FY 2022 Annual Report

National Program 211 - Water Availability and Watershed Management

Introduction

Fresh water is essential to maintaining both agricultural and industrial production, ecosystem integrity, and human health. Throughout history, a key measure of civilization's success has been the degree to which human ingenuity has harnessed freshwater resources for the public good.

As the Nation was established and expanded, it flourished in part because of abundant and readily available water and other natural resources. With expansion to the arid west, investments in the use of limited water resources became critical to economic growth and prosperity. In the 19th century, water supplies for new cities were secured by building reservoirs and water distribution systems. The 20th century was characterized by pivotal accomplishments in U.S. water resource development and engineering. Investments in dams, water infrastructure, irrigation, and water treatment provided safe, abundant, and inexpensive sources of drinking water, aided flood management and soil conservation, created recreational opportunities for the public, and dramatically improved hygiene, health, and economic prosperity. The Nation's water resources and water technologies were the envy of the world. Certainly, water-related science and technology had served our Nation well. However, the 20th century was also characterized by significant increases in irrigated area, fertilizer use, and improved crop genetics that combined to produce explosive growth in agricultural production as the Nation became a major exporter of agricultural products. Concurrently, agriculture became the largest consumptive user of freshwater, but possibly the least understood in terms of opportunities for conserving water supplies and improving water quality for all users.

As the 20th century drew to a close, the water resource situation in both the United States and the world began to change. Runoff and drainage from heavily fertilized fields increasingly affected the aquatic health of our waterways and oceans. Key groundwater reserves began to become depleted, water quality became increasingly degraded, and adverse climatic conditions (e.g., drought) began to significantly reduce available freshwater supplies. At the same time, freshwater allocations began to shift among different users and needs (e.g., from agricultural to urban uses; from storing water supplies in reservoirs to maintaining in-stream flows to ensure healthy aquatic ecosystems; from industrial and energy production to recreation). Our shared freshwater supply was significantly reduced as it also became more variable, unreliable, and with increasing frequency, less than adequate to meet the needs and demands of an expanding population. Meanwhile, large-scale and complex water quality issues began to impact the Gulf of Mexico, Chesapeake Bay, and the Great Lakes. Clearly, new technologies were needed to allow agriculture to better manage both water quantity and quality.

As the 21st century unfolds, these new challenges for agriculture are intensifying—increasing demands for water from our cities, farms, and aquatic ecosystems; increasing reliance in the eastern humid and sub-humid states on irrigated agriculture for stable crop and animal production and farm income; changing water supplies due to groundwater depletion in some areas; climate variability and change; and the need to tap alternative water resources. These challenges are not insurmountable, and in terms of their impacts on both water supply and use and water quality, agricultural lands can play an important role in meeting them. Advances in agricultural water management can provide important and unique contributions to the complex problem of water management at regional and national scales. Science and engineering can create new and emerging technologies that widen the range and effectiveness of options for future water management; and science can develop and provide the tools needed by managers and planners to accurately predict the outcomes of proposed water management decisions at farm to national scales. The factual basis for decision-making includes an understanding of these new technologies, their effectiveness as well as potential unintended consequences, and a strategy for getting water users and agencies to adopt the technologies determined to be most effective. Thus the Nation has the opportunity to apply and use science and technology to protect, sustain, enhance, and manage our water resources, improving human and ecological health while continuing to build a strong and growing economy.

The USDA-ARS National Program for Water Availability and Watershed Management (NP211) had a productive and dynamic year in 2022. Scientists in NP211 continue to make extraordinary impact in numerous diverse areas of research relating to global root-zone soil moisture monitoring, mitigating phosphorus losses from tile-drained landscapes, and publishing landmark historical data sets as part of the Long-Term Agro-ecosystem Research (LTAR) network.

NP211 addresses the highest priorities for agricultural water management (effective water management; erosion, sedimentation, and water quality protection; enhancing and documenting the benefits of conservation practices; and watershed management to improve ecosystem services in agricultural landscapes). Research will also be conducted to determine the transport and fate of potential contaminants (sediments, nutrients, pesticides, pathogens, pharmaceutically active and other organic chemicals, and salts and trace elements) as well as to assess our capabilities to conserve and reuse waters in both urban and agricultural landscapes and watersheds.

The overall goal is to provide solutions to problems in the utilization of the Nation's water resources. Specific topics under investigation under the current plan include: Multi-scale irrigation management technologies for sustainability; Irrigation application methods, components, and management; Rainfed, dryland, and limited-irrigation water use and management; Alternative water resources for agriculture and aquifer recharge; Simulation modeling, data, and decision support tools for water management; In-field processes controlling soil erosion and fate of sediment and contaminants; In-stream processes affecting contaminant fate, transport, and biological elements; Development of practices to control the transport and fate of contaminants; Development of tools for improved water quality management in the landscape; Understanding and quantifying the governing processes associated with implementing conservation practices; Assessing and implementing conservation practices in agricultural landscapes; Synthesizing and forecasting the impacts of conservation practices and changing environments; Managing agroecosystems through collection of long-term observations, data interpretation, and data dissemination; Modeling and tools for agroecosystem management; and Quantifying agroecosystem performance and tradeoffs.

NP211 is organized into four Components:

- Effective Water Management in Agriculture
- Erosion, Sedimentation, and Water Quality Protection
- Conservation Practices in Agricultural Watersheds
- Watershed Management to Improve Agroecosystem Services

During FY 2022, 137 full-time scientists working at 25 locations across the United States actively engaged in 33 ARS-led and 353 cooperative research projects in NP211. The ARS scientists also collaborated/participated on several international projects. Base funding for the program was $79M.

Personnel news for NP211

New additions to the NP211 team in 2022 are:

- **Natalia Rogovska** joined the National Laboratory for Agriculture and the Environment, Agroecosystems as a Research Soil Scientist in Ames, IA. Her current research will focus on investigating how various in-field and edge-of-the-field conservation practices impact water quality.
- **Dr. Wayne Roper III** is a Research Biologist in the Wind Erosion and Water Conservation Research Unit as a Postdoc Soil Microbiology Research Associate. Dr. Roper joined the program of Dr. Acosta-Martinez, Lubbock, TX.
- **Dr. Dalmo Vieira** joined the Watershed Physical Processes Research Unit as Physical Scientist, in Oxford, MS. Dr. Vieira has been studying soil erosion processes in

agricultural fields and watersheds for over 15 years with ARS and AR leading to enhancements to RUSLE2 erosion prediction technology. His expertise is in developing and enhancing methods to measure, control, and predict erosion and sediment yield from fields, streams, and impoundments in agricultural watersheds and to develop water management practices and systems that improve water availability for agricultural sustainability.

- **Dr. Chris Renschler** joined the NSERL as Research Leader and Soil Scientist at West Lafayette, IN. He earned his Ph.D. in Natural Sciences, University of Bonn, Bonn, German. Prior to joining NSERL, Dr. Renschler worked at University at Buffalo – Soil Erosion Modeling with GIS and Remote Sensing, Sustainability and Resilience Indicators.
- **Austin White** joined the National Soil Erosion Research Laboratory as a Support Scientist. His expertise is in AECOM Hydrologic data management, analysis, research, and technical competence. He earned his B.S. in Agricultural Engineering, Purdue University, West Lafayette, IN.
- **Dr. Ryan McGehee** was hired as a Post Doctoral Biological Science Lab Technician in the Agroecosystem Management Research Unit; He received his Ph.D. in Agricultural and Biological Engineering, Purdue University, West Lafayette, IN.
- **Dr. William Ford** joined the team at the University of Kentucky - Water and sediment transport and modeling as a visiting scientist; he earned his Ph.D. in Civil Engineering, University of Kentucky, Lexington, KY
- **Dr. Austin Rutherford** was hired as a Post-Doctoral Research Ecologist. Dr. Rutherford work will focus on vegetation analyses of the NRCS National Resource Inventory (NRI) dataset. He recently completed his Ph.D. in Ecology, Management, and Restoration of Rangelands program where he studied under Steve Archer at the University of Arizona.
- **Erika Gallo** was hired as a Research Hydrologist to help support Russ Scott on his eddy flux tower work in Tucson, AZ. Prior to this position she worked at the University of Arizona in the Hydrology and Atmospheric Sciences department.
- **Dr. Jesus Alberto Casillas-Trasvina** is a postdoctoral scholar researcher at the University of California, Davis, that has been hired through a NACA. His work will focus on the development of an Integrated Watershed Scale Model that includes the Sierra mountains and the California Central valley. He is presently focusing on developing a reference water balance model for the Turlock/Merced basins using the USGS's coupled surface/groundwater flow model GSFLOW. Dr. Casillas received his Ph.D. degree at Ghent University in Belgium.
- **Dr. Anish Sapkota** is a postdoctoral at the Sustainable Agricultural Water Systems Research, Davis, CA. Dr. Sapkota has been hired through a NACA to research the influence of cover crops on carbon and water cycling in perennial orchard agroecosystems. He is currently working on identifying research questions that can be

addressed with multi-scale datasets, including soil chambers, flux towers, and remote sensing. Prior to this position, Dr. Sapkota was a Ph.D. student at the University of California, Riverside.

- **Dr. Wooikley Paye** is a Post-Doctoral Soil Scientist. He earned his Ph.D. in Agro-ecology and Sustainable Agriculture with focus on Soil Fertility and Nutrient Management from Louisiana State University in Baton Rouge, LA. His work will focus on improving soil health, carbon sequestration, nutrient cycling, plant-nutrient and water use efficiency, and mitigating the environmental impact of excess nutrients in the Coastal Plain Region.
- **Dr. Andrew Hedrick** was converted from a post-doc to a permanent Research Hydrologist at the Northwest Watershed Research Center. His research will focus on snowmelt runoff forecasting.
- **Dr. Octavia Crompton** is a Research Scientist in Agricultural Research Service Unit, she joins us from Duke University where she completed a Postdoc. She earned her Ph.D. from the University of California, Berkeley. She will be working on NP212 activities but will be engaged with LTAR. She is a hydrologist and a modeler.
- **Dr. Victoria Walker** joined the USDA-ARS Hydrology and Remote Sensing Laboratory, in Beltsville, MD as a Postdoc Research Associate, she earned her Ph.D. from Iowa State University. She will be focusing on soil moisture remote sensing and field experimentation.
- **Dr. Sumanta Chatterjee** is a visiting Postdoctoral student from India. Dr. Chatterjee expertise is in evapotranspiration and wildfire.
- **Dr. Hyunglok Kim** is a Postdoctoral Research Fellow with a Ph.D. from University of Virginia. Her areas of expertise are hydrologic modelling, land surface remote sensing and machine learning. Dr. Kim is working on using remotely sensed soil moisture to measure streamflow and improve the calibration of hydrologic models in ungauged agricultural basins working with Wade Crow.
- **Dr. Mahesh Maskey** joined the Sustainable Water Management Research Unit as post-doc, hydrologic modeler. Dr. Maskey was previously in a post-doc position at UC-Davis. He is conducting research on using advanced computing techniques to streamline the parameterization of hydrologic-crop models, as well as ways to combine hydrologic-crop models with groundwater and economic models.
- **Dr. Natalia Rogovska** joined the National Laboratory of Agriculture and Environment as a Soil Scientist from Iowa State University. Prior to working at USDA, she worked as an Assistant Soil Scientist and graduate lecturer at Iowa State University. Her current research focuses on investigating how various in-field and edge-of-the-field conservation practices impact water quality.
- **Dr. Kenneth Wacha** was hired as a Research Hydrologist at the Agroecosystems Management Research Unit at the NLAE in Ames, Iowa. Prior, to USDA Dr. Wacha

worked as an Agricultural Engineer at the National Soil Erosion Research Laboratory, research focused on quantifying, and managing interactions between climate, soils, and management and their impact on hydrology and water quality at field, landscape, and watershed scales.

- **Dr. Isis S. P. C. Scott.** Joined the Northwest Irrigation & Soils Research Unit as a Soil Scientist. Prior to joining USDA, she was a Postdoc student at University of Maryland. Dr. Isis S. P. C. Scott earned her Ph.D. in Agricultural and Biological Engineering and is working on the Legacy P project associated with CEAP. Her research will be focusing on measuring phosphorus transport and deposition in irrigation laterals, return flow streams and water quality ponds.
- **Dr. Colby Reavis** is a post-doctoral researcher with ORISE in collaboration with the Sustainable Water Management Research Unit. Dr. Reavis received his Ph.D. from University of Arkansas, field-scale greenhouse gas emissions in rice/soybean systems.
- **Dr. Luke Heintzman** joined the Water Quality and Ecology Research as a Research Ecologist in Oxford, MS. Dr. Dr. Heintzman came to ARS via ORISE SCINet post-doctoral fellow in Las Cruces, New Mexico. He is a landscape ecologist with expertise in remote sensing/GIS technology working on the Lower Mississippi River Basin Long-Term Agroecosystem Research Project and the Conservation Effects Assessment Project in the Beasley Lake watershed.
- **Dr. Ethan Pawlowski** came to WQERU from his previous position as an ORISE post-doctoral fellow. Dr. Pawlowski earned his Ph.D. from the University of Minnesota. He is now applying his expertise in biogeochemistry and hydrology at Oxford, MS.
- **Dr. Carrie Laboski** was hired as a Research Leader at the Pasture Systems & Watershed Management Research, University Park, PA. Dr. Laboski’s research is currently focused on improving sustainability and resilience of agroecosystems through improved soil fertility and nutrient management practices. Before joining ARS, Dr. Laboski was a Professor and Extension Specialist at the University of Wisconsin-Madison.
- **Cody Cochran** joined ARS Parlier, CA in July 2022 as an engineering technician.
- **Helen Heng** joined ARS Parlier, CA as a Biological Science Technician position to assist projects on soil-water health projects.
- **Dr. Sumanta Chatterjee**, India, USDA-ARS joined Hydrology and Remote Sensing Laboratory followed by post-doctoral expertise in evapotranspiration and wildfire causality (working with Martha Anderson).
- **Dr. Hyunglok Kim**, received his Ph.D. from University of Virginia in 2022. His expertise is in hydrologic modelling, land surface remote sensing and machine learning. Working on using remotely sensed soil moisture to measure streamflow and improve the calibration of hydrologic models in ungauged agricultural basins (working with Wade Crow)

The following scientists have left the ranks of NP211 in 2022:

- Wind Erosion and Water Conservation Laboratory said farewell to **Dr. Jeff Baker**, Plant Physiologist and **Mr. Charles Yates**, Research Engineering Technician.
- **Dr. Chi-hua Huang,** retired from the National Soil Erosion Research Laboratory, West Lafayette. IN. He developed methodologies to quantify soil surfaces boundaries and conditions and erosion processes.
- **Stan Livingston**, Soil Scientist of the National Soil Erosion Research Laboratory retired after 41 years with ARS. He was named the Scientific Support Award for outstanding and innovation contributions critical to conservation practice assessment in tile drained landscapes.
- **Dr. Ken Wacha**, Scientist transferred to USDA-AR postdoc positions in NLAE in Ames, Iowa.
- **Dr. Tian Guo** departed her position at Purdue University at the NSERL.
- **Dr. Amit Chatterjee,** Research Soil Scientist, took a new position at the USDA-ARS Soil, Water & Air Resources Research Unit in Ames, Iowa.
- **Dr. Gilbert Sigua**, Soil Scientist retired on December 31, 2021. His research work was on nutrient cycling in irrigated soils. Dr. Sigua's scholarly achievements, expertise, and professional status have been widely recognized through numerous national and international honors and awards.
- **Dr. Tom Moorman**, Research Leader/ Microbiologist at the National Laboratory for Agriculture and the Environment, Agroecosystems Management Research Unit; Retired on February 14, 2021; Dr. Moorman notably led the Upper Mississippi River Basin LTAR and developed new information establishing that antibiotic resistance genes and antibiotics are being transported off farmed fields in drainage water and are present in larger riverine environments.
- **Dr. Mark Tomer,** Soil Scientist at the National Laboratory for Agriculture and the Environment, Agroecosystems Management Research Unit; Retired on June 30, 2021; notably developed the Agricultural Conservation Planning Framework (ACPF) that provides watershed databases and software tools for placement of conservation practices to improve water quality and used by numerous agencies and groups.
- **Dr. Sally Logsdon,** retired as a Soil Scientist in the National Laboratory for Agriculture and the Environment, Agroecosystems Management Research Unit; Dr. Logsdon, notably served as Editor-in-Chief for 6 years for Soil Science Society of America Journal.
- **Dr. Mark Seyfried**, Soil Scientist of the Northwest Watershed Research Center, retired in December 2021.

- **Dr. Earl Vories**, retired as a Res. Agricultural Engineer. Dr. Vories is internationally recognized for his work to improve irrigation systems for humid and sub-humid climates, and for his contributions to precision, variable-rate irrigation.
- **Dr. Dhurva Kathuria**, A postdoc at UC Davis, left USDA.
- **Dr. Barry Allred,** Research Agricultural Engineer retired from the Soil Drainage Research Unit.
- **Dr. Ruixiu Sui** retired from the Agricultural Engineer Sustainable Water Management Research Unit. He had been with ARS since 2009 and served as SWMRU's lead scientist since its inception. Prior to that, he was in the Crop Production Systems Research Unit. He holds four patents in engineering technology, two of which have been licensed by companies for commercialization. Dr. Sui has authored/coauthored 176 scientific publications, gave over 100 technical presentations at regional, national, and international meetings. In 2021, he was on the team that won the ARS Technology Transfer Award.
- **Dr. James Kim**, Agricultural Engineer, remote sensing left ARS in September 2022. He joined SWMRU in June 2021, transferring from ARS in Maricopa where he had been since 2018.
- **Dr. Ken Wacha, Scientist**, transferred to USDA-ARS NLAE in Ames, Iowa.
- **Dr. Tian Guo** Postdoctoral student, Purdue University departed her position at the NSERL.
- **Dr. Amit Chatterjee**, Research Soil Scientist, took a new position at the USDA-ARS Soil, Water & Air Resources Research Unit in Ames, Iowa.
- **Jason Kelley** left ARS Parlier.

The following scientists in NP211 received awards in 2022:

- **Mark Williams**, of the National Soil Erosion Research Laboratory was named Finalist for Samuel J. Heyman Service to America Medal for Excellence in Water Quality Research in recognition of his pioneering research to protect water quality and aquatic life from pollutants in agricultural runoff. Samuel J. Heyman Service to America Medal for Excellence in Water Quality Research
- **Dr. Kenneth Stone**, Coastal Plain Soil, Water and Plant Conservation Research, Research Agricultural Engineer was inducted into the American Society of Agricultural and Biological Engineers' 2022 Class of ASABE Fellows. Congratulations to the 2022 Class of ASABE Fellows
- **Dr. Steve Evett** became fellow of the American Society of Agricultural and Biological Engineers Award.

- **Kevin King**, awarded fellow within American Society of Agricultural and Biological Engineers
- **Michael Cosh** received the Soil Moisture Community Leadership Award in August 2022, from the National Coordinated Soil Moisture Monitoring Network/NOAA/NIDIS.
- **Michele L Reba**, of the DWM Research Unit, Jonesboro AR, received the Rice Researcher of the Year from at the 25th Annual National Conservation Systems Cotton and Rice Conference and the Award for the Advancement of Surface Irrigation from the American Society of Agricultural and Biological Engineering
- **Dr. Earl Vories** was elected Fellow of the American Society of Agricultural and Biological Engineers “for contributions toward improving the efficient use of water in agriculture.”
- **Dr. Kristen Veum** was elected as President-Elect of the American Society of Agronomy.
- **Dr. Lori Abendroth** received the LTAR Early Career Award and the LTAR Network Impact Award
- **Dr. Chris Delhom** received the Outstanding Contribution to the Cotton Industry award from Delta Council in July 2022 while serving as the acting RL of SWMRU.
- **Dr. Martha Anderson** received the John Dalton Medal for hydrology from the European Geophysical Union. 2022 John Dalton Medal is awarded. Dr. Anderson also received the 202 Class of AGU Fellows Award, two of which have been licensed by companies for commercialization.
- **Dr. Sui** has authored/coauthored 176 scientific publications, gave over 100 technical presentations at regional, national, and international meetings. In 2021, he was on the team that won the ARS Technology Transfer Award.
- **The Southwest Watershed Research Center Unit** was given The Nature Conservancy of Arizona 2022 Morris K. Udall Award for Conservation Achievement for their work in the San Pedro Valley and across the state.
- **Dr. Lauren Hale** at ARS Parlier received the PWA earlier career scientist of the year award.

In 2022, several factors demonstrated the quality and impact of NP 211 research:

- Publication of 242 peer-reviewed journal articles;
- 44 new agreements with incoming funds;
- 1 new invention disclosures, 1 new patent; and
- 125 students and postdoctoral research associates training with ARS

NP211 Accomplishments for FY2022

This section summarizes significant and high impact research results that address specific components of the FY 2021-2025 action plan for NP211. Each section summarizes accomplishments of individual research projects in NP211. Many of the programs summarized for FY 2022 include significant domestic and international collaborations with both industry and academia. These collaborations provide extraordinary opportunities to leverage funding and scientific expertise for USDA-ARS research by rapidly disseminating technology, enhancing the impact of ARS research programs.

Effective Water Management in Agriculture
Selected Accomplishments

Snowmelt modeling technology to predict water availability in California. Drought and ongoing climate warming have greatly altered snow water supply in the mountainous Western United States, requiring new approaches to water supply forecasting that explicitly account for variations in snow accumulation and melt. California receives most of its precipitation during the winter, and mountain snowmelt typically accounts for about one-third of the annual water used by California farms and cities. The California Department of Water Resources (CADWR) initiated a pilot program for incorporating the Automated Water Supply Model (AWSM)/iSnobal snow model developed by ARS researchers in Boise, Idaho, into their operational snow water supply forecasting infrastructure, and ARS researchers provided technical support and software troubleshooting to CADWR engineers. The physically based modeling framework was successfully implemented in real time on CADWR computing resources, and the spatial snowmelt information was integrated into the CADWR operational forecast used to allocate limited water resources. This valuable tool has allowed water supply forecasters with CADWR to readily incorporate complex physically based modeling to forecast reliable estimates of the amount and timing of available snowmelt, which is critical for ensuring sustained production across California. This improved ability to monitor snow depth and predict the volume and timing of spring and summer snowmelt and river flow can greatly aid in early warning of drought or flooding and help optimize planning for agricultural and urban water use.

Optimal precision placement of crops when managing a no-till system. As farmers adopt recommended no-till farming systems, precision placement of various crops within the no-till cropping system can minimize environmental impacts while maximizing crop yields. ARS researchers in El Reno, Oklahoma, used the Multi-objective Evolutionary Algorithm for Soil and Water Assessment Tool (SWAT-MEA) to determine optimal spatial placement of soybeans, winter wheat, grain sorghum, upland cotton, and peanut cropping systems under no-till production in southwest Oklahoma's Fort Cobb Reservoir watershed. Results showed that under optimal crop placement, no-till management-maintained crop yields and reduced nitrogen, phosphorus, and sediment losses by 45 percent, 32 percent, and 65 percent, respectively. These results also showed that the SWAT-MEA can potentially be used as a precision agriculture decision-making tool to determine optimal land use and management to minimize environmental impacts while maintaining yields.

Cost-effective, real-time weather and reservoir monitoring sensors. ARS scientists in Stillwater, Oklahoma, collaborated with Virginia Tech scientists to develop low-cost weather and reservoir-monitoring sensor stations. These stations cost $250, while commercially available scientific grade weather stations cost approximately $30,000, so the new stations are 99 percent less expensive and present the opportunity to deploy 99 sensors for the previous cost of deploying one sensor. Scientists will be able to deploy sensor networks more densely for developing new and improved decision support tools, models, and applications for forecasting flooding and drought. These sensors provide data and information to a vast array of end users such as farmers, producers, emergency managers, dam owners, investors, and policy makers. This data and information can be accessible for irrigation scheduling, rural and municipal water supply allocations, emergency preparedness, dam operation and maintenance, and development of zoning regulations.

Predicting soil water holding capacity from soil organic content. There are growing concerns that as the climate changes, the frequency of drought will increase in many areas of the world. The impact of drought can be mitigated by increasing the water holding capacity (WHC) of soils. Some studies suggest WHC can be increased substantially by increasing soil organic carbon (SOC), but more data are needed to support this conclusion. ARS scientists from multiple locations and scientists from the Soil Health Institute's North America Project to Evaluate Soil Health Measurements participated in a project to relate changes in SOC to the measured soil water content. The data and resulting improved modeling showed that WHC increased as SOC increased; across all soil texture classes, there was an average 3 percent increase in WHC for every 1 percent increase in SOC. Improving the understanding of how SOC functions and improving the precise modeling of associated WHC benefits helps producers evaluate opportunities to implement management practices that increase SOC and build drought resilience.

Poor water use by potatoes infected with zebra chip. Zebra chip (ZC) virus is a relatively new disease that has a devastating impact on potato production in the western United States. Reductions in tuber yield and crop water productivity have gone unreported and it is unknown if irrigation level influences the severity of the disease. ARS scientists in Bushland, Texas, and Texas A&M AgriLife scientists conducted a 2-year study that investigated the effects of three irrigation levels on non-diseased and ZC-diseased potato plants. They compared tuber yield, seasonal crop water use, crop water use efficiency (WUE), and irrigation water use efficiency and found that ZC disease significantly reduced tuber yield and WUE by 20-55 percent, depending on the year. Irrigation levels did not lessen disease severity. This information indicates that once areas of ZC diseased potatoes are detected within in a field, irrigation should be withheld over these areas to prevent water waste.

Groundwater transfer and injection for augmenting depleted aquifer. Using groundwater for irrigation has resulted in long-term declines in the Mississippi River Valley alluvial aquifer. The Groundwater Transfer and Injection Pilot (GTIP) project was constructed in Mississippi’s Delta region to test the feasibility of withdrawing water near the Tallahatchie River, where it is filtered naturally by passing through sands adjacent to the river, and injecting the water into an area where the aquifer is depleted. ARS researchers in Oxford, Mississippi, studied groundwater levels and quality near the withdrawal and injection sites during short-term experiments ranging from 3 to 6 months of continuous operation. Results show that this technology can increase the amount of water in the aquifer under these regional conditions. Filtration of river water through the sandy sediments adjacent to the river improved its quality and pumping the water into the aquifer increased groundwater levels 1 to 7 feet within a radius of 1 mile from the injection wells. Regional stakeholders have expressed keen interest in this project and are considering the potential for applying this technology as one tool to support irrigated agriculture and sustain natural ecosystems.

Improving the efficiency, quality, and accessibility of real-time data via seamless integrated transmission systems. ARS scientists in Stillwater, Oklahoma, in collaboration with scientists at Virginia Tech and ARS Partnerships for Data Innovations (PDI), developed a seamlessly integrated system that transmits real-time data from the field through radio or cellular connection to the ARS Geoevents server without the use of a data logger as a go-between. The data transmission enables real-time data delivery to a vast array of end users through data dashboards. As data loggers for data collection can be costly (e.g., $2000 per data logger), this integrated system for transmitting data will provide the scientific community millions of dollars in cost savings. In addition, the transmission of data through this seamless system will reduce the number of data handlers, improve efficiency of data collection, and reduce data errors.

UAV and image processing software for scientific use. Unmanned aerial vehicles (UAV) and image processing software for scientific use are vital for monitoring dam performance, crop yields, harmful algal blooms in reservoirs, and reservoir water levels for residential and commercial water use. ARS scientists in Stillwater, Oklahoma, worked with ARS Partnerships for Data Innovations and private partners to develop and train Federal partners (e.g., ARS scientists from across the agency and USDA Forest Service engineers) on the operation of a new U.S. manufactured unmanned aerial vehicle and image processing software specifically developed for scientific research. The new device addresses Federal UAS cybersecurity concerns and helps ensure high-quality integrated and interoperable datasets for research and decision-making.

Erosion, Sedimentation, and Water Quality Protection
Selected Accomplishments

Newly developed steel slag phosphorus (P) filters reduce off-site dissolved P Losses. Excess transport of dissolved P from soils has negatively impacted sensitive surface waters such as the Western Lake Erie Basin and Lake Macatawa through increasing lake eutrophication. Landscape-scale P removal structures provide filtration that can remove dissolved P before it reaches surface waters, and steel slag is a readily available and inexpensive industrial byproduct that has been proven effective for this purpose. ARS researchers in West Lafayette, Indiana, designed and constructed three steel slag P removal structures on a swine farm in Holland, Michigan, to treat tile drainage water that flows into Lake Macatawa. Over a 1-year period, the structures removed nearly 77 percent of P from the tile discharge, and levels of toxic metals, polycyclic aromatic hydrocarbons, and cyanide were all below drinking water standards, demonstrating that this edge of field filtration technique greatly improved quality of water flowing into the lake. Use of P-removal filters can greatly reduce off-site dissolved P losses, thus reducing potential levels of harmful algal blooms and lake eutrophication.

A living mulch system enhances soil infiltration and reduces soil erosion in row crops. Corn and soybean farmers are encouraged to use winter cover crops for a variety of reasons, but it is challenging and expensive to replant them every fall. Perennial living mulches have been proposed as way to obtain the benefits of cover crops while having to plant them only once. ARS researchers in St. Paul, Minnesota, completed a 5-year project at two locations in the upper Midwest that examined the long-term environmental impact of growing corn and soybeans in a perennial living mulch of kura clover. While no differences were found in many soil properties, water infiltration rates were 10-19 times higher in the living mulch system compared to the conventional system. Storm runoff was also measured on sloped plots with both systems, and the living mulch system reduced erosive soil loss by 93 percent, compared to the conventional system. Perennial living mulch systems are a promising management practice for increasing infiltration rates, reducing runoff, and protecting surrounding surface water quality.

Fescue vegetative filter strips mitigate herbicide transport in runoff. Herbicides are a useful tool for controlling weeds in crops and on managed landscapes, but surface runoff can transport them to locations where they impact sensitive non-target organisms. ARS researchers in St. Paul, Minnesota, evaluated the ability of a vegetative filter strip of a fine fescue mixture to reduce quantities of herbicides transported with surface runoff. They found that channeling runoff through a 50-foot vegetative filter strip composed of a fine fescue turfgrass mixture removed from 67 to 99 percent of the herbicides that were transported in the runoff. This information provides land managers support for decisions toward enhanced environmental stewardship and gives scientists a model for larger scale impacts of implementing these mitigation measures.

Iron and biochar interaction increases chemical sorption capacity of biochar. Antibiotic chemicals are increasingly being detected in the environment. ARS researchers in St. Paul, Minnesota, examined the potential use of biochar to reduce the presence and availability of antibiotics in agricultural soils, as well as simple biochar pretreatments with iron salt solutions to increase biochar' effectiveness in removing antibiotics. Modifying the biochar with an iron-salt solution nearly doubled the increase in the observed antibiotic sorption capacity of the biochar. They also found that adding the iron-treated biochar to the soil system increased retention of antibiotics in the system by more than 2 days, thus decreasing the amount of antibiotic entering the ground water supply. This information provides guidance for using biochar to mitigate antibiotics and other agrochemicals in the soil system.

Conservation Practices in Agricultural Watersheds
Selected Accomplishments

Forest thinning to reduce wildfire risk reduced soil moisture stress for remaining trees. Western forests are a critical source of water supply, and they face increasing pressure from climate change, which increases their susceptibility to die-off from drought, fire, and insect infestation. Tree stress depends largely on the depth, duration and intensity of soil moisture stress. ARS scientists in Tucson, Arizona, collaborated with university partners to measure soil moisture stress in the root zone of a ponderosa pine forest for two years following a range of thinning treatments and compared this against an unthinned control stand. Forest thinning was effective at reducing soil moisture stress for the remaining trees. Post-thinning stands with taller trees experienced less stress than stands with shorter trees, possibly due to different water use or to the effects of short trees in reducing snow accumulation. Collectively, our results demonstrate new ways to assess objectively, the impacts of forest thinning on the health of remaining trees.

Streamflow response to wildfire differs with season and elevation in the Lower Colorado River Basin. In the western United States, wildfires are impacting the forested mountains important to agricultural and urban water supply. While peak streamflow and soil erosion often increase immediately after fires, it is unknown whether water supplies are altered over multiple years. ARS scientists in Tucson, Arizona, quantified streamflow in eight watersheds within Arizona's Salt River basin during 15 years following two of the largest fires in the modern history of the western United States. Four independent methods suggested that streamflow declined or remained the same. Dominant winter/spring streamflow was unchanged in higher/colder headwaters but decreased in lower/warmer headwaters. Summer flows increased in two of the most heavily burned watersheds. With greater than 80% of the annual streamflow generated during winter, winter response to vegetation change dominates annual response. They demonstrate the importance of separately analyzing wet and dry years to detect wildfire impacts on hydrology in the 21st century, which has been warmer and drier than most of the pre-fire record. Climatological asynchrony of snowmelt and transpiration in warmer, lower-elevation or lower-latitude watersheds may reduce streamflow benefits of fire.

Winter rye and clover may have more utility as cover crops in the upper Midwest compared to turnips and hairy vetch. Over time, cover crops (CCs) may improve the soil quality, and hence the crop production. ARS researchers in Ames, Iowa, completed a study showing that some of the CC mixes contained plants that could survive the winter such as winter rye and red clover; however, turnips and hairy vetch often did not survive well in the upper Midwest winters and may not be suitable for this region. The CCs had no effect on the main crop yields during this three-year study. This information is important for scientists and crop advisors on the best use of CCs in the upper Midwest.

Identified factors influencing denitrification in claypan soils. Greenhouse gas production in the agricultural landscape has important implications for climate change. Claypan soils, which are prone to saturation of the topsoil layer, are particularly vulnerable to denitrification when fertilized for grain crop production. ARS scientists in Columbia, Missouri, and collaborators at the University of Missouri evaluated how management of cropping systems interacted with landscape characteristics to impact denitrification and production of nitrous oxide, a potent greenhouse gas. On these degraded claypan soils, emissions were dominated by nitrogen gas (> 85%) rather than nitrous oxide. Investigators also found that long-term erosion patterns across the landscape and the associated differences in soil properties exerted more control over denitrification than current management practices in these cropping systems. However, fertilizer management practices affected denitrification enzyme activity and actual denitrification, with more frequent and lower nitrogen application rates resulting in overall lower fluxes relative to a single annual application as is usually the case. This study benefits scientists and producers by highlighting the importance of landscape level and management factors that may influence greenhouse gas production from agricultural systems.

Multi-species biodiversity assessment under pine plantation biofuel management strategies. Increased demand for sustainable energy feedstock production has the potential to drive agricultural land use changes that would have unknown impacts on biodiversity. ARS researchers in Tifton, Georgia, worked in partnership with a team led by the University of Florida to evaluate the impact of three pine plantation management strategies (thinning, short-rotation, and clear-cut) on the biodiversity of bats, bees, birds, and reptiles at multiple sites within the southeastern United States. The biodiversity of all groups was lower under short-rotation and clear-cut conditions but increased under pine thinning. Beta-diversity, a measure of how species composition differs across sites, was also observed to provide a clearer picture of differences among habitats occupied by the four species groups under each management strategy. The results suggest that landowners may be able to increase local biodiversity by thinning pine plantations and that beta-diversity may be a useful tool for incorporating biodiversity goals into regional landscape management plans.

RUSLE2 continues to serve farmers and the Natural Resources Conservation Service (NRCS). The USDA-NRCS is responsible for protecting soil natural resources in the U.S. Each farm within the U.S. must have a conservation management plan that is guided by erosion technology, RUSLE2. In 2016, NRCS announced the replacement of RUSLE2 by the Water Erosion Prediction Project (WEPP) technology. ARS Headquarters, in collaboration with ARS researchers in Oxford, Mississippi and West Lafayette, Indiana, presided over a joint comparison project of RUSLE2 and WEPP, which concluded that RUSLE2 should continue to serve NRCS as the soil erosion prediction technology for conservation planning. NRCS awarded development and maintenance contracts to RUSLE2 that will lead to a WebApp containing two-dimensional and ephemeral gully forms of RUSLE2, as well as the standard version.

Watershed Management to Improve Agroecosystem Services

Selected Accomplishments

New design procedures for furrow irrigation tailwater recovery systems developed. Tailwater recovery systems are still promoted by the Natural Resources Conservation Service (NRCS) and U.S. university agricultural extension services as a water conservation technique in furrow irrigation. However, their design is still based on concepts developed in the 1970's, which assume that all pertinent inputs are known with certainty. Management of those systems is extremely complicated if actual conditions differ from those assumed in the design. New design concepts for tailwater recovery systems have been developed by ARS researchers in Maricopa, Arizona. The new concepts attempt to incorporate the uncertainty of inputs, and system flexibilities, into the design process. This technology is useful for landowners and consultants considering the use of tailwater recovery systems.

Low-cost, flexible monitoring system helps understand Colorado River snowpack. Snowpack monitoring in forested settings is uneven across the west, with monitoring traditionally done in accessible locations and in level clearings where snowpacks are not influenced by trees or local topography. In reality, elevation, vegetation, slope, aspect, and other variables strongly control accumulation or loss of snow and the spatial distribution of snow and soil moisture. Even within very short distances, differences in key processes regulating snow accumulation and loss may result in dramatically different amounts and timing of snowmelt water. In collaboration with academic partners and The Nature Conservancy, ARS researchers in Tucson, Arizona, wrote and distributed a practitioner's handbook of Snowtography, a low-cost, flexible system of snowpack monitoring based on automated remote cameras. This manual provides guidance on site selection, equipment, budgeting, fabrication, installation, and operation of a Snowtography station. Optional upgrades including remote data access and soil moisture monitoring. The handbook has been viewed over 1000 times and downloaded over 200 times.

Climate warming in the western United States is amplifying drought impacts on agroecosystems. Droughts are among our costliest and deadliest natural disasters. Human-caused warming enhances the severity of drought and its impacts on ecosystems both by quickening soil drying and through plant responses to warming-enhanced atmospheric dryness.

ARS researchers in at Tucson, Arizona, in collaboration with university researchers, examined the 2020 southwestern U.S. drought. During the summer and autumn of 2020, much of the U.S. Southwest experienced its hottest and driest conditions since the late 1800s, resulting in large reductions in plant photosynthesis across the region (enough to feed approximately 50 million cattle for a month across shrublands and grasslands alone). Importantly, exceptionally high heat and atmospheric dryness, both largely the result of recent warming, drove much of this reduction in productivity, suggesting amplified impacts of drought on Earth's ecosystems in a hotter future world.

Improving temporal resolution of evapotranspiration (ET) estimates in vineyards. Landsat satellites, which provide optimal spatial and spectral information for monitoring evapotranspiration (ET) at field scale, have low temporal revisit frequency that can be exacerbated by cloud cover. Therefore, improving the temporal frequency of field-scale estimates of ET is critical for improved irrigation management. Recent work by ARS researchers in Davis, California, has addressed this limitation by combining information from many satellite platforms and ET models, and fusing with thermal-proxies. Refined satellite predictions of ET are being used by growers to determine irrigation requirements for specialty crops across fields and throughout the growing season.

Spatially explicit watershed model for agricultural and ecohydrological systems (Ages, version 1.0). Users, mostly researchers, need a model that is scalable, written in open-source code, and integrated with cloud computing services, including open access tools for building model input files, calibrating model results to match site-specific data, and analyzing results for decision support. ARS researchers in Fort Collins, Colorado, developed the Ages model to uniquely account for spatial process interactions between land areas from field management areas to hillslopes to large mixed-use watersheds. We designed Ages to meet the needs of diverse stakeholders, including non-profits (Southfork Watershed Association, Iowa; Big Dry Creek Watershed Association, Colorado), universities (Colorado State University, University of Nebraska, Prairie View A&M, Colorado School of Mines), Federal agencies (U.S. Forest Service, U.S. Geological Survey), and international organizations (Embrapa Environment, Brazil; University of São Paulo, Brazil; Inner Mongolia Agricultural University, China; University of Trento, Italy). Ages is programmed to allow new features and functions to be readily added as needed to meet emerging stakeholder needs.

Model shows how fire changes forested mountain source-water hydrology. Forest fire occurrence and severity have dramatically increased in the western U.S. and are causing major changes to agricultural source-water hydrology, which could dramatically affect food production, municipal water supplies, and flood occurrence and severity. ARS scientists in Fort

Collins, Colorado, developed a new model, building on collaboration with the U.S. Geological Survey, Forest Service, Colorado State University, and others, that directly addresses the needs of New Mexico Department of Homeland Security and Emergency Management for sustainable preservation, management, and response in fire-impacted source-water areas. Model results of sub-alpine forest conditions after a fire in south-central New Mexico accurately demonstrated a 170% increase in streamflow and predicted drier forest soils, which may hinder forest restoration. The modeling tool improves understanding of hydrologic response to fire and will be used by municipalities and forest managers to guide both fire mitigation and post-fire restoration in the western U.S.

Enhanced SWAT+ model. River basin models are needed to determine the impact of climate and land use changes on regional and national water supplies, water quality, and crop production. Science-based solutions are needed by USDA in conservation planning, United States Environmental Protection Agency (USEPA) in environmental planning, and LTAR to assess inspirational scenarios. To meet these important national needs, development continued on the SWAT+ (Soil and Water Assessment Tool) model. A comprehensive watershed scale carbon fate and transport model has been coded and validated in the SWAT model. The carbon code is currently being translated into object-oriented code for SWAT+ inclusion. Work also continued on developing a comprehensive fate and transport model for salt in SWAT+. A new groundwater model was developed and incorporated into SWAT+. During the last year, the model was parameterized and applied in the Mississippi delta and the Chesapeake Bay basin. A new water allocation submodel was developed and implemented in SWAT+. The model simulates water transfer and allocation from multiple sources (rivers, reservoirs, and aquifers) to competing water demand objects (municipal/industrial and irrigation demand from agricultural fields). The water allocation submodel is a critical addition to the model since most rivers in the United States have competing demands for water. The impact of this research is a validated, science-based tool that provides the framework for assessing and defining regional and national water, environmental, and conservation policy.

Importance of long-term data in understanding soil moisture. Soil moisture is fundamental to agricultural management and provides critical information on hydrologic and climatic processes. The validation of national and global soil moisture utilizing data collected from satellites and simulated by numerical models uses ground-based measurements for verification purposes. The ground-based measurements are often assumed stable over time, but there has been little research demonstrating the consistency of a data and their variability over time. A nationwide study including ARS researchers in Tifton, Georgia, and from several other ARS watershed locations, found that ground-based measurements were able to adequately capture a full range of soil moisture conditions within one calendar year. The incorporation of long-term soil moisture data is helping to improve national and global models of soil moisture dynamics, including drought impacts, and is encouraging for network scaling activities and validation campaigns.

Optimizing row spacing can improve yields when sunlight and water are limited. Sugarcane (*Saccharum spp*.) is the world's largest biomass crop producing over thirty tons per acre each year in Louisiana and sequesters high levels of carbon dioxide (CO2), an important greenhouse gas. Sugarcane in Louisiana is normally grown on rows spaced 1.8 m apart, but interest in planting on 2.4 m rows is increasing. In this study, ARS researchers in Houma, Louisiana, hypothesized that wider row spacing results in greater water availability due to a decrease in the number of field drains with wider rows. Soil moisture sensors were placed at three depths in fields planted on 1.8 and 2.4 m row spacings with two commercial sugarcane varieties. Soil moisture was monitored over three years. Yields in the two row spacings were similar. As expected, the soil water content was greater in the wider rows (2.4 m), when compared to the normal-spaced rows (1.8 m). However, in both row spacings, plant-available water was always present in the top 45 cm, even during periods of low rainfall. Potentially, high water availability provides an opportunity to increase photosynthesis in sugarcane varieties by selecting for greater photosynthetic capacity and CO2 uptake through increased stomatal conductance. This in turn could increase crop yield and sequestration of carbon.

Novel time series analysis methods aid in evaluating land use and management impacts on watershed-scale sediment transport processes. Suspended sediment is listed as one of the leading pollutants that adversely impact the quality of U.S. rivers and water bodies. Effective management of suspended sediments at the watershed scale is difficult because of the spatial variability in sediment sources, land use and land management, and temporal lag effects caused by the event cycle of erosion and deposition. ARS researchers in Oxford, Mississippi, in collaboration with scientists from the University of British Columbia, Canada, used novel techniques (wavelet transform and coherence) to analyze a comprehensive 20-year record of land use, rainfall, stream flow, and suspended sediment concentration collected by the USDA, ARS, National Sedimentation Laboratory in the Goodwin Creek Experimental Watershed, Mississippi, at various spatial scales between 1982 and 2002. During the study period an overall decline in clay and silt suspended sediment load occurred across all time scales, which was primarily caused by land use change and in-channel stabilization. The spatiotemporal pattern of sand dynamics reflects both the state of channel stability and the availability of sand stored within the channel. The study shows that wavelet analysis can help evaluate the impact of land management practices on sediment transport processes, and therefore identify appropriate policies for future land use while mitigating environmental consequences.

Manuresheds: A concept for closing the nutrient cycle in animal agriculture. The nutrient cycle in modern animal agriculture in the United States is broken. Nutrients in grain grown with commercial fertilizers in the Midwest are fed to swine in the Carolinas, poultry in the mid-Atlantic, and dairy cows in the Northeast and other parts of the country where nutrients accumulate as manure in large animal production facilities. In collaboration with other ARS and university researchers, USDA-ARS scientists at University Park used ag census data to conduct analyses that link manure source areas from animal production facilities to nearby croplands where nutrients are needed for crop production. The nutrient source and need area relationships are termed manuresheds and provide opportunities for reconnecting the nutrient cycle, promoting agriculture's sustainability, protecting the environment, and alleviating current fertilizer shortages.