long-term experiments and evaluation of their impact. The full impact of research often occurs long after peer-reviewed publication when knowledge is integrated into practice, as supported by the USDA Climate Hub Network. Transdisciplinary research will rely on the network of experimental farms and large datasets at ARS sites, including the Long-Term Agroecosystem Research Network and Conservation Effects Assessment Project locations. ARS will continue to provide scientists with experience and training, encouraging cross-disciplinary partnerships, communication, and collaboration to develop skills needed to overcome our nation's agricultural and water challenges.

Figure 5

Agricultural Research Service water research vision addresses current and anticipate challenges for sustainable, healthy landscapes and communities by 2050 (figure from Tsegaye et al. [2022]; concept by Kyle Mankin).
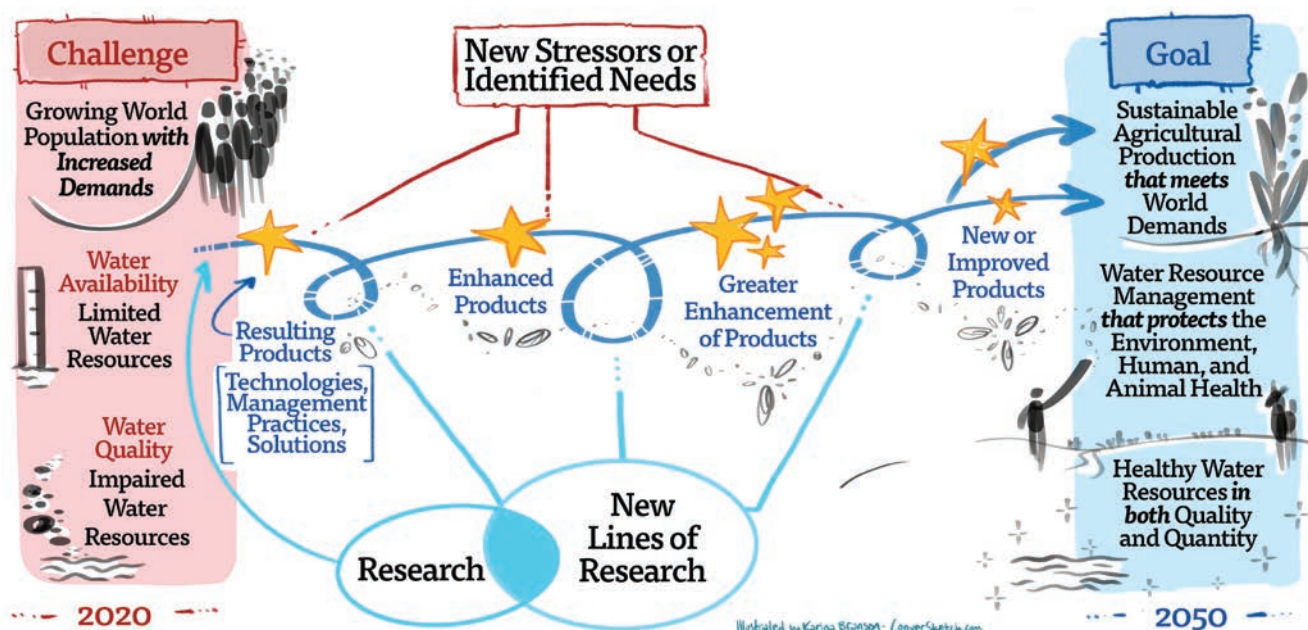
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