FY 2016 Annual Report
National Program 211 - Water Availability and Watershed Management

Introduction

The USDA-ARS National Program for Water Availability and Watershed Management (NP211) had a productive and dynamic year in 2016. 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.

The overarching goal of NP 211 is:
to effectively and safely manage water resources while protecting the environment and human and animal health.

There is no substitute for fresh water, nor is there any replacement for its essential role in maintaining human health, agriculture, industry, and ecosystem integrity. 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 its 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 saw 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 water, aided flood management and soil conservation, and dramatically improved hygiene, health, and economic prosperity. The U.S. water resources and technologies were the envy of the world.

In the 21st century, the situation is much different for the U.S., and indeed for the world. Depleted ground water reserves, degraded water quality, and adverse climate conditions are reducing the amount of available freshwater. At the same time, allocations of our freshwater resources are shifting among different users and different needs (e.g., from agricultural to urban uses; from storing water supplies in reservoirs to maintaining in-stream flows to support healthy aquatic ecosystems; from industrial and energy production to recreation). Our shared freshwater supply has been reduced significantly and is becoming more variable, unreliable, and inadequate to meet the needs and demands of an expanding population.

Water-related science and technology have served our Nation well. We have built infrastructure that provides safe drinking water to our cities, irrigation water to grow a large portion of our Nation's food supply, water for industry, and the means to keep waterways navigable. Through improved waste treatment technologies, we have made great strides in improving water quality, and have protected and enhanced our waterways to provide habitat for aquatic organisms and recreational opportunities for the public.

Today, the agricultural and energy sectors are the two largest users of water in the U.S. Some of the water use is consumptive—water is lost through crop water use or evaporation from cooling. When considering both fresh and saline water withdrawals for thermoelectric use and for hydropower, the energy sector has the largest water use. When only freshwater withdrawals are considered, agriculture is clearly the largest user of water, and the least understood in terms of opportunities for conserving water supplies and improving water quality for drinking, swimming, and fishing.

In the 21st century, agriculture faces new challenges—the increasing demand for water by our cities, farms, and aquatic ecosystems; the increasing reliance on irrigated agriculture for crop and animal production and farm income; and changing water supplies due to groundwater depletion in some areas; and climate change. These challenges are not insurmountable. Science can provide the tools needed by water planners and managers to predict accurately the outcomes of proposed water management decisions, and new technologies can widen the range of options for future water management. The factual basis for decision-making includes an understanding of effectiveness, potential unintended consequences, and a plan for getting water users and agencies to adopt the most effective technologies. The Nation has the opportunity to use science and technology to build a strong economy and to improve human and ecological health.

The approach for this National Program is to address the highest priorities for agricultural water management (effective water management, erosion, sedimentation, and water quality protection, improving conservation effectiveness in agricultural watersheds, and improving watershed management and ecosystem services in agricultural landscapes). Research will also elucidate 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 assess our capabilities to conserve and reuse waters in both urban and agricultural landscapes and watersheds.

This National Program comprises four components:
• Effective Water Management in Agriculture
• Erosion, Sedimentation, and Water Quality Protection
• Improving Conservation Effectiveness
• Improving Watershed Management and Ecosystem Services in Agricultural Landscapes

During FY 2016, 126 full-time scientists working at 26 locations across the U.S. actively engaged in 36 ARS-led and 299 cooperative research projects in NP211. ARS-led projects were approved through the ARS Office of Scientific Quality Review in 2011, making this the final year of implementation of these five-year projects. New project plans have been written and will be implemented starting in 2017. The gross fiscal year 2015 funding for NP211 was $62 million.

New additions to the NP211 team in 2016 are:

- **Dr. Steve Evett** of the Conservation & Production Research Laboratory, Bushland TX, completed a six-month detail with ARS's Office of National Programs (ONP) as Acting National Program Leader for Water Resources, and **Dr. Teferi Tsegaye**, formerly of Kentucky State University, joined ONP in September 2016 as the new permanent NPL for Water Resources.

- **Dr. Glenn Moglen** was named the new Research Leader for the Hydrology and Remote Sensing Laboratory, Beltsville, MD.
- The Delta Water Management Research Unit in Jonesboro, AR welcomed new Research Agronomists Dr. Joseph Massey and **Dr. Arlene Adviento-Borbe.**
- The Southeastern Watershed Research Laboratory in Tifton, GA welcomed **Dr. Oliva Pisani**, whose area of expertise is soil, water, and plant tissue nutrients and organic constituents Also joining SEWRL were postdoctoral research associate **Dr. Jerome Maleski** Database Manager **Earl Keel**; and support chemist **Daniel Liebert.**
- **Dr. Christopher Williams** joined the Southwest Watershed Research Center, Tucson, AZ, as a Research Chemist.
- **Dr. Merle Vigil**, Research Leader at the Central Great Plains Research Station in Akron, CO served as Acting RL for the Water Management Systems Research Unit, Ft. Collins, CO.
- The National Soil Erosion Research Lab in West Lafayette, IN welcomed the following new employees in 2016: **Dr. Mark Williams**, Agricultural Engineer, **Dr. Chad Penn**, Soil Scientist, and **Jim Frankenberger**, computer engineer.
- **Dr. Gary Marek**, Research Agricultural Engineer, joined the Soil and Water Management Research Laboratory, Bushland, TX.
- **Dr. David Brown** was named Director of the Southern Plains Climate Hub, El Reno, OK.
- **Dr. Brekke Peterson Munks** was hired as a new Research Soil Scientist at the Agroclimate and Natural Resources Research Laboratory, El Reno, OK.

The following scientists left the ranks of NP211 in 2016:

- **Dr. Susan Moran** retired from the Southwest Watershed Research Center, Tucson, AZ
- **Dr. Judy Tolk,** Research plant Physiologist, retired from the Soil and Water Management Research Laboratory, Bushland, TX.
- **Dr. Gary Lehrsch** retired from the Northwest Irrigation & Soils Research Laboratory, Kimberly, ID.
- **Dr. Jim Ippolito** left the Northwest Irrigation & Soils Research Lab, Kimberly, ID to take a faculty position with Colorado State University.
- **Dr. Jim Ascough** of the Water Management Systems Research Unit, Fort Collins, CO passed away in 2016. Dr. Ascough will be greatly missed by his colleagues.
- **Dr. Sabine Goldberg** retired from the Salinity Laboratory in Riverside CA, after 33 years of service.

The distinguished record of service of these scientists is recognized worldwide; they will be missed in NP211.

The following scientists in NP 211 received prominent awards in 2016:

- **Dr. Susan Moran** of the Southwest Watershed Research Center, Tucson, AZ was elected to the ARS Hall of Fame in 2016. Also at SWRC, **Dr. Philip Heilman** was named the ARS Pacific West Area Research Leader of the Year.
- **Drs. Wade Crow, Thomas Jackson** and **Michael Cosh** of the Hydrology and Remote Sensing Laboratory, Beltsville, MD received a Federal Laboratory Consortium Interagency

Partnership Award for their work on the Soil Moisture Active Passive (SMAP) satellite. **Dr. Jackson** also received the Golden Florin Award from the Center for Microwave Remote Sensing and the IEEE Geoscience and Remote Sensing Society, for contributions to the passive microwave remote sensing of the Earth. Also from HRSL, **Dr. Martha Anderson** received an Arthur S. Flemming Award in Applied Science and Engineering from the George Washington University's Trachtenburg School of Public Policy & Public Administration. The Flemming award is given each year to outstanding men and women in the federal government; Dr. Anderson was honored for her contributions to satellite remote sensing of global cropland and freshwater resources.

- **Dr. Joseph Massey** of the Delta Water Management Research Unit, Jonesboro, AR, received the Rice Researcher of the Year award at the 2016 National Conservation Systems Cotton & Rice Conference.
- **Dr. Robert Wells** of the Watershed Physical Processes Research Unit, Oxford, MS, was selected as an ASCE Journal of Hydrologic Engineering Outstanding Reviewer.
- **Dr. David Bosch** of the Southeast Watershed Research Laboratory, Tifton, GA was named a Fellow of the American Society of Agricultural and Biological Engineers (ASABE).
- **Dr. Earl Vories** at the Cropping Systems & Water Quality Research Unit, Columbia MO, received the ASABE Award for the Advancement of Surface Irrigation. Also at CSWQR, **Dr. Newell Kitchen** received the Carl Sprengel Agronomic Research Award from the American Society for Agronomy, and **Dr. John Sadler** received the ARS Distinguished Senior Scientist of the Year Award.
- **Dr. Dave Goodrich** at the Southwest Watershed Research Center, Tucson, AZ was the only USDA employee to win a Bronze Award from the EPA's Office of Research and Development as part of a team for development of the EPA's 2015 Clean Water Rule and authoring the Connectivity Science Synthesis Report. Also at SWRC, **Dr. Susan Moran** (along with the aforementioned scientists at the Hydrology and Remote Sensing Laboratory in Beltsville), won the 2016 Federal Laboratory Consortium (FLC) for Technology Transfer's Interagency Partnership Award for their work on the Soil Moisture Active Passive (SMAP) satellite.
- **Dr. Daren Harmel** of the Center for Agricultural Resources Research, Fort Collins, CO, received the ASABE's ADS/Hancor Soil and Water Engineering Award for noteworthy contributions to the advancement of soil and water engineering in teaching, research, planning, design, construction, management or development of materials.
- **Dr. Gary Banuelos** of the Water Management Research Unit in Parlier, CA received the ARS Pacific West Area Senior Scientist of the Year award.
- **Drs. Martin Locke** and **Michael Jenkins** of the National Sedimentation Laboratory, Oxford MS, received an FLC Interagency Partnership Award in recognition of their work regarding "By-product Gypsum to Reduce Runoff Pollution and Improve Water Quality."
- **The Water Management and Systems Research Unit**, Fort Collins CO, received the USCID Service to the Profession Award from the United States Committee on Irrigation and

Drainage. **Dr. Tom Trout,** emeritus of the WMSRU, received the Tipton award from the American Society of Civil Engineers (ASCE) in recognition of his contributions to the advancement of irrigation and drainage engineering.

- **Dr. Doug Smith** of the Grassland, Soil and Water Research Laboratory in Temple, TX along with Drs. **Kevin King** of the Soil Drainage Research Laboratory in Columbus, OH and **Mark Williams** of the National Soil Erosion Research Laboratory in West Lafayette IN, were presented with the Soil and Water Conservation Society 2016 Editor's Choice Award. **Dr. King** was also recognized as an ABE Outstanding Alumni from Purdue University.
- **Dr. Ray Anderson** of the U.S. Salinity Laboratory in Riverside, CA received ARS's Early Career Scientist Award for 2016. Also at USSL, **Dr. Donald Suarez** received the Applied Research Award from the Soil Science Society of America.
- **Dr. Jean Steiner** of the Agroclimate and Natural Resources Research Laboratory in El Reno, OK completed a 3-year term as Past President on the executive board of the American Society of Agronomy in 2016.
- **Dr. Ray Bryant** of the Pasture System and Watershed Management Research Unit, University Park, PA was presented with the 2015 Champion Award by the American Coal Ash Association (ACAA) for his leadership in the research and development of the use of flue gas desulfurization (FGD) gypsum for agriculture. **Dr. Bryant** was also selected, along with cooperators in USDA-NRCS and USEPA, as a recipient of the Southeast Regional 2016 Interagency Partnership Award by the Federal Laboratory Consortium for Technology Transfer (FLC) in recognition of the work regarding "By-product Gypsum to Reduce Runoff Pollution and Improve Water Quality". The FLC is a chartered organization mandated by Congress to promote, educate and facilitate technology transfer among more than 300 federal laboratories, research centers and agencies.
- **Drs. Peter Kleinman** and **Tony Buda** of the Pasture Systems and Watershed Management Research Unit, University Park, PA along with their co-authors, received the Journal of Environmental Quality's 2016 Award for Best Paper.

In 2016, a number of factors demonstrated the quality and impact of NP 211 research:

- Publication of 294 refereed journal articles;
- Five new patents issued;
- One current cooperative research and development agreement with stakeholders and four material transfer agreements;
- The development or administration of 27 web sites for academia or stakeholders.

In 2016, NP 211 scientists collaborated with scientists in Argentina, Australia, Austria, Belgium, Brazil, Canada, China, Democratic Republic of Congo, Czech Republic, Denmark, Ethiopia, France, Germany, Indonesia, Israel, Italy, Japan, Jordan, Kenya, Korea, Mexico, Netherlands, Palestine, Philippines, PR, Spain, Sweden, Switzerland, Taiwan, Tunisia, Turkey, Uruguay, and Uzbekistan.

NP 211 Accomplishments for FY2016

This section summarizes significant and high impact research results that address specific components of the FY 2011 – 2015 action plan for NP 211. Each section summarizes accomplishments of individual research projects in NP 211. Many of the programs summarized for FY 2016 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, which enhances the impact of ARS research programs.

COMPONENT 1: EFFECTIVE WATER MANAGEMENT IN AGRICULTURE

Human civilization learned millennia ago that supplying adequate food and fiber in many regions requires artificial manipulation of the natural hydrology through irrigation and drainage. In the U.S., irrigated agriculture produces 49% of crop market value on 18% of cropped lands. Irrigation is essential to the most highly productive, intensely managed, and internationally competitive sectors of our agricultural economy, which play a key role in meeting growing global food, fiber, and energy needs. Equally important to production agriculture are surface and subsurface drainage. On approximately 120 million acres throughout the nation, removing excess water has resulted in reliable crop production. Yet agriculture is subject to growing competition for water resources, and dealing with adverse environmental effects and inevitable reductions in water resources available for irrigated agriculture in some areas necessitates the development of improved irrigation and drainage systems.

Selected Accomplishments

Non-flooded rice production with center pivot irrigation systems increases water use efficiency and expands production to lighter soils. Traditional U.S. rice production employs flooded conditions for much of the growing season and many areas in the U.S. and throughout the world are not well suited for flooded production due to soil type and topography. Aerobic production without long-term soil flooding offers an alternative on high-infiltration soils, but little research exists on irrigation management for non-flooded production. ARS researchers at Portageville, Missouri, and collaborators have demonstrated that an irrigation scheduling system developed for other crops can be successfully adapted for rice production on coarse-textured soil using center pivot irrigation. Rice is a major component of the diet throughout the world and these results will assist producers to manage irrigation optimally when rice is produced with center pivot irrigation to reduce the water requirements on coarse-textured soils.

Crop yield benefits of water capture and subirrigation based on future climate change projections. Climate change projections for the Midwest U.S. indicate increased crop water deficits in the future growing seasons that will adversely impact agricultural production. Systems that capture water on site for later subirrigation use, three of which were operated in northwest Ohio from 1996-2008, have potential as a climate adaptation strategy to mitigate increased crop water deficits. ARS researchers in Columbus, Ohio used the historical subirrigated field crop yield differences (with respect to non-irrigated control fields with free drainage) from these three systems to estimate future subirrigated field crop yield increases for northwest Ohio, based on modeled climate projections for 2041 to 2070. The results showed that the overall subirrigated field corn yield increase is estimated to rise—from an observed value of 20.5% in the 1996 – 2008 data—to 27.5% - 30.0% in 2041 - 2070, while the subirrigated field soybean yield increase is estimated to improve from the 12.2% observed from 1996 – 2008, to a range of 19.8% to 21.5% for 2041 - 2070. As growing season drought becomes more frequent, crop yield benefits with agricultural water capture and subirrigation systems will improve, thereby providing a viable climate adaptation strategy for helping to sustain agricultural production.

Variable rate irrigation management saves water. Soil properties and plant characteristics can vary considerably within a single field, resulting in variability in the amount of water needed for the crop to reach its yield potential. Variable rate irrigation (VRI) technology is able to apply irrigation water site-specifically at variable rates within a single field and may be able to account for the temporal and spatial variability in soil and plant characteristics. ARS scientists at Stoneville, Mississippi conducted a 2-year field study in the Mississippi Delta to compare VRI management with conventional uniform rate irrigation (URI) management. It was found that the VRI management saved 25% of irrigation water, while the yield of VRI was equivalent to the yield of URI. Irrigation water use efficiencies (and thus productivity) for soybean and corn under VRI were 25% and 27% higher than under URI, respectively. VRI management allows more efficient use of irrigation water in the humid region, thus allowing producers to use their irrigation systems more effectively.

New approach sustains water resources for irrigation. The Lower Mississippi Valley is one of the most intensively irrigated agricultural landscapes in the country, producing 65% of U.S. rice and 20% of U.S. cotton. Irrigation demands have resulted in rapidly depleting groundwater across the alluvial valley. ARS researchers in Stoneville have developed a novel approach to supplementing groundwater resources for irrigation, using a combination of stream capture, bank filtration, and groundwater injection. The concept supplements groundwater recharge by capturing water from a major river through the subsurface, using bank filtration to improve water quality, and transferring the water to a region of critical groundwater decline for subsequent injection where the water is needed most. Broad stakeholder interest in the merits of the approach has instigated a pilot project to be constructed in 2017. This project promises to be a major component in solving the water needs of the lower Mississippi valley.

Less expensive regional assessments aid water and land management during drought. Soil salinity negatively impacts the productivity and profitability of farmland in arid and semi-arid regions, and is particularly problematic during droughts, such as that currently experienced in California. Satellite remote sensing is one of the only feasible methods to assess agricultural productivity, water consumption, and soil salinity at regional scales. ARS researchers in Riverside, California have developed new capabilities for regional-scale assessments, including: (i.) new satellite remote sensing techniques for mapping root zone salinity at regional scales; (ii) a simplified methodology for mapping soil salinity at field-to-landscape scales requiring significantly fewer soil samples; and (iii.) new techniques for incorporating satellite-based estimates of evapotranspiration and groundwater storage changes into land surface models. The new salinity maps and remote sensing techniques should help in assessing and mapping water use and soil salinity at regional and state levels, which is essential for identifying and understanding drivers and trends in water use and salinity, and for developing management plans and mitigation strategies. The methodology allows broad application by government agencies with substantial cost reduction and has international implications, particularly for use in countries with limited resources, as well as serving as a tool for water and land resource managers, producers, agriculture consultants, and extension specialists.

Remote monitoring of wine grape water stress. Wine grape production is a $5 billion industry in the U.S. Mild to moderate water stress is desirable in wine grapes to optimize fruit yield and quality, but precision irrigation management is hindered by the lack of a reliable method to easily quantify and monitor vine water status. ARS researchers in Kimberly and Parma, Idaho, used canopy temperature measurements and artificial neural network modeling to calculate the crop water stress index (CWSI) of two wine grape varieties that were deficit irrigated. Daily CWSI was consistently different between deficit irrigation amounts, irrigation events, and rainfall, indicating that the neural network model accurately predicted water stress. This methodology has been incorporated into a wireless network currently used on two vineyards to provide daily CWSI values to verify that irrigation amounts are achieving desired water stress levels with greater ease and frequency than traditional manual wine grape vine water stress measurements.

Agricultural residues improve bioreactor nitrate removal at low temperatures. Nitrate losses in drainage waters from the Upper Mississippi River Basin are highest in spring when temperatures are low and flow rates are high. These factors retard biological removal of nitrate by the process of microbial denitrification in woodchip-based bioreactors. ARS scientists in St. Paul, Minnesota, and Ames, Iowa, compared agricultural residues – corn cobs, corn stover, barley straw – to woodchips for capacity to support denitrification in early spring (1.5°C) and summer (15°C). The nitrogen removal rates for agricultural residues were higher than for woodchips, consistent with higher bacterial populations. Removal rates for the agricultural residues were much lower at the colder temperature even though bacterial populations were equivalent, suggesting that the availability of dissolved carbon limited denitrification rather than microbial biomass. Production of nitrous oxide relative to nitrate removal was greater at 1.5°C compared to 15°C and greater for woodchips compared to corn cobs or corn stover. The study serves to inform policy makers, engineers, and field technicians about the range of expected results using various carbon sources to support nitrate removal in denitrifying bioreactors.

A new modeling framework for watershed simulations. Assessing the impacts of anthropogenic and naturally driven changes in watershed dynamics (e.g., hydrological response, transport of contaminants, and ecosystem services) requires integration of knowledge and modeling capacities spanning biophysical responses, environmental problems, policies, economic activity, and datasets that are connected either to the surface watershed or to the aquifer (subsurface) system. A team of ARS scientists at El Reno, Oklahoma, Bushland, Texas, and Temple, Texas; and colleagues at Texas A&M University in College Station have linked the Soil and Water Assessment Tool (SWAT) and Modular Three-Dimensional Finite-Difference Groundwater Flow (MODFLOW) models to improve hydrologic and water quality simulations in the surface and groundwater domains. The integrated SWATmf model was tested using datasets from the Fort Cobb Reservoir experimental watershed in Oklahoma. Simulated streamflow and groundwater levels generally agreed with observation trends, showing that the SWATmf can be used for simulating surface and groundwater interactions. The integrated modeling framework is expected to improve watershed-scale model simulations and provide a modeling platform to better understand linked surface-subsurface hydrologic processes and associated transport phenomena under time-variant conditions.

Variable-rate irrigation. Variable rate (or precision) irrigation offers the potential to improve the efficiency of center pivot irrigation. Variable rate irrigation systems are commercially available, but they are not widely used because better methods to make application prescriptions are needed. Scientists in Florence, South Carolina, found that for corn, using remote sensing of canopy size provided similar irrigation prescription maps to the more labor-intensive method of using numerous soil water monitoring devices. Using remotely sensed canopy size to produce irrigation prescription maps has the potential to reduce labor cost and conserve water. Farmers, consultants and industry will use these results to better manage their variable-rate irrigation systems.

Accumulation of four pharmaceuticals in wheat irrigated with reclaimed municipal wastewater. Rising demands on fresh water have resulted in the need to reuse municipal effluent for irrigation. Pharmaceuticals are frequently found in effluent due to limited removal during wastewater treatment. ARS scientists in Maricopa, Arizona, in collaboration with scientists from Pennsylvania State University, measured the uptake of four drugs (sulfamethoxazole, trimethoprim, ofloxacin and carbamazepine) by wheat plants irrigated with reclaimed water. Residues of all four compounds were found on plant surfaces with trimethoprim being found only on external surfaces. Ofloxacin had the highest average concentration (10.2 ng g-1, straw; 2.28 ng g-1, grain) with carbamazepine and sulfamethoxazole at much lower concentrations. The results that drugs found in wastewater used for irrigation accumulate predominantly in the non-edible portions of wheat suggest that reuse of municipal effluents is a safe way to increase water supplies for irrigation, providing a new and sustainable water source.

Strip-tilling sugar beet maintains yield and increases infiltration. About half of U.S. sugar production comes from sugar beet. ARS researchers in Kimberly, Idaho, compared sugar beet production with strip tillage and conventional tillage under full and deficit irrigation. Sugar yields were similar for both tillage practices under all irrigation amounts. Strip tillage, however, has several advantages over conventional tillage, including $50 to $75 per acre lower tillage cost and increased water infiltration. Using strip tillage can reduce production costs and increase irrigation efficiency while maintaining sugar beet yield.

Spring frost protection in cranberry farms. Irrigation of cranberries is key to preventing bud damage in the spring season, but requires large quantities of water. ARS scientists in University Park, Pennsylvania, with collaborators at University of Massachusetts, evaluated a water-conserving irrigation method to determine its effectiveness in protecting cranberry buds from spring frost. They found that the new technology was equally effective as conventional irrigation in frost protection while using 35-77% less water than conventional irrigation. The new technique will allow cranberry growers to conserve water while still protecting their crop from frost.

COMPONENT 2: EROSION, SEDIMENTATION, AND WATER QUALITY PROTECTION

Surface and/or subsurface hydrologic transport of nutrients, pesticides, pathogens, and emerging pollutants can contaminate water resources and harm aquatic ecosystems. Interactions of land resource management practices with climate, soil, and landscape properties control the processes of sediment detachment, the fate and transformation of contaminants transported in both dissolved and sediment-associated states, and the impacts of these materials on aquatic ecosystems.

Selected Accomplishments

Windows Dam Analysis Modules (WinDAM) guide rehabilitation priorities for aging dams. WinDAM C, a Common Computing Environment (CCE)-certified software, was released by the Natural Resource Conservation Service (NRCS) in cooperation with ARS and Kansas State University. This software incorporates algorithms developed by ARS scientists for predicting failure of embankment dams due to internal erosion and embankment overtopping. Code verification was completed in a collaborative effort by ARS in Stillwater Oklahoma, NRCS, Kansas State University, and collaborators. Although further validation of the tool is required for the internal erosion component, WinDAM C was tested against ARS physical model study data of embankment dam failures resulting from internal erosion and overtopping. This technology is anticipated to assist dam safety engineers in NRCS, the Tennessee Valley Authority, FERC (Federal Energy Regulatory Commission) and other federal and state agencies in the prioritization of aging multi-purpose embankment dams for rehabilitation. Requests have also come in from Brazil, Spain and the UK.

Grassed filter strips do not contribute to riparian restoration of channelized agricultural headwater streams. Understanding the influence of grass filter strips on the structure and function of riparian habitat of agricultural streams is critical for determining if this widely used agricultural conservation practice is contributing to the restoration of riparian habitats adjacent to agricultural headwater streams, particularly those that exhibit riparian habitat degradation. ARS researchers in Columbus Ohio evaluated the influence of grass filter strips and determined that grass filter strips did not differ in structure and function from unplanted riparian habitats. It was also observed that forested riparian habitats exhibited greater diversity in structure and greater levels of function than herbaceous riparian habitat types. These results indicate that current guidelines for planting grass filter strips are not contributing to the conservation and restoration of riparian habitats adjacent to channelized agricultural headwater streams. This information can be used by action agencies to modify policies and approaches for the management of riparian habitats adjacent to agricultural streams.

Soil profiling and subsurface imaging using seismic surface waves. Non-invasive soil profile measurement and subsurface soil imaging are important for agriculture applications such as soil mechanical and hydraulic properties measurement, soil layering such as plowpan and fragipan detection, and soil surface erosion (surface crusting/sealing) evaluation. A high-frequency multi-channel analysis of surface wave method has been developed at the University of Mississippi National Center for Physical Acoustics, with the collaboration of researchers at ARS's National

Sedimentation Laboratory in Oxford, Mississippi. The technique can non-invasively measure one-dimensional soil profile and two-dimensional image of subsurface soil in the vadose zone in terms of the shear wave velocity that is related to soil strength, water content, and water potential. The method has been successfully applied to study seasonal and weather effects, to detect plowpan and fragipan, and to evaluate surface crusting/sealing.

COMPONENT 3: IMPROVING CONSERVATION EFFECTIVENESS

The magnitude of annual Federal expenditures for conservation programs (at least $4B per year) necessitates evaluation of the cost of conservation practices implemented through those programs in comparison with the environmental benefits they provide. While examining the effects of existing practices can provide a retrospective analysis of prior expenditures, researchable questions remain as to how new practices can be developed, and existing and new practices implemented, to improve the benefits achieved with available funds. The demands for information from ongoing research projects like the CEAP and regional initiatives such as in the Mississippi River Basin (MRBI) and the Chesapeake Bay (CBI), demonstrate the continuing need to assess and improve the benefits of conservation practices.

Selected Accomplishments

New "blind" inlet conservation structure design reduces pesticide runoff. By efficiently removing excess water from low spots (e.g., potholes) in drained fields, conventional tile risers improve agricultural productivity but also promote loss of pesticides in runoff. A 6-year field study conclusively documented the effectiveness of a new conservation practice (blind inlets), developed by ARS scientists at West Lafayette, Indiana, in reducing pesticide losses, when compared to losses from conventional tile risers. Effectiveness of blind inlets was compound specific, and the significant reduction levels were: 57% reduction of atrazine losses, 58% reduction of alachlor pesticide losses, 53% reduction of metolachlor losses, and 11% reduction of glyphosate losses. These findings demonstrate that blind inlets provide pesticide reduction benefits in addition to their original sediment reduction purpose.

Enhanced watershed planning tool reduces funds needed for conservation practices. Conservation practice placement on the ground can be ineffective and costly because current watershed models do not adequately simulate the processes associated with gullies, wetlands, and riparian buffers in the context of an agricultural watershed. ARS scientists at Oxford, Mississippi, collaborated to release the watershed planning tool, AnnAGNPS v5.44. The tool was released with enhanced gully, wetland and riparian buffer components important to developing integrated conservation management practice watershed plans. The AnnAGNPS watershed modeling tool enables evaluation of the effectiveness of conservation practices to reduce pollutants on a watershed scale. This helps watershed conservation managers to implement the efficient placement of practices with minimum utilization of resources.

COMPONENT 4: IMPROVING WATERSHED MANAGEMENT AND ECOSYSTEM SERVICES IN AGRICULTURAL LANDSCAPES

Society relies on adequate freshwater resources to support households, agriculture, industry, wildlife habitat, aquatic ecosystems, and a healthy environment. Eighty-seven percent of the nation's drinking water flows over or through agricultural lands. Agricultural watersheds, including crop, pasture, and range lands, cover over 70% of the continental U.S. In the 21st century, unprecedented demands for freshwater, rapidly changing land use, recurring droughts, regional climatic variations, and new demands for energy production on working lands mean that the Nation's freshwater resources are at risk now more than ever before. A primary concern of ARS customers, stakeholders, and partners is the accurate quantification and management of our water resources to support people, agriculture, and the environment, across heterogeneous agricultural and urban landscapes. At the watershed or landscape scale, the provision of ecosystem services (e.g., agricultural production, a clean and abundant water supply, improved wildlife habitat, greenhouse gas reduction, soil stabilization, recreational opportunities, reduced energy consumption, and reduction of urban wastes) can involve multiple stakeholders with conflicting objectives. Because simultaneously optimizing for even two objectives involves compromise, integrated watershed and landscape management is thus a complex task, but necessary—not only to support the goals of legislation such as the Clean Water and Endangered Species Acts, but also to address the concerns of watershed coalitions, policy makers, and the public.

Selected Accomplishments

Rangeland Hydrology and Erosion Model Risk Assessment Tool now used by NRCS, Forest Service and BLM. Prediction technologies are critical for managing rangeland resources. ARS scientists in Tucson, Arizona, developed the Rangeland Hydrology and Erosion Model (RHEM) tool to evaluate and illustrate the risk of excessive runoff and soil erosion on rangeland sites relative to desired or optimal rangeland conditions. The tool is implemented through a website where the user can run various alternative scenarios of land conditions for a particular rangeland site, including a user defined "baseline", desired, or good condition alternative. Statistics are used to define low, medium, high, and very high yearly rates of erosion determined from the baseline conditions against which other scenarios, or possible site conditions, are compared. In addition, this tool will greatly facilitate the process of developing Ecological Site Descriptions, which are formal documents that are currently being developed in a large and active program across the U.S. by Natural Resources Conservation Service (NRCS), Forest Service, and Bureau of Land Management (BLM) to describe the hydrologic and vegetation functions of land resources, particularly for grazing lands.

Recent tree die-off has little effect on streamflow. Over the last two decades, beetle infestation has killed billions of trees and affected millions of acres of forest in the Rocky Mountains of North America, many of which are critical sources of human water supply. ARS scientists in Tucson, Arizona, in collaboration with others, quantified annual streamflow responses in the decade following mortality and compared them to 25 to 40 years of pre-mortality records. In contrast to streamflow increases predicted by historical paired catchment studies and recent modeling, observed streamflow changes were weak, variable, and more frequently showed declines than increases. Although initially surprising, these results are consistent with the growing body of literature documenting increased snow sublimation and evaporation from the sub-canopy following die-off in forests of the Rocky Mountains. These forests are at the headwaters of rivers vital to the reliable water supply of the western U.S., and so these results indicate that water supplies across this region will likely not change due to this remarkable die-off of trees.

The GOES Evapotranspiration and Drought (GET-D) Product System. The Geostationary Operational Environmental Satellite (GOES) Evapotranspiration and Drought (GET-D) Product System passed Operational Readiness Review by the National Oceanic and Atmospheric Administration (NOAA) in January 2016 and became operational June 6, 2016. The GET-D system is based on remote sensing approaches initially developed by ARS scientists in Beltsville, Maryland. It will operationally produce daily maps of evapotranspiration (ET) and an associated Evaporative Stress Index (ESI) over North America at 8-km spatial resolution. These routine ET and ESI products will be used within NOAA's drought monitoring and land-surface modeling programs, and additionally disseminated through the National Integrated Drought Information System. This project is an example of multi-agency collaboration, with ARS models transitioned to operational production at NOAA, funded in part by NASA's Applied Sciences program. See http://www.ospo.noaa.gov/Products/land/getd/.

Integrated remote sensing system maps crop growth and stage at field scales. Crop growth information can benefit farmers in scheduling irrigation, fertilization and harvest operations. The USDA National Agricultural Statistics Service (NASS) reports crop progress and condition supplied by local farmers weekly at the state and district levels; however, ground data collection is time consuming, highly localized, and produces inconsistent data quality. While remote sensing can provide timely and consistent large-area coverage, standard products based on only one satellite lack either the spatial or temporal resolution needed for robust monitoring at field scale. ARS scientists at Beltsville, Maryland, developed an integrated remote sensing system to map crop growth using remote sensing data from multiple satellite platforms. Near-daily vegetation indices at 30-m spatial resolution were produced for monitoring crop progress and condition. Further, these time-series datasets were used to deduce key crop growth stages (e.g., emergence, maximum green-up, and harvest) over agricultural landscapes. Such information is critical for monitoring the growth and development of agricultural crops and will be used by NASS to provide improved in-season monitoring of domestic agricultural production.

Improved Soil and Water Assessment Tool (SWAT) algorithms, data and methods to support next generation Conservation Effects Assessment Project (CEAP) analysis. CEAP is an Office of Management and Budget-mandated effort to evaluate the effect of U.S. conservation programs and policies. CEAP I has been completed and a new analysis through CEAP II is underway. To support CEAP II core changes to the structure and function of the SWAT model have been necessary. The new model, SWAT+, has a modular code design and improved input/output data structures. These enhanced features allow SWAT+ to ingest larger national scale datasets while simultaneously better representing the connections among landscape and water features at the local level. To best utilize SWAT+ within CEAP II, new national scale input data have been developed. National climatic and crop management data have been developed and released to the public. Highly detailed stream network and water feature data have been developed, and are under review. A nationwide survey of more than 15,000 points has been conducted using aerial photography to describe the distribution of structural conservation practices and gullies. All of these data and models are being released via the web as they become available.

Testing and algorithm improvement of soil moisture satellite ensures usefulness for land and water management. Accurate soil moisture remote sensing is crucial to provide soil moisture data globally at a spatial resolution that supports a wide range of agricultural, hydrologic, and climate applications. A NASA satellite mission (the Soil Moisture Active Passive mission or SMAP) was launched in 2015 and can potentially meet this need; however, ground-based testing and algorithm improvements are needed to ensure sufficient soil moisture retrievals. During 2016, ARS scientists played a critical leadership role in providing such testing. In particular, they led a ground and aircraft validation campaign in and around the Walnut Gulch Experimental Watershed near Tombstone, Arizona during the 2015 summer monsoon to collect ground truth data for satellite soil moisture retrievals. Data analysis in 2016 enabled revision of SMAP algorithms for monitoring soil moisture in semi-arid domains, such as the southwestern U.S., which will improve the understanding of climate and weather dynamics in a drought prone region of significant interest to USDA NOAA.

Bias in evapotranspiration reference maps. Accurate daily reference evapotranspiration (ET) is needed for efficient water management from field to regional scales. To meet this need, scientists at NOAA have developed spatially representative daily reference ET maps for the contiguous U.S. using data from non-agricultural weather networks. These maps are expected to be used as input into various water demand and availability models. In this study, scientists from ARS in Bushland, Texas, NOAA, U.S. Geological Survey, and Texas A&M AgriLife Research evaluated the accuracy of the NOAA reference ET maps using data from the agriculture-based Texas High Plains ET network. Results showed that the NOAA reference ET values were generally higher than those from the Texas High Plains ET network. Therefore, a bias correction to air temperature and wind speed data used in generating NOAA reference ET or adjustment to the resulting NOAA reference ET may be needed to improve its accuracy. Integration of this information with existing ET data will improve the efficiency of crop water management.

Soil heating successfully modeled. Irrigated crops consume a large portion of freshwater resources, but irrigation results in up to four times greater crop production compared with non-irrigated crops. It is therefore important to manage irrigation water in order to maintain or increase crop production for a growing world population while conserving freshwater resources for municipal, industrial, environmental, and recreational uses. Management of irrigation water requires knowledge of crop water use; however, crop water use is related to numerous complex factors. One important factor is how much the soil beneath a crop is sunlit or shaded. Sun lighting and shading of the soil change with time of day, type of crop, crop row direction, and crop growth stage, among other factors. Scientists from ARS laboratories in Bushland, Texas and Beltsville, Maryland, and Ben-Gurion University of the Negev, Israel developed and tested a new mathematical model to calculate soil sun lighting and shading beneath a row crop. The new model resulted in improved estimates of factors related to crop water use. The use of this model will improve irrigation water management and conserve freshwater resources.

Multi-objective model calibrations using water balance. Automated procedures are often used to provide fits between hydrologic model estimates and observed data. While the models may provide good fits based upon numeric criteria, they still might not represent the basic hydrologic characteristics of the represented watershed accurately. ARS researchers at Tifton Georgia, along with ARS, university, and international partners, developed a method for calibrating hydrological models considering both discharge and individual water balance components as evaluation criteria. Results indicate that several trade-offs exist between good statistics for discharge simulations and reasonable water balance. The application of statistical measures for discharge dynamics and magnitude is not sufficient to ensure a reasonable simulation of the hydrological system and ARS scientists recommend constraining the ranges of water balance components to achieve a more realistic simulation of hydrological system.

Energycane: a successful bioenergy feedstock for Louisiana. Sustainable production of high quality biomass crops is a necessity for a successful bio-based economy. In experiments conducted over a five-year period by ARS scientists in Houma Louisiana, energycane yields in southern and northern Louisiana ranged from 12 to 23 tons of dry biomass per acre. These yields were obtained using minimal management requiring no irrigation water and reduced tillage practices. Energycane was available for industrial conversion from August to March each year. These results demonstrate that Louisiana can produce high-yielding and sustainable feedstocks reliably for potential bioenergy industrial partners.