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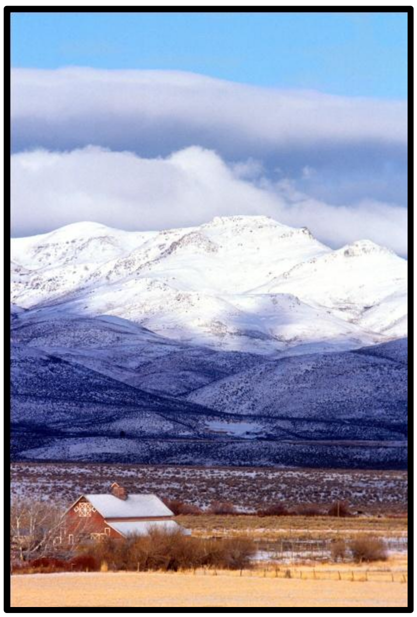
National Program 211:

Water Availability & Watershed Management

ACCOMPLISHMENT REPORT 2007-2011



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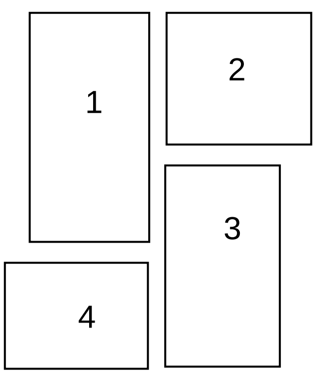

1. Site of the 90-square-mile Reynolds Creek Experimental Watershed in the Owyhee Mountains about 50 miles southwest of Boise, Idaho. *Photo by Scott Bauer/ARS.*

2. Subsurface tile discharge to Tipton Creek in north-central Iowa. This drainage main is a 36-inch diameter clay pipe draining over 4000 acres of cropland. Note white conduit connecting to depth velocity sensors and water sampling equipment. *Photo by Mark Tomer/ARS.*

3. Computer-controlled center pivot irrigation systems can be connected by modem to radios or telephones so farmers can run them remotely. *Photo by Doug Wilson/ARS.*

4. Massive erosion in which gully formed and extended 375 m during a 229 mm rain event during tropical storm Erin in the Fort Cobb Reservoir watershed in southwestern Oklahoma on August 19, 2007. *Photo by Patrick J. Starks/ARS.*

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Accomplishment Report 2007-2011

BACKGROUND AND GENERAL INFORMATION

This report is a compilation of some of the most significant research accomplishments of the past 5 years achieved by scientists working in the USDA Agricultural Research Service's (ARS) National Program 211 (NP211) Water Availability and Watershed Management (*previously* Water Resource Management). The NP211 mission is twofold: (1) to conduct research on the processes that control water availability and quality for the health and economic growth of U.S. citizens; and (2) to apply this new knowledge to develop new and improved technologies for managing the Nation's agricultural and water resources. Advances in knowledge and technologies provide producers, action agencies, local communities, and resource advisors with the practices, tools, models, and decision support systems they need to improve water conservation and water use efficiency in agriculture, enhance water quality, protect rural and urban communities from the ravages of drought and floods, improve agricultural and urban watershed management, and prevent the degradation of riparian areas, wetlands, and stream corridors.

At the start of the period of record, NP211 consisted of approximately 43 primary projects and 23 contributing projects located in 24 different states (see Appendix 1). The more than 146 scientists working within this national program represent multidisciplinary teams that include specialists in agricultural engineering, civil and hydraulic engineering, agronomy, biology, ecology, geography, geology, hydrology, chemistry, physical science, or soil science.

Water is fundamental to life and a basic requirement for virtually all of our agricultural, industrial, urban, and recreational activities, as well as for the sustained health of our natural ecosystems. In that sense, the activities and accomplishments described in this report have at least some relevance to nearly every other ARS national program.

At the global scale, the availability of fresh water is strongly linked to food security. During the last century, Earth's human population tripled, but the global demand for Earth's finite supply of available fresh water increased six-fold. According to the United Nations, more than a billion people still live without access to clean water, while more than 2.4 billion people lack the basic sanitation needed for human health. To help address these important global concerns, in December 2010, Secretary Vilsack approved the USDA Global Food Security Action Plan, subsequently endorsed by US-AID and the State Department (visit the *Feed the Future* website at http://www.feedthefuture.gov).

In more advanced economies, clean water availability is increasingly threatened due to contamination from agriculture (e.g., crop fertilizers and animal manure), urban sources (e.g., storm and wastewater runoff, pharmaceuticals, disinfection byproducts) and industry. Since 2009, global concerns about the effects of climate change on water availability have also come to the forefront. At the same time, agriculture has been called upon to help meet the Nation's energy needs by increasing the production of renewable biofuel feedstocks. In October 2010, Secretary Vilsack formally announced the establishment of five regional USDA Biomass Research Centers to help ensure the availability of dependable supplies of the feedstocks needed for the production of advanced biofuels to meet legislated goals and market demand, and enable as many rural areas across the country as possible to participate and benefit economically. All of these issues significantly affect water availability (quantity and quality). In light of these serious and growing problems, the importance of conserving water resources has never been greater.

During the 5-year period covered by this report, examples of ARS accomplishments in water-related research include: 1) remote sensing tools to assess the availability of soil water in the root zone for drought detection; 2) a watershed model, the Soil and Water Assessment Tool (SWAT), for national assessment of conservation effects; 3) irrigation scheduling tools for the Texas High Plains, where water levels in the Ogallala Aquifer are rapidly declining; 4) a model to simulate plant responses to water deficit that allows producers to make management decisions to improve the efficiency of irrigation water use; 6) demonstrating that drainage water management and/or controlled drainage can increase crop yield and reduce nutrient losses to aquatic ecosystems; 7) a Rangeland and Hydrology and Erosion Model (RHEM) for managing western rangelands; 8) a manure injection technology that lowers both odor and ammonia emissions to air and reduces phosphorus in runoff waters; 9) a pesticide index, based on long-term watershed data, that explains pesticide transport as a function of planting, crop development, rainfall, and dissipation in soil; and 10) new surface irrigation management software that can be used to calibrate radial gates and automatically control canal gates to minimize water spills. In assessing conservation effects, ARS scientists have demonstrated the water quality benefits of riparian buffers, cover crops, wetlands, and developed new innovative on-site treatment technologies such as low-grade vegetative ditches and a gypsum curtain. Many more significant accomplishments are highlighted in the main portion of this report.

New knowledge generated by NP211 scientists has led to better farming, conservation, and water management practices. The water quality information from long-term watersheds and the many water management tools are used by a host government agencies, researchers, customers, and stakeholders. Examples include: 1) the Automated Canal Management Program – SacMan; 2) the Integrated Hydraulic Analysis for Surface irrigation WinSRFR; 3) the Dam Safety Analysis Model – WinDAM; and 4) Bank Stability and Toe Erosion Model – BSTEM.

PLANNING AND COORDINATION FOR THE NP 211 5-YEAR CYCLE

The NP211 2006-2010 Action Plan served as the guide for research conducted within this national program through 2011. The plan was drafted in 2005 by a writing team composed of ARS scientists and members of the NP211 National Program Leader (NPL) team. Incorporating input from more than 200 scientists, administrators, customers, and stakeholders who attended the NP 211 National Program Workshop in June 2005, the NPLs' knowledge of the subject matter and national needs, ARS scientists unable to attend the workshop, and an assessment of

NP 211's impact during the previous 5 year program cycle, the writing team prioritized the research needs identified by these various contributors in light of ARS base funding and other resources. Inputs from the NP211 NPL team included those gathered from participation in various USDA and interagency water-related programs, committees, and meetings, recent reports published by the National Academy of Science, the National Science and Technology Council, and the U.S. Government Accountability Office, and research needs identified by, and subsequent activities arising from, the Agricultural Water Security Listening Session held in September 2004 at Park City, Utah. Individual research needs were then aggregated into six problem areas, with distinct products, outputs, and outcomes proposed under each problem area. The final action plan guided the development of new individual NP211 research projects that began the current 5-year research cycle in 2007.

Individual NP211 project plans were then written to address one or more of these six problem areas, focusing on specific products, outputs, and outcomes as relevant to each participating research location. Project plans were evaluated for scientific quality and feasibility by external peer review panels through ARS's Office of Scientific Quality Review (OSQR) during 2006. The ARS Peer Review Process is an essential part of the 5-year ARS research program cycle. The process was mandated by the Agricultural Research, Extension, and Education Reform Act of 1998, that required successful completion of peer review as a prerequisite to perform research. Each research project in every ARS national program includes statements of the agricultural problem(s) being addressed, the anticipated outputs or information to be generated by the project, how the planned research contributes to mitigating or solving the larger national program problem statements, and timelines and milestones for measuring progress toward achieving project objectives. Project plans were revised in response to review panel recommendations as needed, and then implemented in late 2006/early 2007. The next 5-year research cycle for NP211 has already begun, with a new Action Plan written for 2011-2015. New plans for individual research projects have already been subject to formal prospective review, and are currently undergoing revisions as necessary, followed by official certification.

Coordination and planning for NP 211 are the tasks of the NP 211 leadership team. Among other things, this team coordinates NP 211 activities with those of other ARS national programs, other agencies, and other departments. Some of the interagency research coordination associated with NP 211 is conducted through Federal Interagency Committees like: (1) the Committee on Environment and Natural Resources (CENR) (the relevant National Science and Technology Council committee for water research) Subcommittee on Water Availability and Quality (SWAQ); (2) the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, charged by Congress with conducting a reassessment of (i) nutrient load reductions and the response of the hypoxic zone, (ii) water quality throughout the Mississippi River Basin, and (iii) economic and social effects; (3) the Advisory Committee on Water Information (ACWI) Subcommittee on Sedimentation; (4) the Conservation Effects Assessment Project (CEAP) Steering Committee; (5) various working groups of the US Climate Change Science Program; and (6) the Interagency Water Working Group chaired by the State Department. The NP 211 team also confers and coordinates with colleagues from other USDA agencies, including the Economic Research Service, the Farm Services Agency, the Foreign Agricultural Service, the National Agricultural Statistics Service, the National Institute of Food and Agriculture, the Natural Resource Conservation Service, and the U.S. Forest Service, both individually and in association with

USDA interagency committees including: (1) the National Agricultural Research, Extension, Education, and Economics (NAREEE) Advisory Board, which evaluates USDA Research and Development Programs and provides recommendations to the Secretary and REE Undersecretaries; (2) the USDA Drought Team and the USDA Working Group on Water Resources; and (3) the USDA Water Team.

Figure 1: Primary (black) and contributing (blue) locations that contribute research to National Program 211, Water Availability & Watershed Management. Open circles (black) indicate projects that moved or left the program during the course of the Action Plan.

Customer and stakeholder interaction and research coordination continue to play important roles in helping NPLs guide NP 211 research to maintain its relevance to U.S. agriculture. NP 211 NPLs attended or organized numerous research planning, coordination, and stakeholder workshops during 2006-2011. These workshops addressed a variety of agriculturally-relevant topics including specific challenges, emerging high-priority issues, and new scientific developments in fields related to water availability and watershed management.

STRUCTURE OF NP 211

The approach for this National Program is to address the highest priorities for agricultural water management. The core concept in formulating NP211 research projects is based on the progression of science and technology development. This includes: basic understanding of the scientific principles; verification of concepts and designs at the field scale; development of practice standards for field implementations; assessment of aggregated effects from different management practices; and finally delivering models and tools that can be used the users and customers.

The NP 211 Action Plan (2006-2010) was composed of the following six components that together and in concert with other national programs, worked to achieve breakthroughs in the understanding and management of water quantity and quality at scales ranging from fields to watersheds to landscapes to regional to global, to maintain or enhance agricultural production, environmental quality, and our natural resource base. ARS Action Plans are living documents that can be changed in light of emerging problems and needs, new techniques, and new information.

PROBLEM AREA 1: EFFECTIVENESS OF CONSERVATION PRACTICES.
Understanding the complexities how conservation practices interact with biological, chemical, and physical processes at watershed and landscape scales is critical to properly evaluating the effectiveness of USDA's significant investment in conservation programs. The goals of this Problem Area are to: (1) develop technologies for the detailed assessment of conservation programs at the watershed scale; (2) validate and improve the models used to analyze relevant biological, chemical, and physical processes; and (3) support coordinated research on the effects of conservation practices across a range of resource characteristics (e.g., climate, terrain, land use, soils). Accomplishments in this component serve the needs of USDA's Natural Resource Conservation Service and Farm Services Agency, helping farmers to maximize production while minimizing the impacts of agriculture on our natural resources.

PROBLEM AREA 2: IRRIGATION WATER MANAGEMENT
Irrigated agriculture produces 60% of crop market value on less than 20% of the cultivated land in the US, but doing so accounts for approximately 80% of the consumptive use of freshwater in the US, with growing competition from urban, suburban, and industrial sectors. Research in this Problem Area focuses on improving the efficiency of agricultural water use in both arid and humid regions, including developing technologies and practices for using alternate water sources (i.e., re-use of degraded waters) to support agricultural production. Anticipated outcomes and products include: (1) improved irrigation scheduling tools and water delivery technologies; (2) on-site sensors or remote sensing techniques to measure soil water content and plant responses for site specific irrigation water management; (3) cropping and management strategies under limited water supplies and using degraded waters; and (4) tools for irrigation scheduling in humid regions.

PROBLEM AREA 3: DRAINAGE WATER MANAGEMENT SYSTEMS
Surface and subsurface drainage water management (DWM) systems are crucial for mitigating the environmental impacts of agricultural drainage waters in both rainfed and irrigated croplands, well-known as major contributors of nonpoint source pollution to streams and lakes. Research in this problem area focuses on the specific guidelines and tools needed for both surface and subsurface drainage water management systems to minimize the impacts of drainage on water quality, including design specifications, installation protocols, and automation techniques, with associated evaluation of their effects on water quantity and quality, soil quality, and wildlife benefits, and the incorporation of improved drainage water management systems into environmental and economic decision support systems. Research in this Problem Area is of particular

interest to USDA's Natural Resource Conservation Service, in light of their recently announced (2011) Drainage Water Management Initiative.

PROBLEM AREA 4: INTEGTRATED EROSION AND SEDIMENTATION TECHNOLOGIES

Because it is linked to both soil fertility and costly negative impacts on channel evolution, flooding, water and air quality, controlling soil erosion is an essential component of developing sustainable agricultural production systems. Customers identified two basic needs: (1) better erosion control technologies; and (2) improved decision support systems for planning and assessment. Thus the research focus of this Problem Area is shifting from the traditional study of rainfall-runoff induced sediment detachment and transport processes, towards quantifying subsurface hydrologic effects on ephemeral gully formation and stream bank erosion and identifying sediment sources on the landscape for targeting control strategies. Assessment tools and techniques to prevent concentrated flow erosion in irrigation furrows, and in earthen spillways and embankments associated with flood control structures, are also important. This latter research is particularly important to the USDA's Natural Resources Conservation Service, charged with managing and/or rehabilitating thousands of earthen dams and embankments that are reaching the end of the recommended life span.

PROBLEM AREA 5: WATERSHED MANAGEMENT, WATER AVAILABILITY, AND ECOSYSTEM RESTORATION

Society relies on adequate freshwater resources to support populations, agriculture, industry, wildlife habitat, aquatic ecosystems, and a healthy environment. Because agricultural watersheds, including crop, pasture, and range lands, account for more than 70% of the land surface in the continental US, agricultural watershed management plays a dominant role in managing the Nation's freshwater resources. As exemplified by research in this Problem Area, the primary research challenge remains developing and applying an integrated research approach, based on ecological, geomorphic, and hydrological principles, to develop better understanding and management of water availability, allocation potential, and their impacts on wetlands, riparian ecosystems, and associated fluvial systems, at the watershed scale.

Research in this Problem Area focuses on: (1) developing Best Management Practices (BMPs), assessment tools, and decision support systems for managing water quantity and quality in a variety of watersheds, landscapes, and climates; and (2) improving a variety of tools (e.g., simulation models, remote sensing techniques) to improve estimates of water budgets and their components, including water quality assessments and assessments of flood and drought risk. Products of this research are of interest to a variety of Federal agencies including the National Weather Service, the National Oceanic and Atmospheric Administration, and the National Aeronautics and Space Administration, to improve understanding and prediction of weather, climate, and atmospheric processes at a range of scales, and using satellite-collected by satellites and other types of remote sensing data.

PROBLEM AREA 6: WATER QUALITY PROTECTION SYSTEMS

To be economically viable, most crop production systems rely on chemical inputs (e.g., nutrients, pesticides), but excess nutrients can cause eutrophication of both fresh and marine coastal waters, and elevated levels of some species (e.g., nitrate) also impact human health. Research in this Problem Area focuses on developing reliable and effective control strategies and technologies to reduce the transport of nutrients, pesticides, pharmaceuticals, and pathogens from agricultural lands to aquatic ecosystems. Products of this research are of interest to farmers working to maintain the economic viability of their operations, to the Natural Resource Conservation Service, in light of their mission to improve conservation on agricultural lands, and to the Environmental Protection Agency, charged with maintaining the quality of the nation's water resources.

Due to the multi-disciplinary nature of the research conducted in NP 211 and the research teams that contribute to the program, it is common for research teams in NP 211 to work on multiple products, often crossing the boundaries of individual Problem Areas and National Programs. It is also common for multiple ARS units to engage in cooperative research to develop some of the products and achieve some of the outcomes identified in this action plan. Conservation Effects Assessment Project (CEAP) Benchmark Watersheds research is one example of this type of collaborative effort.

RELATIONSHIP OF NP 211 TO OTHER NATIONAL PROGRAMS AND COLLABORATIONS WITH PARTNERS OUTSIDE OF ARS

ARS research is organized into four national program areas: (1) Animal Production and Protection (APP); (2) Crop Production and Protection (CPP); (3) Natural Resources and Sustainable Agricultural Systems (NRSAS); and (4) Nutrition, Food Safety, and Quality (NFSQ). NP 211 is one of six national programs within NRSAS. Since water is fundamental to life and a basic requirement for virtually all agricultural activities, research conducted under NP 211 often contributes to attaining the goals of other national programs:

- NP 212 – Climate Change, Soils, and Emissions. NP 211 scientists have significant partnerships with their counterparts in NP 212 in addressing topics like soil erosion and soil fertility as affected by irrigation and drainage. In addition, NP 211 scientists cover the majority of water-related research linked to climate change. Finally, for nutrient elements such as nitrogen that have both aqueous and gaseous forms, strong linkages between research on water quality and emissions are essential for closing the agricultural nitrogen budget.
- NP 213 – Bioenergy. NP 211 scientists contribute to NP 213 in their examination of water quantity and quality issues related to biofuel feedstock production.
- NP 214 – Agricultural and Industrial Byproducts. Land application of manure can be a significant source of the nutrients in agricultural runoff that can cause the eutrophication of aquatic ecosystems, particularly phosphorus. A significant proportion of ARS research on sustainable use of manure as an agricultural fertilizer, and developing practices to avoid undesirable effects on water quality, is conducted in NP 211. NP 211 scientists also conduct significant research on how industrial byproducts can be used to help solve agricultural water quality problems.
- NP 215 – Pasture, Forage and Rangeland Systems. NP 211 scientists contribute significantly to the Conservation Effects Assessment Project (CEAP) activities on range and pasturelands, where water quantity and quality issues are both major concerns.

- NP 216 – Agricultural System Competitiveness and Sustainability. Sustainable agricultural systems cannot be developed without paying attention to water quantity and quality concerns. NP 211 provides significant input to NP 216 scientists in the sustainable use of water to maintain and enhance agricultural productivity in a variety of agricultural production systems.

For example, ARS NP 212 and NP 215 researchers Cheyenne, WY, found that soil organic carbon (C) storage in rangelands was significantly positively correlated with mean annual precipitation, and that the impact of grazing management practices on soil C storage also differed as a function of mean annual precipitation (Figure 2). This is a prime example of the potentially complex interactions among water availability, soil processes, and land management practices that can affect management decisions.

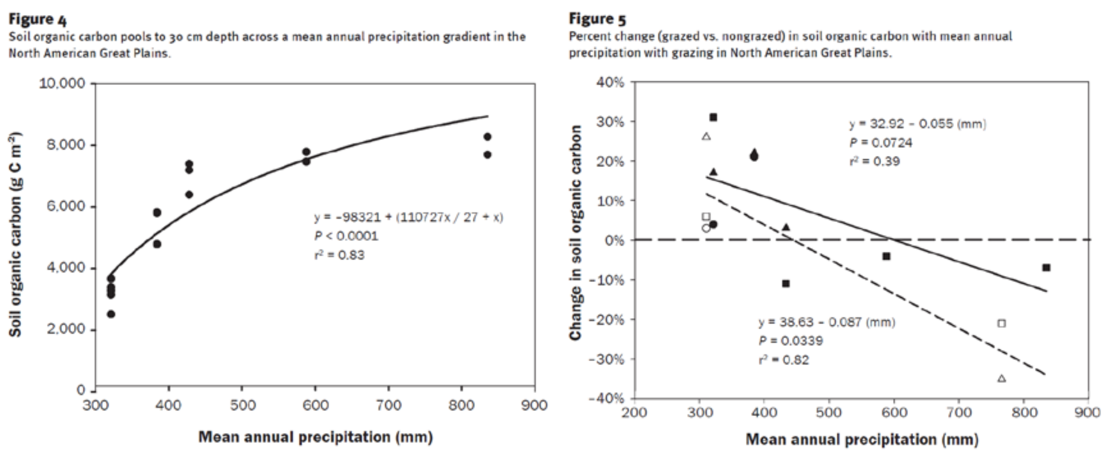


Figure 2: Reference: Derner, J.D. and Schuman, G.E. Carbon sequestration and rangelands: a synthesis of land management and precipitation effects. Journal Soil Water Conservation 62:77-85. 2007.

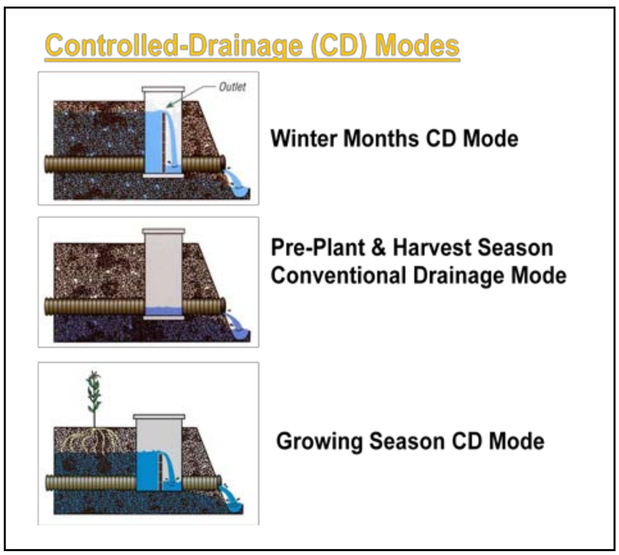
ARS' research on water is not just focused on agricultural crop or animal production systems. The following example shows how ARS NP 211 research directly addresses a public health concern on park lands irrigated with treated sewage water, associated with the increased use of the recycled water to increase water availability in arid regions. NP 211 scientists at Maricopa, AZ monitored levels of fecal bacteria (*E. coli*, *Enterococcus*) in a reclaimed water holding pond used as a source of irrigation water, in water leaving the irrigation system, and in irrigated soils over two years in a municipal parkland. While they did find spikes of bacteria in the pond water, possibly due to fecal inputs from parkland dogs, birds, and fish, there was no detectable buildup of fecal bacteria in irrigated soils over

NP 211 Microbiologist J. McLain (left) examines bacteria from a park irrigated with treated wastewater.

a two year period. The highest *E. coli* levels were found in deeper soils during summer, suggesting that surface conditions (intense solar radiation and desiccation) were lethal to bacteria, reducing potential human health risks in irrigated areas.

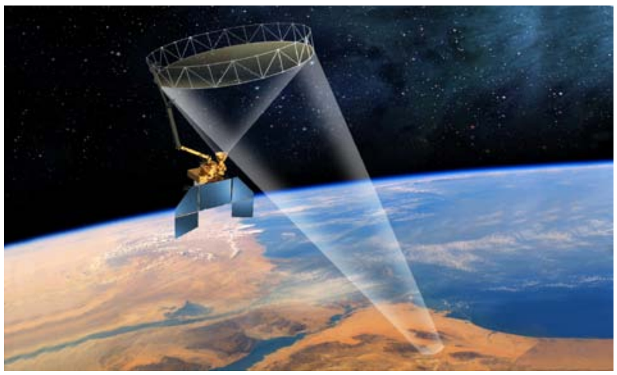
One key to success in natural resources research is developing collaborations and partnerships with other government agencies (Federal, state and local), NGOs, commodity groups, landowners, and farmers. Water management practices (e.g., new irrigation techniques, water quality protection systems) need to be tested in operational farm fields, as well as in research plots. Research findings need to be translated into guidelines, practice standards, and decision support systems. NP 211 scientists have a long history of collaboration with outside entities. Many Federal agencies, including the USDA Natural Resources Conservation Service (NRCS), the US Forest Service, the US Environmental Protection Agency, the US Geological Survey, the Bureau of Land Management, the US Army Corps of Engineers, and the National Aeronautics and Space Administration, rely on ARS research products. At the local level, ARS scientists work closely with university research partners, state and local departments of natural resources or environmental quality, local grower associations, water management and/or irrigation districts, soil and water conservation districts, environmental groups, watershed associations, and most importantly farmers and land managers, on planning the research and delivering the technologies that are relevant and practical to help managing water resources.

An example of ARS collaboration with NRCS is in the development and revision of their National Conservation Practice Standards, including the recent revision of NRCS National Nutrient Management Standard #590. ARS scientists played a significant role in providing the research findings and proposing nutrient application criteria that will help to maximize yield while minimizing environmental impact. At the local level, many ARS scientists provide assistance to NRCS State Technical Committees in developing state-specific nutrient management guidelines.



An example of an ARS collaboration with external partners is the NRCS-funded 2007-2009 Conservation Innovation Grant (CIG) on controlled drainage in five Midwestern states: Iowa, Minnesota, Illinois, Indiana, and Ohio. Participants in this project included NP 211 and other ARS scientists, university researchers, representatives from the drainage industry, and farmers. The purpose of the project was to use farmland under active cultivation to demonstrate that controlling ground water levels in tile-drained fields can minimize nitrogen leaching through the drains, reducing costly fertilizer losses while improving both environmental quality and the farmer's bottom line.

Another example that will have national and international significance in the future is NASA's Soil Moisture Active and Passive (SMAP) satellite, currently scheduled to launch in 2014. This is a "Tier-1" mission recommended by the U.S. National Research Council's Committee on Earth Science and Applications from Space. The purpose of the mission is to provide global coverage of soil moisture and freeze-thaw measurements--measurements that have significant value in a variety of scientific disciplines including atmospheric and climate change science, global biogeochemistry, ecology and environmental science, hydrology, and meteorology. ARS scientists have been a key part of this mission since the initial field campaign in the Southern Great Plains in 1999 (SGP1999). The initial and subsequent campaigns have been used to field-test instrumentation that will be carried by the SMAP satellite when launched in 2014. Once the satellite is launched, several ARS watersheds will serve as field validation sites. This activity, which spans at least three 5-year program cycles and associated action plans, demonstrates the broad scale impact of ARS' NP211 research.



NASA SMAP Mission is planned to launch in 2014.

The accomplishments of NP 211 are often attained in close cooperation with public and private sector collaborators, and in fact, many NP 211 researchers are co-located with land-grant university faculty. The ability of ARS to partner with land-grant universities strengthens the capacities of both the institutions and NP 211. As an added benefit, NP 211 researchers help to train the next generation of agricultural researchers, by hosting visiting scientists and post docs, mentoring or directing graduate student projects, and providing undergraduate student work experiences. In fact, many ARS scientists started their career as undergraduate student workers. ARS laboratories are also the top choices for many international scholars when they come to the US for training or sabbaticals. These students and scholars have contributed significantly to help advance the national program's research agenda. Although training students is not a primary mission of ARS, it is nonetheless an important measure of leadership and stewardship that NP 211 scientists contribute to the agricultural research community. In addition, NP 211 scientists have accommodated a number of visiting scientists interested in gaining specific research expertise and/or research collaborations.

During the past 5 years, the progress and achievements of NP 211 were also strengthened significantly by collaborative and coordinated research supported by non-governmental organizations, private industry, and international partners. This support can be in the form of in-kind contributions, trust agreements, or cooperative research and development agreements (CRADAs). NP 211 NPLs and scientists often participate in strategic planning and coordination efforts with these commodity research communities to integrate public- and private-sector partners into cooperative research. These partnerships enable NP 211 to effectively leverage additional resources to conduct and transfer research that addresses critical agricultural problems.

HOW THIS REPORT WAS CONSTRUCTED AND WHAT IT REFLECTS

In this report, NP 211 accomplishments and their impacts are organized and presented according to the six Problem Areas and their associated products, outputs, and outcomes, as outlined in the NP 211 2006 to 2010 Action Plan. Under the Problem Areas, accomplishments are grouped by relevant themes that reference one or more of the products described in the Action Plan. Since fiscal resources and research capacity are not uniformly distributed either within or among the six Problem Areas, more accomplishments may be reported under some Problem Areas than others.

The content of this accomplishment report is derived from the past 5 years of NP 211 Annual Reports and the reports of its constituent research projects. This report stresses the impacts of those accomplishments and, where relevant, cites key publications or Web URLs documenting those accomplishments. The 43 primary and 23 contributing research projects in NP 211 are listed in Appendix 1 under the associated Action Plan Problem Area. A complete list of publications is given in Appendix 2. References for publications authored by NP 211 scientists and cited in the body of the report, appear at the end of each Problem Area. Appendix 3 is the Action Plan table showing all the proposed products and research locations and scientists involved in each of the products.

This report was prepared for an external (to USDA) retrospective review of NP 211 to assess how well this national program attained its projected goals as outlined in the 2006 to 2010 Action Plan. Accordingly, the purpose of the retrospective review is not to judge the performance of individual NP 211 research projects, but to gauge the overall impact of the national program. Consequently, the report does not attempt to catalogue all of the individual accomplishments of NP 211 research projects. Individual scientists or projects are not identified by name in the narrative text. Instead, their achievements are described in the context of contributions towards accomplishing NP 211's stated commitments to the mission of the Agricultural Research Service and the U.S. Department of Agriculture.

Some of the projects and locations that were part of NP 211 at the start of the 5-year program cycle (i.e., during the writing of the Action Plan) moved to other National Programs during the evaluation period. For example, NP 211 projects at Pullman, WA, and Lincoln, NE, moved to NP 212 (Climate Change, Soils, and Emissions). The NP 211 project at Watkinsville, GA, moved to NP 216 (Agricultural System Competitiveness and Sustainability). The NP 211 project initially located at Baton Rouge, LA, moved to Houma, LA, during the program cycle, with an associated change in project emphasis, from drainage water management in humid and sub-humid environments to developing best management practices for managing water quantity and quality associated with the production of energy cane. The NP211 project at Miami, FL, moved into the Crop Production and Protection National Program Area altogether, to better support subtropical horticultural research. Because of associated changes in research emphasis, productivity associated with NP 211 products at these locations may have been impacted.

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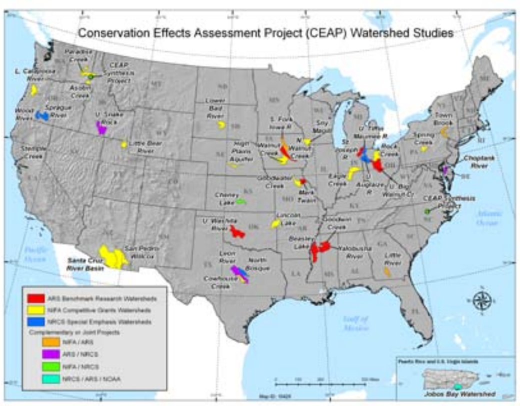
Problem Area 1: Effectiveness of Conservation Practices

Improved conservation practices reduce sediment and nutrient losses from agriculture. Ideal practices will reduce the cost of inputs for the producer, improve the sustainability of land resources, and minimize the impacts of agriculture on water quality. Assessments of the impact of conservation practices across large, complex watersheds depend on the development of reliable assessment criteria, an understanding of physical, chemical, and biological processes that occur at scales ranging from fields to watersheds, and on the integration of this knowledge into improved, validated models and tools to evaluate and predict the impact and result of management options.



Watersheds in the Conservation Effects Assessment Project (CEAP).

Theme 1: Organized efforts and data from ARS research watersheds

With the initiation of CEAP, one challenge was to determine how data and information could be shared among research locations and with customers and stakeholders. Reported here are selected accomplishments demonstrating how ARS scientists worked together to establish a framework where research data can be deposited and made available to others to use. These selected accomplishments are associated with Product 1: A data system to organize, document, manipulate and compile water, soil, management, and socio-economic data for assessment of conservation practices.

Selected Accomplishments under Theme 1 of Problem Area 1

The Agricultural Research Service (ARS) conducts watershed-scale research at 14 locations as part of the United States Department of Agriculture (USDA)-led Conservation Effects Assessment Project (CEAP). Watershed-scale modeling, field studies to assess the effectiveness of conservation practices, and evaluation of practice placement in watersheds, are used to assess the impacts of conservation practices on water quality in large agricultural watersheds. Field studies show that conservation practices improve water quality, but water quality problems persist in larger watersheds. The apparent dissociation between practice-focused assessment and water quality status occurs because: 1) conservation practices are not targeted according to critical sources and pathways of contaminants; 2) sediments carried by streams often originate from channel and bank erosion, rather than from erosion of soil in fields; 3) timing lags, historical legacies, and shifting climate combine to mask the effects of practice implementation; and 4) water quality management strategies that address single contaminants do not consider inherent trade-offs among multiple contaminants. These lessons can be leveraged to improve strategies for implementing conservation programs and to set water quality goals with realistic timelines (Tomer and Locke, 2011).

Cobb Creek and its tributaries in Oklahoma are part of a watershed being studied by ARS to gauge the effects of agricultural conservation practices on water quality.

As part of the ARS CEAP watershed studies on croplands, data and information from ARS benchmark watersheds have been assembled into a web-based data system—Sustaining the Earth's Watersheds Agricultural Research Data System (STEWARDS)—that organizes and documents soil, water, climate, land-management, and socio-economic data from multiple agricultural watersheds across the US, allowing users to search, download, visualize, and explore data for research and conservation management purposes. STEWARDS helps: 1) researchers obtain ARS' long-term data for hydrological studies; 2) modelers retrieve data for model calibration and validation; and 3) watershed managers and a wide array of partners and stakeholders access long term data to support conservation planning and assessment (Sadler et al., 2008).

STEWARDS data screen [need more information here].

One of the benefits of long-term data collection relates to the potential for subsequent integrative and comprehensive analyses. ARS scientists at Tifton, GA, have collected stream flow and water quality data on the Little River Experimental Watershed (LREW) in south central Georgia for the past 37 years, and sediment and agrichemical concentrations in stream flow for the past 20 years. The resulting database contains hydrologic and water quality data, combined with terrain, soils, geology, vegetation, and conservation practices, for this watershed. The database was published in six manuscripts and via a public ftp site, ftp://www.tiftonars.org/, and is being used to closely examine long-term water quantity and quality patterns for the watershed. The research illustrates the dramatic importance of riparian buffers within the watershed, which remove sediment and nutrients from upland agricultural sources, preventing them from entering adjacent streams and causing eutrophication (Bosch et al., 2007).

Theme 2: Evidence of water quality and ecological benefits

When implemented, conservation practices may produce anticipated benefits at the field-scale, but at the down-stream or watershed scale, it can take years for the aggregated effects of conservation practices to be realized. Collecting the long-term data necessary for watershed scale conservation assessment is also challenging. ARS scientists demonstrated that satellite imagery can be used to identify fields that have been implemented with conservation practices such as cover crops or conservation tillage (from crop residue cover). ARS research also showed that streams can be a primary source of sediment, but can also offer another line of protection against agricultural pollutants. These selected accomplishments demonstrate the effects of innovative in-stream treatments such as grade-control structures, vegetated drainage ditches, wetlands, and blind-inlets (where an inlet for drainage water is considered as the beginning of the artificial stream network).

The selected accomplishments are associated with Product 2: Water quality, water quantity, soil quality, and ecosystem effects of conservation practices at the field, farm, and watershed scales. Some accomplishments focusing on the remediation of specific agricultural pollutants (i.e., nutrients, pesticides) are reported in Problem Area 6, Theme 2 'Remediation of Agricultural Pollutants'.

Selected Accomplishments under Theme 2 of Problem Area 1

Winter cover crops have been shown to effectively reduce both N and phosphorus (P) losses from agricultural fields, but the extent of adoption is difficult to monitor at the watershed or landscape scale. In collaboration with the USGS and the Maryland Department of Agriculture (MDA), ARS researchers in Beltsville, MD, developed and implemented geospatial tools to aid in quantifying the areal extent of cover crop adoption and associated N and P retention. In the Choptank River

Watershed, part of ARS' CEAP croplands watershed research network, field-specific data on conservation program enrollment were combined with satellite imagery analysis to rapidly verify, quantify, and certify cover crop performance. Following successful development of these methodologies, the State of Maryland began using these geospatial cover crop management toolkits in the Talbot County Soil Conservation District. Part of the strategy is to automate the aggregation of site-specific data on conservation program performance to match watershed and county boundaries, providing useful, rapid appraisal of cover crop success in protecting water quality, while maintaining farm data privacy as required in Section 1619 of the Farm Bill. Continuing this collaboration among the MDA, USDA, USGS, the US Fish and Wildlife Service (USFWS), and other partners, will substantially improve the potential contribution of winter cover crops to preventing nitrogen and phosphorus release from agricultural fields to the Chesapeake Bay (Hively et al., 2009).

University of Maryland PhD student Gabriela Niño de Guzmán collects water samples for pesticide and antibiotics analyses in a stream within the Choptank River Watershed.

Similar to assessing the effectiveness of winter cover crops, in order to assess the effectiveness of conservation tillage adoption on water availability, it is critical to first quantify the extent of conservation tillage adoption at the watershed scale. However there are currently no methods in place to monitor conservation tillage adoption at the watershed scale. Using commonly available satellite imagery, ARS researchers at Tifton, GA, developed a mapping algorithm that depicted conservation tillage adoption within the Little River Experimental Watershed (LREW). The resulting map identified farm sites using conservation tillage, defined as having >30% crop residue cover, with 71-78% confidence. Results suggest that currently available satellite imagery can be used to accurately map conservation tillage adoption with a minimum amount of ground control points (Sullivan et al., 2008).

In addition to providing producer guidance on effective practices and their placement on the landscape, it is critical that USDA objectively evaluate its own performance as advisors. A 26 year history of NRCS-assisted conservation practice placement was evaluated for the Little River Experimental Watershed (LREW) at Tifton, GA. Nearly 50% of all croplands fields were identified as having participated in NRCS conservation programs, with 62% of fields (77% of land area) receiving assistance for soil erosion and water erosion quality control practices in high resource concern areas (slope > 2.7 % and low infiltration). ARS also estimated that 30-40% of the time, erosion control practices were implemented in areas not rated as a high concern. Forty seven percent of all fields sampled implemented visible erosion control-specific conservation practices and the implementation was linearly related to slope class. The relationship observed between erosion control practice placement and slope in the sub-watershed database is encouraging and suggests a commitment to good stewardship regardless of participation in federally funded conservation programs (Settimi et al., 2010).

ARS scientists in Oxford, MS, found that conservation efforts to reduce sediment loadings to receiving streams and other water bodies may only be successful if mitigation measures target the major sources of sediment in a watershed. In many watersheds, stream channels represent a significant sediment source that has been largely ignored. Results show that CEAP watersheds like the Fort Cobb and Little Washita, OK, Goodwin Creek, MS, the South Fork of the Iowa River, IA, and Town Brook, NY, produce substantially more sediment than other watersheds in their respective regions that have stable stream channels. In some cases, watersheds with unstable streams produce orders of magnitude more sediment than their stable counterparts. Reconnaissance of these channels showed that they are dominated by stream bank erosion. This finding is further supported by on-site measurements using naturally occurring radionuclides as tracers. In contrast, the Little River, GA, a stream in dynamic equilibrium without accelerated rates of bank erosion, displayed transport rates similar to calculated background rates. Knowledge of the dominant sources of sediments carried by streams identifies the need to design and implement measures to stabilize channels in watersheds with unstable streams, thereby reducing impacts on aquatic communities and the quality of surface waters (Wilson et al., 2008; Romkens, 2010).

CEAP studies cost-effectiveness of conservation practices, such as this restored riparian forest buffer that ecologist Richard Lowrance is standing next to.

Billions of dollars are spent annually on BMPs to control the water quality impacts of crop production, but the specific benefits of these investments are rarely quantified. ARS scientists in Oxford, MS, measured long-term improvements in the quality of Beasley Lake, a natural lake receiving runoff from a heavily cultivated watershed, following BMP implementation. During the preceding 15 years, BMPs were installed both within crop fields and at field edges throughout the 915 ha watershed, including the enrollment of 113 ha of formerly cultivated land into the CRP, and then planted to trees. With the exception of dissolved P, sediment and nutrient levels decreased annually over a 14-year period, while algal populations and water clarity increased. Improvements were most pronounced in spring. These findings provide the scientific basis for future investments in conservation programs supporting land retirement and BMP establishment (Cullum et al., 2010; Zablotowicz et al., 2010).

In recent years, a resurgence of algal blooms has occurred in western Lake Erie, due in part to high loadings of phosphorus. Agriculture in the watershed has been identified as a key contributor of phosphorus loadings to Lake Erie. Agricultural Research Service scientists at West Lafayette, IN, have worked with local cooperators in the St. Joseph River watershed in northeast Indiana, to assess the influence of conservation practices on the quality of water conveyed to Lake Erie. Within the monitored watersheds, tile-risers have been identified as conveying very high loads of sediment and contaminants to stream water. In cooperation with the Indiana NRCS, a set of blind inlet construction criteria was developed and implemented at both the field and small watershed scales. At the field scale, installation of blind inlets was followed by observed decreases in sediment, phosphorus, and nitrogen. When this technology was used to replace all tile risers in a 700 acre watershed, there was a clear reduction in P transported to the stream following rainfall events. Within individual fields, blind inlets reduced phosphorus loadings by as much as an additional 86%. This research documents the effectiveness of specific NRCS conservation practices, and quantifies their benefits to water quality (Smith et al., 2008).

ARS scientists at Oxford, MS, evaluated in-stream grade stabilization structures in the 2,132 ha Goodwin Creek Experimental Watershed, a CEAP benchmark watershed in northern Mississippi. Their research showed that the combined effects of grade control structures and conversion of croplands to CRP lands, which reduced cultivated land from 26 to 8%, caused a 78% reduction in sediment yield near the outlet of the watershed. The evaluation was a successful real-world test of watershed simulation models intended to help watershed managers choose combinations of practices to increase environmental benefits (Kuhnle et al., 2008).

In agricultural landscapes where forest buffers are no longer present, vegetative buffer strips (VBS) represent an important alternative for improving water quality. In association with University of Missouri researchers, ARS scientists in Columbia, MO, quantified how VBS help to reduce the transport of herbicides and veterinary antibiotics (VAs) in surface runoff. The practice involves the combination of altering surface hydrology to initially trap contaminants, followed by enhanced soil degradation. Two separate but interconnected studies investigated: 1) the effectiveness of different grass species in reducing herbicide and VA transport in surface runoff; and 2) the ability of several grass species to promote the breakdown of atrazine in soil. All VBS significantly reduced the transport of herbicides and VAs in surface runoff. Native grasses (i.e., Eastern gamagrass, switchgrass) were most effective for reducing herbicide transport; tall fescue was most effective at reducing VA transport. Based on these findings, relationships were developed relating buffer size to pollutant transport, providing needed design criteria for effective implementation of VBS. In the second study, while all grasses tested showed significant increases in atrazine breakdown as compared to bare soil, eastern gammagrass, smooth bromegrass, and switchgrass exhibited the greatest ability to enhance atrazine breakdown in soil. Overall, these studies demonstrate that VBS are an effective conservation practice for reducing the off-site movement of herbicides and VAs. Both land management agencies (e.g., NRCS and State conservation agencies) and landowners can use this research to help design VBS to more effectively protect water resources from non-point source pollution in agricultural watersheds (Lin et al., 2011a; 2011b)

While the study above clearly demonstrates the water quality benefits of VBS, their ecological benefits in agricultural streams are less well known. To address this deficiency, ARS scientists in Columbus, OH, assessed the effects of grass buffer strips on physical habitat, water chemistry, and fishes in channelized agricultural headwater streams. Installation of grass filter strips did not influence vegetative structure, vegetative type, channel form, in-stream habitat, water chemistry, or the stream biota. Thus unless used in combination with other conservation practices such as no-till or cover crops, grass filter strips may only provide limited ecological benefits in channelized headwater streams. Federal, state, and private agencies charged with managing agricultural watersheds can use these findings to help plan their conservation and restoration activities (Smiley et al., 2011).


Ecologist Rocky Smiley and technician Sarah Boone use a backpack electrofisher to assess fish communities in headwater streams and drainage ditches.

Conservation practices are regularly implemented within agricultural watersheds throughout the United States without evaluating their ecological impacts. Scientific evaluations documenting how habitat and aquatic biota within streams respond to these practices are needed for evaluating the effects of conservation practices. Numerous sampling protocols have been developed for monitoring streams, but protocols designed for monitoring studies are not necessarily appropriate for scientific evaluations. ARS scientists at Columbus, OH, and Oxford, MS, developed a framework for designing scientific evaluations of ecological responses to conservation practices. The framework includes six principles: 1) develop the hypothesis first; 2) use replicated experimental designs having controls and treatments; 3) assess the habitat and biological characteristics;

4) select quantitative and repeatable habitat sampling methods; 5) use multiple sampling techniques for collecting aquatic organisms; and 6) standardize sampling efforts for aquatic organisms. Application of these recommendations will result in scientific evaluations that are hypothesis-driven and incorporate quantitative methods for the measurement of abiotic and biotic attributes (Smiley et al., 2009).

Conservation tillage, vegetative buffers, and controlled irrigation are relatively effective measures for reducing erosion losses and maintaining high soil productivity, but these systems can be somewhat ‘leaky’, especially on highly erodible soils. As a part of CEAP, ARS scientists in Kimberly, ID, examined sediment dynamics in the 200,000 acre Upper Snake River, Rock Creek watershed, ID. Sediment retention ponds were found to be an effective conservation practice in this watershed, contributing to observed decreases in suspended sediment loss from 400 lb/acre in 1971, to 50 lb/acre in 2005. Sediment retention ponds installed on one return flow stream in 2006, reduced annual average sediment concentrations from 400 mg/L in 2005 to 70 mg/L in 2007, reducing sediment loads by 5500 tons. This work provides much-needed quantification of the value of sediment retention ponds in controlling sediment losses at the watershed scale helping the NRCS to document the effectiveness of USDA-sponsored conservation practices (Bjorneberg et al., 2008).

Atrazine is a cost-effective and proven herbicide for corn production in the US, and atrazine concentrations in surface water frequently exceed drinking water standards. The USDA sponsored Environmental Quality Incentive Program provides incentives to farmers to adopt conservation practices that reduce the delivery of agrichemicals to streams. However, quantitative information on the effectiveness of these practices is often limited. One such practice is the pesticide management practice. ARS scientists at Columbus, OH, quantified the effectiveness of the pesticide management practice, when applied at a watershed scale, to reduce the delivery of atrazine to a drinking water supply reservoir. Significant differences in reservoir atrazine concentrations were measured between three distinct time periods: before there were any restrictions on the amount of atrazine that could be applied (pre-label); after atrazine label restrictions were implemented; and during a subsequent EQIP atrazine pesticide management practice implementation. The primary benefit of the practice, reduced water treatment cost, greatly outweighed the incentive payment costs for implementing the practice. This result indicates that the watershed scale implementation of a conservation practice can be a cost effective approach for addressing nonpoint source pollution (King et al., 2009; King et al., 2012)

Theme 3: Models for assessing conservation effects at watershed and regional scales

From selecting the proper conservation practices at the field scale, to making policy decisions at watershed, river basin, or national scales, conservation planning relies on models that accurately calibrated and validated. In natural resource research, the ultimate goal of the scientific efforts is to either develop practices that can be implemented to address specific production and environmental concerns, or to have a model or a modeling component that is based on sound science and has been validated. ARS scientists have a long tradition of developing natural resource models and tools that are now used routinely in conservation planning. In the following section, selected accomplishments on watershed scale modeling are presented.

These accomplishments cover three proposed products in the NP211 2006-2010 Action Plan: Product 3--Validate models, quantify uncertainties in model output, and conduct analyses with models at field, farm, and watershed scales; Product 4--Policy-planning tools to aid selection and placement of conservation practices to optimize profits, environmental quality, and conservation program efficiency; and Product 5--Regional watershed models that can be used to quantify the environmental outcomes of conservation practices in major agricultural regions. These products focus on the development, calibration, and validation of models or tools that can be used to assess the effectiveness of conservation delivery.

Selected Accomplishments under Theme 3 of Problem Area 1

Simulation models are critical to accurately assessing water quality concerns and the effects of conservation practices designed to improve water quality. The EPA and state environmental agencies have identified approximately 15,000 water quality-impaired water bodies in the U.S. At the same time, USDA is mandated to: 1) conduct a thorough analysis of the risks and benefits of USDA's conservation programs to human health, safety, and the environment; 2) determine alternative ways of reducing risk; and 3) conduct cost-benefit assessments of these programs and alternatives. To help address these issues, ARS scientists at Temple, TX, developed a number of new algorithms for the river basin scale model, SWAT, to simulate on-site septic systems, stream sediment routing, urban management practices, improved phosphorus fate and transport, and stream health. As part of the CEAP National Croplands Assessment, SWAT was validated at more than 70 USGS stream gauges across the country, to assure realistic simulation of stream flow, sediment, nutrient, and pesticide (atrazine) loads. Final SWAT validation and scenario analyses were completed for the Upper Mississippi river basin, the Chesapeake Bay watershed, the Ohio-Tennessee river basin, and the Great Lakes watershed. Final draft reports are under review by NRCS and are available on the CEAP website (http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap). Validation and scenario analyses have also been completed for the Missouri, Arkansas-Red, and Lower Mississippi river basins, with reports currently being developed. Scenario runs from this model are being used by NRCS to identify places where conservation practices, such as conservation tillage, terraces, and the CRP, will be most efficient and provide the greatest benefits. The results of these activities will help guide USDA conservation policy and the Farm Bill debate. The model is also being used by EPA in more than 30 states to select land management alternatives to resolve water quality concerns (Migliaccio et al., 2010; Harmel et al., 2010; Jeong et al., 2010; Rabotyagov et al., 2010; White et al., 2010; Vadas and White, 2010; Douglas-Mankin et al., 2010; Bosch et al., 2010; Srinivasan et al., 2010; Chiang et al., 2010; Moriasi et al., 2011; Tuppad et al. 2010; Harmel et al., 2010).

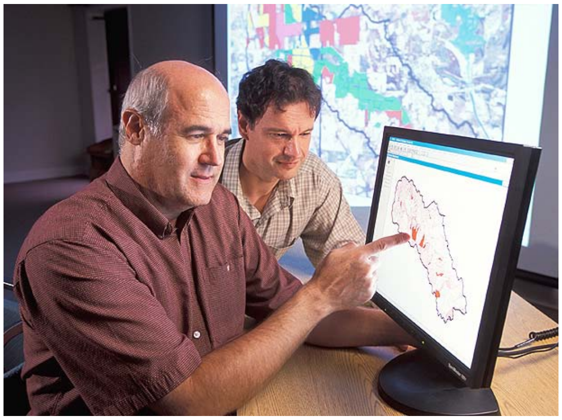

Many CEAP watersheds use the SWAT computer model to predict effects of farm practices on water quality. Here, technician Jeff Nichols collects a sample from a watershed in Ames, Iowa, as part of earlier work to refine the model.

Conservation practices can be implemented both in agricultural fields (e.g., conservation tillage) and along the stream corridors (e.g., buffer strips), but the relative effectiveness of these practices in reducing pollutant loads carried in agricultural runoff has not been evaluated. ARS scientists at Tifton, GA, used SWAT to simulate the water quality effects of upland conservation practices (CPs) commonly adopted in the Little River Experimental Watershed (LREW) for erosion and nutrient control, as compared to the effects of existing riparian forest buffers. Erosion CPs produced the greatest reductions in sediment and phosphorus concentrations, while nutrient reduction practices were most effective in reducing total stream nitrogen. Evaluating three different implementation prioritization scenarios (i.e., random placement, stream order, and nonpoint source pollutant load) showed that prioritizing based on nonpoint source pollutant load yielded more efficient (nonlinear) water quality improvements than the two other scenarios, which yielded linear returns. Riparian forest buffers offered the most comprehensive reduction of all three pollutants. Simulation results indicate that the current level of riparian forest cover in the LREW may be the single largest contributor to reducing nonpoint source pollution loadings in this watershed (Cho et al., 2010a; 2010b).

ARS scientists at Beltsville, MD, and Tifton, GA, used the riparian component of the Little River Experimental Watershed (LREW) database to test the Riparian Ecosystem Management Model (REMM). The sensitivity of REMM nutrient and sediment output was quantified with respect to changes in key riparian buffer parameters (e.g., vegetation, soil characteristics). Parameters associated with vegetation (e.g., rooting depth, plant height) moderately affected nutrient and sediment yields, but outputs were highly sensitive to changes in physical parameters (e.g., slope, Manning's surface roughness coefficient). Scientists at Beltsville are developing a similar evaluation using the SWAT model for the Choptank Watershed. This new model will assist farmers and policy makers in quantifying the effectiveness of specific riparian buffers in reducing pollutant loads to streams and other surface waters (Graff et al., 2005; Sexton et al., 2010).

Recent developments in remote sensing technology provide geospatial data that can be used to assess the effectiveness of conservation practices at watershed and/or landscape scales. To demonstrate this capability, ARS scientists at West Lafayette, IN, used an object-based image analysis approach with Landsat-5 thermal imagery from 2005, and thematic layers of streams, to quantify conservation buffers and grasslands in the Cedar Creek Watershed (CCW) in northeast Indiana. Land cover data were used in the SWAT hydrologic model to assess the impacts of vegetative conservation practices on total P (TP) loads, and the model was calibrated and validated for discharge and TP loads in the CCW. In general, stream flow and TP loads were modeled within acceptable statistical ranges for the total contributing area of two nested catchments within the upper CCW. Compared to no practices, vegetative buffers of 30.5 and 61 m, combined with conservation grasslands generated from the 2005 Landsat imagery, resulted in large reductions in TP loads, but conservation grasslands alone reduced TP loads by less than 2%. These findings demonstrate that the improved representation of vegetative conservation practices in geospatial land cover data sets, combined with hydrologic modeling, enables a more effective assessment of the impacts of conservation buffers and grasslands on water quality (Larose et al., 2011).

ARS scientists at West Lafayette, IN, applied the AnnAGNPS model in the Cedar Creek Watershed (CCW), a main tributary of the St. Joseph River that is the source of drinking water for the city of Fort Wayne, IN. Modeled flow discharge for both the CCW and agricultural drainage ditch sites representing sub-watersheds within the CCW, were well matched with observed values during model calibration and validation. For atrazine concentrations in runoff water, the AnnAGNPS model was satisfactorily calibrated and validated for predictions of atrazine concentrations in the agricultural drainage ditches, but not in the CCW, where only coarsely measured data were available. This work indicates the need to first identify the proper scales at which a water quality model can be calibrated and validated, before an assessment can be made of the effects of conservation practices (Zuercher et al., 2011).

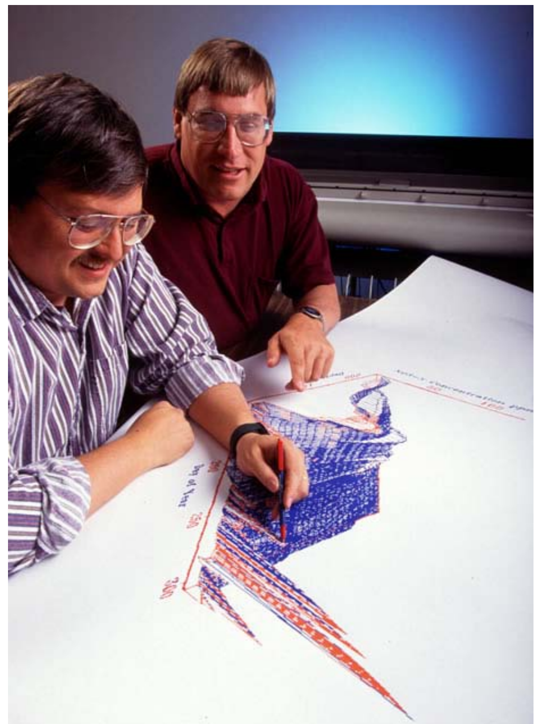


Watershed and channel computer simulation models help scientists identify sediment-producing sources. Here, agricultural engineer Ron Bingner (left) and hydraulic engineer Eddy Langendoen study data generated by a model.

ARS scientists at Beltsville, MD, used the AnnAGNPS model to assess the specific effectiveness of cover crops in protecting water quality in the Choptank River Watershed in Maryland, which drains into Chesapeake Bay. Increases in cover crop acreage resulted in significant reductions in N loads. Increasing cover crop implementation from 40 to 70 % increased N reductions by 58%. Validating predicted N load reductions by examining changes in N loads in the Choptank Watershed following cover crop implementation would increase the confidence in AnnAGNPS and similar models for helping land managers and policy makers make decisions on conservation practice selection, and associated landowner incentives, to reduce nutrient loads into the Choptank River and ultimately the Chesapeake Bay (Sadeghi et al., 2007).

New watershed models are needed that can assess the outcomes of implementing conservation practices at multiple spatial scales and also be customized to regional processes and concerns. ARS scientists and Colorado State University personnel in Fort Collins, CO developed the component-based AgroEcoSystem-Watershed (AgES-W) watershed model running under the Object Modeling System Version 3 framework (OMS3). AgES-W has a multi-flow direction routing scheme for improved transfer of water and chemicals between land units and stream reaches, and contains verified modular components for water balance, infiltration, groundwater recharge, runoff and stream flow dynamics, erosion, nutrient cycling, and plant growth. The model was used to evaluate runoff and stream flow on the CEAP benchmark Cedar Creek Watershed (CCW) in northeastern Indiana, USA, and is now being used for evaluating nitrogen and sediment transport in the CCW. Due to its spatial and temporal simulation capabilities, AgES-W has the potential to better quantify conservation impacts on water quantity and quality at field to watershed scales (Ascough et al., in press).

For both conservation and biofuels assessment needs, simulating the growth and yield of grasses requires an accurate, realistic simulation model that describes various grass types as well as competition among species in complex grass mixtures. ARS scientists at Temple, TX, improved the Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) model for the major commercial grass species and several common native grasses, including major grasses proposed for use as biofuel feed stocks. The efforts involved field measurements to determine leaf area per unit land area for each species, optimum leaf nutrient concentrations, and the efficiency with which each grass species converted sunlight into biomass. Through these investigations, appropriate equations were developed for switchgrass cultivars in both Texas and the Upper Midwest, and then validated against data from a wide range of latitudes, from Texas to North Dakota and Wisconsin. These new equations provide realistic simulations of grass growth and productivity for a wide range of soils and climatic conditions. The model is currently being used by the Department of Energy (DOE) and university scientists to assess potential biofuel productivity and natural resource sustainability of grasslands across the U. S. (Johnson et al., 2010; Johnson et al., 2011).



Computer specialist Ken Rojas (left) and range scientist Jon Hanson use the Root Zone Water Quality Model (RZWQM) to examine nitrate distribution in a simulated soil profile. The model enables scientists to forecast potential environmental pollution, such as from excessive nitrate leaching.

Nitrogen (N) losses from agricultural lands represent a serious water quality problem in many areas of the U.S., including the Mississippi River Basin and the Chesapeake Bay. To further support regionalized watershed model development, field-scale model evaluation is needed to quantify the effects of cover cropping, water table and N management, and other management practices under tile drainage conditions. ARS scientists at Ames, IA, and Fort Collins, CO, calibrated a hybrid of the Root Zone Water Quality Model (RZWQM) and the Decision Support System for Agrotechnology Transfer (DSSAT), to simulate a rye winter cover crop in a corn-soybean rotation, testing the ability of the coupled RZWQM-DSSAT model to simulate the effects of cover crops on nitrate leaching losses in subsurface drainage waters under a corn-soybean rotation. When simulations were run at various N-fertilizer application rates using a long-term climate record, results showed that the percentage reduction of nitrate in tile drainage due to the cover crop remained relatively constant over a wide range of applied nitrogen rates. This analysis suggests that rye winter cover crops can reduce nitrate in tile drainage waters, even at relatively low nitrogen application rates. Accurate quantification of the nutrient removal potential of various cover crops could be linked to nutrient credit trading scenarios, to foster the adoption of conservation practices aimed at improving water quality (Li et al., 2008; Qi et al., 2011a).

Current soil and water conservation programs consist primarily of compensating farmers for implementing pre-defined best management practices without considering their site specific cost-effectiveness. Performance-based incentives, an alternative approach, consists of payments attached to a specified environmental performance, such as the reduction in nutrient loss from a field or the reduction in stream loading at the mouth of a watershed. Performance evaluation requires the definition of a performance measure used to calculate the payments. To enable rational comparison of this approach with conventional approaches, an ARS scientist from Columbia, MO, collaborated with scientists from several universities to characterize performance measures adopted or considered by watershed stakeholders in several states, and to identify the issues related to the selection of a measure: the scale at which the performance is measured; modeling versus monitoring; and feedback to the farmer. Performance measures can then be integrated in decision support tools for implementing practices where they are most cost effective. Watershed managers, policy makers, and extension agents can consider this information to make informed choices among proposed approaches toward improving water quality in streams affected by agricultural nonpoint source pollution (Winsten et al., 2011).

Developing environmental models and tools for natural resource conservation is both expensive and time consuming; environmental modeling frameworks (EMFs) help facilitate this process. ARS scientists and their collaborators at Fort Collins, CO, released the Object Modeling System (OMS) 3.1 EMF which includes numerous improvements and better methodology for developing and connecting science components in FORTRAN. A new Cloud Services Innovation Platform (CSIP) was developed to run large and complex environmental models quickly and remotely, with OMS as the underlying modeling vehicle. The Revised Universal Soil Loss Equation 2 (RUSLE2) model was successfully tested as a cloud computer application under CSIP. The US Army Corps of Engineers (COE), the USGS, and university partners are currently developing and implementing models under the OMS. Ongoing work with these modeling applications has shown the scientific usefulness (environmental modeling using cloud computing) and economic efficiency (cost reduction for model development) of the OMS approach (David et al., 2010).

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Problem Area 2: Irrigation Water Management

Agricultural producers depend on the availability of surface and groundwater to supply irrigation needs and mitigate drought. While just 17 % of all harvested cropland in the U.S. is irrigated, these lands contribute over 40 % of our food supply, including the majority of high market value crops such as fruits, nuts, and vegetables. Improving the efficiency of irrigation practices can increase the availability of water for other uses (urban, industrial, ecosystem, recreation, and the environment). Irrigated areas of the United States have grown from 7.8 million acres in 1900 to 56.6 million acres in 2007. About 42 million acres of irrigated land are in the 17 western States, with the remaining 14 million acres in the humid East. The East is experiencing faster growth in irrigated acreage than any other region, having gained almost 190,000 acres annually from 1997 to 2007. As demand for biofuel feedstock increases, there will be increasing pressure to produce more food on less land using irrigation technologies. The increased demand for water from all sectors leads to an emphasis on producing more ‘crop per drop’, while increasing the efficiency of irrigation practices. Climate change induced variations in precipitation and snowmelt will also foster a greater need for more efficient methods to trap, store, and deliver the water needed for irrigation.

Theme 1: Managing and scheduling irrigation for efficient water use

While irrigation provides the needed water for crop production, developing techniques for efficient use of irrigation water, especially in areas where water scarcity threatens the livelihood of society, is an urgent priority. Working under the Irrigation Water Management Problem Area, ARS scientists have developed real-time sensing technology that can be used to schedule irrigation events. These types of research are helping farmers and irrigation water district managers to decide when and how much water to apply to minimize the waste.

The selected accomplishments are associated with Product 1: Quantification of evapotranspiration (ET) and crop coefficients under all constraints, including partitioning of ET components, regional variations, effects of tillage/irrigation methods, incomplete canopies, and deficit irrigation; Product 2: Remote sensing tools for ET and water stress predictions for field and farm district levels; and Product 3: Irrigation scheduling tools for humid and sub-humid regions, including crop coefficients, plant stress indicators, soil water sensing, and a rice automation/feedback irrigation system.

Selected Accomplishments under Theme 1 of Problem Area 2

For both irrigated and dry land agriculture, accurate knowledge of soil water content is the key to efficient water management, but existing soil water sensors do not work well under all conditions. ARS scientists in Bushland, TX, led an international team convened by the International Atomic Energy Agency, to assess the accuracy and utility of the major types of sensors, and to produce a book, 'Field Estimation of Soil Water Content: A Practical Guide to Methods, Instrumentation, and Sensor Technology,’ for use by irrigation and natural resource managers, scientists, and engineers. The guide indicates which sensors are useful under which soil conditions. New knowledge about sensor problems in common soil conditions, used to develop improved sensors, has been transmitted to the Irrigation Association to guide sensor evaluation in the Smart Water Application Technologies program approved by EPA. Sensor manufacturers have requested assistance in solving problems with the sensors. Efficient water management can save irrigation costs and conserve valuable groundwater resources without putting crop yields and profits at risk (Evett et al., 2008; Evett et al., 2009).

The ability to map evapotranspiration (ET) and soil moisture availability via satellite has broad applications in monitoring drought and consumptive water use, administering irrigation projects, predicting local and regional water demand, and in providing important boundary conditions to hydrological and weather forecast models. Recent advancements in thermal infrared (TIR) cameras mounted in small aircraft and unmanned aerial systems have allowed researchers to assess crop response to irrigation and winter cover crop management at the field scale, while modeling and data acquisition systems that integrate weather satellite observations provide global scale coverage. ARS scientists in Beltsville, MD, and Tifton, GA, have developed algorithms that relate real-time thermal measurements acquired from satellites or unmanned aircraft to crop water needs and crop production projections in both irrigated and rain-fed agricultural landscapes. Compared to traditional and more time intensive methods of assessment, TIR data acquired from unmanned aerial systems are more sensitive to crop response and microclimate conditions. In combination, the practical implications of this research, including mitigation of in-season crop stress, improved irrigation strategies, and an assessment of their landscape-level effects on crop productivity, lower grower risk, increase potential water savings, and reduce nitrogen losses from agricultural fields (Sullivan et al., 2008; Anderson et al., 2011).

Despite the advantages of thermal infrared TIR remote sensing in detecting crop water stress, cloudy skies, infrequent images, and/or coarse data resolution exacerbate the implementation of remote sensing image data into farm-scale routines. ARS scientists in Maricopa, AZ, demonstrated that these problems can be reduced by combining spatially-oriented remote sensing data with time-oriented land surface temperature data from fixed ground-based sites. This combined data approach can reasonably forecast crop ET up to 10 days in advance without additional remote sensing data. This information is valuable for scientists and engineers involved in developing decision support tools for improving irrigation efficiency and effectiveness (French et al., 2009).

Recent agricultural statistics reports indicate that the majority of farming households have computers and internet access, creating an environment in which web-based technology transfer is possible. From its inception, the Ogallala Aquifer Program has had a presence on the worldwide web (www.ogallala.ars.usda.gov). National and international news organizations use information from the Ogallala Aquifer Program web site to create mass media stories on the potential impacts of declining water levels in the Ogallala Aquifer on agriculture world-wide. One story by "The Telegraph", a United Kingdom publication, was picked up by several news services in the U.S. and can be found at (http://www.telegraph.co.uk/earth/8359076/US-farmers-fear-the-return-of-the-Dust-Bowl.html). A second story, produced by CNN, can be found at (http://www.cnn.com/video/#/video/us/2011/03/29/pkg.marciano.dust.bowl.cnn?iref=allsearch). The CNN story was broadcast by local TV stations in both Lubbock and Amarillo, TX. These popular press stories have increased the visibility of the Ogallala Aquifer research program, the problems of aquifer decline and drought in general, and the positive impact of the OAP in helping to find solutions to these problems.

In the northern Texas High Plains, where irrigation accounts for 90% of all water use, accurate and representative water use estimates are needed to sustain agricultural production. In collaboration with Texas AgriLife researchers, ARS scientists at Bushland, TX, updated and improved data on plant and evaporative water loss (ET) from the Texas High Plains ET Network (TXHPET), using these data to estimate water use and irrigation water demand for all crops grown in the Texas Panhandle. The ET data are used with Farm Service Agency crop acreage data and precipitation on a county basis to run the Texas A&M–Amarillo (TAMA) irrigation demand model, modified to include new crop categories and yearly and forecasted ET data inputs. These new estimates reflect both regional production potential as well as actual reductions in water use by producers using new and improved irrigation management techniques. They are used by regional water planners for water demand planning purposes, by water conservation districts for establishing groundwater pumping regulations, and for regional socio-economic and sustainability analyses (Farahani et al., 2007; Ko et al., 2009; Marek et al., 2010).

Over the latter half of the 20th century and the first years of the 21st, pumping to support irrigated agriculture has led to water level declines in the Ogallala aquifer, declines that have not been compensated for by natural recharge. The drawdown of this important water resource has led to questions about the long-term viability of the area's agricultural economy. To provide accurate information about the required irrigation levels for a range of crops in addition to climate and crop ET statistics for the Ogallala region, ARS scientists at Lubbock, TX, developed the Ogallala Agro-Climate Tool. By providing estimates of the water requirements of the area's major crops, this easy-to-use PC tool will help producers identify wasteful irrigation practices and conserve the water resource of the aquifer (Mauget and Leiker, 2010).

As water from the Ogallala Aquifer available for irrigation declines, farmers will need tools to help apply water as efficiently as possible and gain the most yield from the water applied. An online irrigation scheduling and management tool was developed by scientists at ARS in Bushland, TX, and Texas AgriLife, that can accommodate simple, single-field applications as well as multiple field and multiple farm uses. This seasonal planning tool evaluates alternative water management production strategies and scenarios for in-season irrigation scheduling, using either local real-time ET data or crop water use estimates, helping to reduce the over-application of irrigation waters, thereby decreasing production costs and increasing water-use efficiency (Marek et al., 2011).

In a deficit irrigation study, corn on the left side was fully irrigated while that on the right received only half as much water and produced about half as much corn.

Deficit irrigation is a management method to conserve water and energy by supplying only the amount of water necessary to meet crop demands. ARS scientists at Parlier, CA, used thermal infrared sensors to measure canopy temperatures as an indicator of drought stress in a peach orchard. Average maximum canopy temperature was significantly higher for treatments that received deficit drip and furrow irrigation than for those receiving full irrigation. Despite these higher temperatures, deficit irrigation saved over 50% of the water used with no significant impact on peach yield or quality. This study clearly demonstrates that infrared canopy sensors can be used as an onsite guide for managing deficit irrigation in orchard crops (Wang and Gartung, 2010).

Theme 2: Innovative surface and subsurface irrigation tools and techniques

Irrigation water management tools for both surface and subsurface deliveries are necessary to achieve maximal irrigation efficiency. For example, ARS scientists working on irrigation water delivery have found a way to automatically control the hydraulic gates along an irrigation canal to minimize water spills.

These selected accomplishments are associated with Product 4: Management tools, practices, and new technologies to make irrigation and water delivery systems more dependable, flexible, and efficient; and methods to quantify the impacts of these practices at field, farm, project, and watershed scales, including irrigation efficiency evaluation. Some accomplishments selected under this theme, for work done in humid regions (i.e., Dawson, GA; Florence, SC; and Portageville, MO) are also associated with Product 3: Irrigation scheduling tools for humid and sub-humid regions, including crop coefficients, plant stress indicators, soil water sensing, and a rice automation/feedback irrigation system.

Agricultural engineers Susan O'Shaughnessy and Nolan Clark adjust the field of view for wireless infrared thermometers mounted on a center pivot irrigation system. The wireless sensors are used to measure crop canopy temperature for indications of water stress.

Selected Accomplishments under Theme 2 of Problem Area 2

Corn is a major irrigated crop in the U. S. Great Plains. Because corn has a large irrigation requirement, efficient and effective irrigation technology is important. ARS scientists at Bushland, TX, compared corn production under mid-elevation spray irrigation (MESA), low-elevation spray irrigation (LESA), low-energy precision application (LEPA), and subsurface drip irrigation (SDI) at five irrigation rates during the 2009 and 2010 growing seasons. In 2009, grain yield and water use efficiency were significantly greater for SDI as compared to MESA and LESA at the 50 and 75% irrigation rates. In 2010, a more typical year in terms of rainfall, there were no significant differences in grain yield and water use efficiency for MESA, LESA, and SDI for all irrigation rates. In the Southern Great Plains, SDI can reduce corn yield losses during dry years (Colaizzi et al., 2010).

In the southeastern U.S., the effects of various irrigation rates and crop rotations irrigated with SDI on long-term cotton yield are poorly known. ARS scientists at Dawson, GA, installed an SDI system in 1998, and maintained it over the next 10 years. The project consisted of three crop rotations, two drip tube lateral spacings, and three irrigation levels. Crop rotations had either one year (cotton-peanut), two years (cotton-maize-peanut), or three years (cotton-maize-maize-peanut) between cotton plantings. Drip tube laterals were installed underneath each crop row and under alternate crop row furrows. Crops were irrigated daily at 100, 75 and 50% of estimated crop water use. Lint yield did not differ significantly as a function of crop rotation. In 4 out of 8 years, significant differences in lint yield occurred in response to irrigation treatments. In 3 out of 4 years when compared with the 100% irrigation treatment, lint yields were significantly greater when cotton was irrigated at the 75%, as compared to the 50%, level. Higher lint yield with irrigation also coincided with lower seasonal rainfall totals. Drip tube lateral spacing affected lint yield in 4 out of 8 years. Across all years, alternate row middle lateral spacing was as effective as every-row lateral spacing. Some fiber qualities were affected by irrigation, lateral, and rotation treatments, but these effects were small and inconsistent. For SDI, the recommendation would be to irrigate cotton using the 75% irrigation level, and with tubing in alternate row middles (Sorensen et al., 2010).

Technician Ernest Yoder checks waterflow instrumentation on a subsurface drip irrigation system used for peanuts, cotton, and corn crops.

In the eastern US, land application of animal waste from livestock treatment systems is both an environmental and a social concern. ARS scientists in Florence, SC, evaluated the potential of using a SDI system for the application of animal waste effluent to bermudagrass hay. Plots receiving treated effluent had significantly greater hay yields than plots supplied with recommended levels of inorganic fertilizer. Moreover, effluent-treated plots had significantly greater nutrient biomass removal than the commercial fertilizer plots. The higher plant nutrient removal prevented adverse impacts on soil or water quality (Stone et al., 2008).

A method was needed to help cotton farmers in the US Mid-South decide when to stop irrigating their crops: stopping too soon resulted in lost yield; stopping too late produced no additional yield and complicated harvest. An ARS scientist in Portageville, MO, analyzed suitable irrigation termination dates during the 2000 through 2007 growing seasons in furrow irrigated Mid-South cotton fields. While data from the southernmost fields proved too variable to serve as the basis for new guidelines, the resulting functions for the northern portion of the Mid-South were determined to be suitable for developing recommendations. The derived equations can be used to determine the timing of the last profitable irrigation for a known lint price and diesel cost, allowing the producer to react to his or her own individual situation. These results can benefit farmers by eliminating the time and expense associated with unnecessary irrigation, while everyone will benefit from the water that is conserved (Vories et al., 2007).

Because irrigation is a major water use in semiarid regions, efficient water delivery systems are critical to water conservation for agricultural and other uses. Water delivery is either controlled upstream by measuring differences in inflows and outflows, or by flow measurements made downstream. Upstream control can result in operational spills; downstream control can be difficult to implement in practice because of long travel times from the water source to the main canal, constraints imposed by the water supplier, or because inflow rates are determined by river flow, which is variable. ARS scientists and engineers at Maricopa, AZ, developed a method to distribute flow mismatches over the canal length by equalizing water level errors for all canal pools. Essentially a combination of upstream and downstream control, this strategy promises to facilitate automated canal operations, providing a more flexible and accurate water supply to irrigators while reducing operational spills. The strategy has been implemented via the Software for Automated Canal Management (SACMAN) program to facilitate the operation of control gates along the irrigation canal (Clemmens and Strand, 2010; Clemmens et al., 2010; van Overloop et al., 2010).

As measured by the ratio of the amount of water used by a crop versus the amount delivered to the field, the performance of surface irrigation, the prevalent method of on-farm water application both in the U.S. and worldwide, typically is low. To improve performance, ARS scientists at Maricopa, AZ, developed a surface irrigation software program (WinSRFR) that uses hydraulic engineering principles to more effectively manage irrigation system design and operation. The program analyzes field evaluation data, estimates field infiltration properties from these data, analyzes design alternatives, optimizes operations, and conducts simulation studies. Current users include university extension agents, farm advisors, irrigation consultants, irrigation specialists, and the NRCS (Bautista et al., 2009c; 2009d).

At the Central Arizona Irrigation and Drainage District, hydraulic engineer Bert Clemmens (left) and electrical engineer Bob Strand assess the automatic control of one of the many hydraulic gates operated by ARS-developed software while student Matt Robbins (background) checks the communications.

Computer-based, automatic control is a promising technology for regulating water levels upstream from check structures in irrigation canals. Complicated unsteady-flow simulation studies and field tests have been used to build a model that represents the canal response to control inputs. In cooperation with scientists at Montpellier, France, and the Delft University of Technology, The Netherlands, ARS scientists in Maricopa, AZ, developed a procedure for determining a response model for an upstream Proportional-Integral controller based on canal geometry. A method was also developed to tune the controllers for gates in series to avoid problems caused by the interaction between adjacent controllers. This research will help irrigation district personnel and consultants develop upstream controllers without the need for sophisticated computer modeling (van Overloop et al., 2010).

WinSRFR optimizes design of gravity irrigation systems for best water use efficiency.

In surface water irrigation, radial gates are used primarily to control and measure the flow of water in irrigation canals. Radial gates require field calibration, which can lead to inaccurate flow predictions. High costs often prevent irrigation districts from investing in modern flow measurement technologies, resulting in the need for better measurement techniques using existing gates. ARS scientists in Maricopa, AZ, developed new calibration procedures for the new computer program, “Wingate”, developed by cooperating scientists at the U.S. Bureau of Reclamation (USBR), Denver, CO. The USBR will provide this software to cooperating irrigation districts and consultants, improving their ability to accurately measure and distribute water to users (van Overloop et al., 2010; Clemmens and Strelkoff, 2011; Bautista et al., 2010; Perea et al., 2011)

Theme 3: Improved irrigation and cropping for reuse of degraded water

In regions with the limited water supplies, using recycled or treated water for agricultural production is becoming a necessity. ARS scientists at California and Arizona have been developing production systems or identifying crops that can use recycled water for economic benefit. One success story is the identification of plants that can: 1) sequester selenium from the soil; 2) be used for bio-fuel production; and 3) be used for selenium enriched feed after the oil extraction.

These selected accomplishments are associated with Product 5: Guidelines for irrigating in urban and agricultural settings with degraded waters, and models and decision support systems for management of treated municipal wastewaters and other degraded waters in irrigation, including tools for determining the fate and transport of emerging contaminants and pathogens; and Product 6: New and improved crops that use degraded waters and/or phytoremediate soils, including identification of related biological components, and development of breeding lines and experimental germplasm.

Selected Accomplishments under Theme 3 of Problem Area 2

To support sustainable drainage water reuse, ARS scientists in Parlier, CA, identified various plant species, including poplar tree clones, capable of growing in the WSJV of California, in areas with underlying poor water quality due to high selenium concentrations. Annual poplar tree cuttings served as feedstocks for gasification. Within the same drainage-water management system, oil-plant species can produce 1.5 tons of seed/acre as bio-based product that provides economic value for the grower (e.g., bio-fuel and Se-enriched feed products, after extracting the oil from seeds with an on-site press). These studies illustrate ways to use an agronomic-based system as part of an overall drainage-water reuse strategy. Such a system could find widespread usage in portions of central California where selenium toxicity is an issue (Banuelos, 2009; Banuelos and Dhillon, 2011).

Use of recycled water for the production of ornamental crops helps to conserve scarce fresh water supplies in arid regions. In cooperation with scientists at the University of California, Riverside, ARS scientists in Riverside, CA, evaluated the yield and quality of 5 landscape species—boxwood, escallonia, hawthorn, hibiscus, and juniper—grown under greenhouse conditions as container plants and irrigated with Cl-dominated waters at 6 salinity levels. Based on growth and aesthetic quality data from two separate experiments, species were ranked according to their suitability for salt-affected landscapes. The overall ranking was: hibiscus >

juniper > escallonia > hawthorn > boxwood. This research provides nurserymen, home gardeners, and landscape professionals with needed criteria for selecting ornamental species suitable for salt-affected landscape sites (Valdez-Aguilar et al., 2011).

To assist landscape professionals, growers, and home gardeners in managing salinity in recycled irrigation waters, ARS scientists at Riverside, CA, in collaboration with researchers at the University of California, Davis, developed a Salt Management Guide. The guide and accompanying CD include an extensive list of plant species suitable for water reuse systems, ranging from relatively non-saline settings to salt-affected problem sites. The product provides: 1) information on public health aspects and regulations on use of Title 22 waters and their suitability for landscape irrigation relative to plants, soil properties, and irrigation application systems; and 2) information to educate the public about safe use of recycled water and its value in helping to address current and future shortfalls in potable waters (Grieve et al., 2007).

Due to its high alkalinity (pH >12), odor, and the presence of hydrophobic organics, disposal of wastewater from processing plants that extract latex from guayule is problematic. ARS scientists at Maricopa, AZ, determined that up to 50% of this wastewater could be recycled within the processing plant without affecting latex recovery. Treating the resulting wastewater with acid followed by sedimentation removes the odor and the hydrophobic organics and lowers the alkalinity. Because it contains both nitrogen and potassium, the treated wastewater has the additional benefit of being useful as a fertilizer. Overall, the process increases the economic viability of domestic latex and rubber production (Coffelt and Williams, 2009).

Using marginal waters and treated wastewaters for irrigation increases the need for accurate water quality criteria. ARS scientists in Riverside, CA, used results from new field and laboratory experiments to revise earlier water quality criteria, now relating infiltration hazard to pH, SAR (sodium adsorption ratio), and salinity, and replacing earlier FAO criteria that did not consider pH and underestimated the adverse impacts of low SAR on water infiltration. New guidelines related to infiltration hazard are now also provided for environments where rainfall is a contributor to the water budget. Results from this work provide water quality specialists, water planners, regulatory agencies, and producers with the improved ability to evaluate the infiltration hazards associated with the application of irrigation waters based on their chemical composition. The improved guidelines -ensure safer use of saline waters for irrigation and thus extend the supply of water resources available for agriculture (Suarez, 2011).

Boron is a specifically adsorbing anion that can be detrimental to plants at elevated levels. Thus to avoid B toxicity for agricultural crops, there is a need to accurately characterize B pools in soil. Release of native adsorbed B has been reported to be a significant source of soluble B in arid land soils. ARS scientists in Riverside, CA, established that most B release is due to desorption rather than mineral dissolution. Thus producers do not have to be concerned about the regeneration of soluble B and its potential toxicity after leaching to below toxic levels. This research is important for managing and controlling soluble B in regions with high native soil B, such as commonly occur in the arid southwestern U.S (Goldberg and Suarez, 2011).

Theme 4: Sensor technologies for site specific irrigation water management

The concept behind precision agriculture, where real-time sensing and application technology have been developed to guide fertilizer and pesticide applications under spatially varying field conditions, can also be applied to irrigation. The selected accomplishments reported below are associated with Product 7: Systems for spatially and temporally variable water, nutrient, and pesticide application based on soil-crop sensing and feedback.

Selected Accomplishments under Theme 4 of Problem Area 2

As an indicator of crop water stress, infrared thermocouples (IRTs) have proven very reliable for remote measurement of crop canopy temperature. However in commercial systems, it would be cumbersome for a grower to set up, maintain, and dismantle wired IRTs each irrigation season. ARS scientists at Bushland, TX, developed a wireless sensor that interfaces an IRT via a radio module, to sample, average, and send data to an embedded computer at the irrigation center pivot. Wireless IRTs and spectral radiometers mounted on a moving sprinkler system monitor within-field crop water stresses, eliminating problems and costs associated with deploying and maintaining wired sensors. This technology improves automatic irrigation scheduling, resulting in more reliable, more accurate, and more efficient site-specific water applications, with greater associated savings in agricultural water use (O'Shaughnessy et al., 2010; 2011),

Computer-controlled center pivot irrigation systems can be connected by modem to radios or telephones so farmers can run them remotely.

Existing soil water sensors are of two types, those using electronic oscillators and those using electronic pulses. ARS scientists at Bushland, TX, demonstrated that the class of sensors that uses electronic oscillators, also called capacitance sensors, are ill suited for accurate soil water content measurement because they're affected by soil structure, bulk electrical conductivity due to clay content and salinity, and temperature. They also showed why sensors that use electronic pulses, also called time domain reflectometer (TDR) sensors, are fundamentally less affected by those interferences and are inherently better suited for accurate measurement. Proceeding from this knowledge, they developed calibration equations for TDR sensors that reduced the remaining interference effects to negligible levels. The calibrations are being used by a sensor manufacturer to produce a new class of down-hole soil water content sensors for agricultural production and environmental management applications (Schwartz et al., 2009a; 2009b).

In regions with limited water supplies, irrigation systems that apply water to crops based on plant demand are needed to increase water use efficiency. ARS scientists at Bushland, TX, developed, constructed, and tested an automated moving sprinkler irrigation system using a wireless control system. The system is designed to work on a six-span, center pivot, sprinkler irrigation system, but can be adapted to any pressurized irrigation system, including drip irrigation. Automatic irrigation scheduling can aid farmers in decreasing water use, while improving time management and decreasing energy costs and greenhouse gas emissions (Peters and Evett, 2008; O'Shaughnessy and Evett, 2010).

Aerial view of fields in central California (western San Joaquin Valley) suffering from severe salinization.

Field-scale monitoring and mapping of soil salinity with mobile geophysical techniques is based on statistical sampling strategies that use geospatial measurements of apparent soil electrical conductivity (ECa) as a surrogate for characterizing spatial variability in soil salinity. Design-based sampling strategies, such as stratified random sampling and unsupervised classification, are commonly used, but a model-based sampling strategy (i.e., response surface sampling design) offers the advantage of minimizing the sampling requirement. ARS scientists in Riverside, CA, compared model- and design-based sampling strategies for characterizing the spatial variability of soil salinity with ECa-directed soil sampling.

Implementation of this sampling design would facilitate more rapid and less costly salinity mapping, benefiting producers and irrigation districts that utilize mobile geophysical techniques (Corwin and Lesch, 2010; Corwin et al., 2010; Allred et al., 2011).

Theme 5: Cropping and management strategies under limited water supplies

Improving water use efficiency can be approached in two ways: 1) by improving water delivery through better scheduling or more efficient delivery; and 2) by changing the cropping systems and management practices.

The selected accomplishments on alternative cropping and management strategies under limited water supplies are associated with Product 8: Tillage, irrigation, and crop management practices (including amendments and residue management) will be developed to improve crop water use efficiency in rainfed/irrigated cropping systems.

Selected Accomplishments under Theme 5 of Problem Area 2

For agricultural producers in the U.S. southern High Plains, rising energy costs for pumping the diminishing water resources from the Ogallala Aquifer are a major concern. ARS scientists in Bushland, TX, used calculated growing season energy and potential planting dates to show that in 91 of 131 counties in the panhandle regions of TX, OK, and southwestern KS, switching from corn to early-maturing cotton varieties would save both water and energy costs, thereby improving economic returns (Gowda et al., 2007). In-season yield of forage sorghum (1,700 g m^{-2}) was less than corn for silage (2,400 g m^{-2}), but sorghum had 27 % lower ET per unit of dry matter produced. As pumping costs escalate and aquifer water availability decreases, sorghum is an attractive alternative to corn for silage in the Southern High Plains. However, because corn yields and respective economic returns increase at a higher rate than with sorghum, corn for silage would be the preferred alternative if water were not a limiting factor. These findings help growers make informed decisions as they weigh options that vary in both profitability and risk (Piccinni et al., 2009).

Conservation tillage and residue management have been credited with increasing yields of dryland crops, but these principles have not been adapted to deficit irrigation strategies. For irrigation capacities of 2 to 4 gallons of water per minute per acre, ARS scientists at Bushland, TX, found that from 2006 to 2009, cotton lint yields increased by over 300 pounds per acre when a no-till regime was imposed compared to disking. These results indicate that crop production under deficit irrigation could benefit from conservation tillage practices (Baumhardt et al., 2008; 2009).

In irrigated potato production systems, potatoes are planted in ridge-rows. The deep furrows between the ridge-rows are needed for drainage under rain-fed conditions, but also function to drain water under modern sprinkler irrigation. During the past three years, ARS scientists in Kimberly, ID, cooperated with private industry and potato producers to demonstrate the advantages of bed-planted potatoes on more than 10,000 acres of Idaho farmland. Side-by-side field comparisons of potatoes planted in conventional ridge-rows versus 12-foot wide, five-row beds have shown that bed-planting potatoes can decrease irrigation water use 5 to 15%, with equal or increased potato yield (King et al., 2011; Tarkalson et al., 2011).

Producers in southwest Kansas are considering cotton as an alternative crop to conserve water while maintaining economic sustainability. Field research by ARS and Kansas State University scientists demonstrated the feasibility of growing cotton in southwest Kansas. Cotton lint yields average 2.5 bales per acre on 5 to 7 inches of irrigation. The greatest limitations to cotton production were: 1) total growing degree days; and 2) hail damage. These results indicate irrigated cotton as an alternative crop with a lower water demand for this region (Esparza et al., 2007).

To maximize water use efficiency and conserve water, management practices must be adapted to minimize soil water evaporation, a process that is not yet fully understood. ARS scientists at Bushland, TX, measured evaporation in bare soil columns of undisturbed clay loam, silt loam, or fine sand, and in a fine sand cropped to sunflower. When irrigation application exceeded 1.2 inches, evaporation from bare silt loam and clay loam soils was greater than from a bare fine sand soil. Soil water evaporation determined beneath a sunflower canopy averaged about 0.2 inches, which was 25% of total ET. Soil evaporative losses can be significant even when a growing crop is present. To decrease evaporative losses, irrigation should be deeper and less frequent on heavier soils (Tolk and Evett, 2009; Tolk and Howell, 2012).

Michael Bartolo (left) and Ardell Halvorson examine onions in drip-irrigated research plots at the CSU Arkansas Valley Research Center.

To appropriate sufficient amounts of water for new dairies, or to mitigate the effects of existing dairies, water managers need to know how much water is consumed on dairy farms in water-limited areas. ARS scientists at Kimberly, ID, measured water use for one year on six dairy farms in southern Idaho. The average amount of groundwater pumped from wells on the farms was 60 gallons per day per milk cow. Subtracting the amount of wastewater produced on each farm that was used for irrigation reduced the net groundwater use to 30 to 40 gallons per day per milk cow. When calculated on an area basis, these dairy farms used less than 2 ft of water, which is similar or less than irrigated cropland in southern Idaho (Lentz et al., 2011).

Water use efficiency of wheat infected with wheat streak mosaic (WSM) virus in the fall is low. To ensure that water from the Ogallala Aquifer is used as efficiently as possible, irrigation needs to be adjusted according to both crop abiotic and biotic stress levels, as well as its yield potential. In cooperation with Texas AgriLife Research, ARS scientists at Bushland, Texas, conducted experiments in a producer's field (natural infection) and in experimental plots (artificial inoculation). In the producer's field where WSM infection occurred naturally, water use efficiency increased as WSM severity declined. In experimental plots, where wheat was artificially inoculated with WSM virus, water use efficiency of wheat infected in the fall was low. Results suggest that wheat infected with WSM in the fall should not be irrigated in the spring. Following this protocol could result in considerable savings of water, fertilizer, and pumping costs (Price et al., 2010).

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Problem Area 3: Drainage Water Management Systems

Specific guidelines and tools are needed for nutrient and pesticide management in both surface and subsurface drainage water management systems. Automation of these systems, including the integration of weather forecasts, could enhance water conservation benefits during short-term drought periods in humid regions. Long-term soil quality improvement, increased water availability (quantity and quality), and wildlife benefits are all possible with improvements in wetland management practices. Improved drainage water management can also improve water use efficiency in irrigated agriculture while reducing the long-term effects of salinity and trace elements under different cropping systems. The combined effects of improved subsurface drainage water management practices and alternative cropping systems for irrigated agriculture need to be incorporated into an environmental and economic decision support system that fully evaluates the cost-effectiveness of drainage water management systems.

Theme 1: Crop production and environmental benefits of drainage water management

Agricultural drainage water, coming either from irrigated fields or from artificially drained areas to remove excess water, has been known to carry agricultural chemicals that may be harmful to the environment. Draining costly fertilizers is also an economic loss to producers. One of the goals in this problem area is to develop and improved understanding of how to manage water drainage. In cooperation with the drainage industry and university partners, ARS scientists tested an emerging technology in drainage water management to control the level of shallow ground water based on both crop production and environmental benefits.

The selected accomplishments below are associated with Product 1: Guidelines for management practices that optimize soil, water, and economic benefits associated with surface and subsurface drainage water management (DWM) systems and wetland resources in humid rainfed areas; and Product 2: Design specifications of DWM systems for environmental benefits in the Midwest and West. Theme 1 overlaps somewhat with Theme 2, which focuses on on-site treatment technology for drainage water.

Soil scientist Norm Fausey (left) discusses site conditions and design features for a drainage water management and recycling structure with drainage contractor Paul Pullins.

Selected Accomplishments under Theme 1 of Problem Area 3

Drainage water management (DWM) is a promising technology for reducing nitrate losses from artificially drained (or “tiled”) fields, but while there is an extensive history for the practice in North Carolina, little is known about the efficacy or cost effectiveness of the practice under Midwestern conditions where artificial drainage is widely used. ARS scientists at Ames, IA, used soil and land cover databases combined with modeling to estimate that 4.8 million ha of land currently used to grow corn in the Midwest would be suitable for DWM, with the potential to reduce nitrate loss by approximately 83,000 metric tons (91,300 tons) per year. Considering the cost of control structures, the redesign of new drainage systems, and the payments to farmers to adjust control structures to reduce nitrate losses, the cost per kg of nitrate removed from drainage water by DWM was estimated at $2.71 ($1.23/lb). While this is more than the current cost of nitrogen fertilizer, it represents a competitively priced alternative method for removing nitrate from agricultural drainage waters that does not involve taking arable land out of production. Both farmers and state and federal action agencies can use this information to set priorities for the expenditure of conservation funds to improve surface water quality (Jaynes et al., 2010; Thorp et al., 2008).

The eutrophication of Chesapeake Bay, caused by excessive nutrient runoff, has received significant attention. In the Choptank River Watershed, MD, excess nutrient transport from agricultural fields is primarily through extensive open drainage ditches, where on average, 6% of the nitrate applied annually may be transported to streams, rivers, and eventually the Chesapeake Bay. One of the BMPs used in these ditches is the installation of water control structures at the drainage outlet to reduce water flow and nutrient loss. Research conducted by ARS scientists at Beltsville, MD, showed that that increasing water table elevation to just below the root zone during the growing season, while lowering it during planting and harvesting operations, can reduce nitrate losses up to 40%. These findings provide quantitative efficiencies for both water and nitrate reductions, and better management strategies for more efficient use of controlled drainage BMPs (McCarty et al., 2008).

ARS soil physicist Ali Sadeghi (left) and landowner Bill Collier examine water quality in a ditch under controlled drainage management within the Choptank Watershed.

Drainage waters from agricultural lands, especially those coming from subsurface tile drains, carry nutrients that degrade the quality of downstream waters. Managing drainage system outlets during the non-growing season to reduce water and nutrient exports can both improve water quality and increase yields. In cooperation with Ohio State University researchers, ARS scientists at Columbus, OH, found that over a three year period, corn yields increased in 66 % of the fields where DWM was practiced. Increased yields should encourage producers to adopt DWM to reduce water and nutrient delivery to aquatic systems. Doing so will help improve water quality in the Gulf of Mexico, Chesapeake Bay, and Lake Erie, as well as in numerous municipal water supply reservoirs. The Natural Resource Conservation Service (NRCS) is currently using this information to develop a strategy to promote the adoption of DWM by farmers in these priority watersheds (Sadler et al., 2010; Madramootoo et al., 2007).

Flooding stress is second only to combined heat and drought stress as a major cause of economic losses to US agriculture. The most common cause of flooding stress is water ponding in fields during heavy rains, a condition that is predicted to occur more often with global climate change. Soybeans are especially sensitive to flooding stress. In cooperation with the University of Missouri, ARS scientists at Columbus, OH, made two major advances that could contribute to the improvement of soybean productivity in soils prone to flooding. One approach developed transgenic soybean lines containing an anti-senescence gene, and used a series of greenhouse experiments to compare the impacts of flooding on the productivity of transgenic and non-transgenic soybean lines. Under flooded conditions, transgenic plants generally remained green and healthy during the late pod-filling stage and produced twice the seed yield of non-transgenic plants. The second approach identified quantitative trait loci (QTL) and DNA markers associated with flooding tolerance and *Phytophthora* resistance traits in the soybean population developed by crossing a commercial soybean variety with the tolerant non-commercial soybean line PI408105A from Southeast Asia. Analysis of the progeny showed that flooding tolerance and *Phytophthora* resistance are independently inherited, and that PI408105A provides valuable gene pools for both traits. Additional studies examined the flooding responses of eight soybean genotypes that differed in levels of flooding tolerance. Flooding did not significantly affect seed protein, oil, or palmitic acid, but increased oleic and stearic acid levels in all genotypes. Levels of linolenic acid, linolenic acid, daidzein, genistein, and glycitein were significantly reduced in the tolerant and medium tolerant genotypes, but increased in the susceptible genotype. These results provide information to breeders for modeling soybean seed composition traits under flooding. This research could lead to the development of commercial soybean cultivars that are more tolerant of flooded soil conditions thereby improving soybean yields (VanToai et al., 2010; VanToai et al., 2012; Nguyen et al., 2012).

Theme 2: On-site treatment technology for drainage water

Technologies that can intercept drainage waters provide the opportunity for on-site remediation. Reported under this theme are ARS efforts in identifying materials or technologies that can be applied to treat drainage water on-site. One innovation is the use of a 'gypsum curtain' to removed dissolved phosphorus in shallow ground water before it reaches the drainage ditch. The gypsum used—a by-product from a coal burning power plant—is generated during flue gas desulfurization (the process that removes the sulfur which causes acid rain). This is an excellent example of a beneficial use of an industrial by-product.

The selected accomplishments reported under Theme 2 are associated with Product 2: Design specifications of DWM systems for environmental benefits in the Midwest and West; and Product 3: Evaluation of the advantages and limitations associated with operation of DWM systems for irrigated areas.

Selected Accomplishments under Theme 2 of Problem Area 3

The loss of P in shallow groundwater leaving fields of the Delmarva Peninsula can account for more than 90% of the P exported by drainage ditches to tributaries of the Chesapeake Bay. ARS scientists at University Park, PA, installed a curtain of gypsum (calcium sulfate) along the border of a field from which high loads of P had previously been recorded in groundwater. During the first rainstorms after installation, the new curtain (or permeable reactive barrier) removed 38-59% of the dissolved P in groundwater. Efforts are underway to expand the testing of this practice for enhancing water quality to other areas in the region (Penn et al., 2007; Penn et al., 2011).

Soil scientist Ray Bryant (left) and UMES researcher Arthur Allen collect samples of groundwater before and after it is filtered through an underground "curtain" of gypsum. Dissolved phosphorus in groundwater is reduced after flowing through this setup.

Excess nutrients and pesticides in drainage waters degrade surface water quality. Treatment of these affected waters for public distribution, commercial, and recreational use can be costly. Capturing these contaminants prior to surface water entry is a viable solution to maintain cleaner water downstream. The success of these systems depends on finding inexpensive filter materials capable of effectively and efficiently removing nutrients and/or pesticides. ARS scientists in Columbus, OH, found that some relatively new industrial products have potential as filter materials for agricultural water treatment. Tests show that porous iron composite and sulfur modified iron are sufficiently permeable to water flow to be hydraulically efficient and exhibit potential to remove substantial amounts of nitrate and phosphate from water. Porous iron composite additionally shows promise for water treatment of pesticides such as atrazine. Consequently, porous iron composite and sulfur modified iron may in the future prove valuable for reducing the adverse environmental impacts associated with agricultural subsurface drainage practices. Several commercial entities have expressed interest in this technology (Allred 2010; Agrawal et al., 2011a; 2011b).

Constructed wetlands and bioreactors have been used to remove N from drainage waters, but in sensitive water locations and under land-limited conditions, smaller reactors with even higher removal rates may be required. In these conditions, reaction chambers with immobilized denitrifying sludge (IDS) may be very useful. Using bioreactors containing IDS under field conditions, ARS scientists at Florence, SC, demonstrated that 50% of nitrate-N was removed from drainage waters during a 1 hour hydraulic retention time. For a cube-shaped bioreactor, this would translate to an N removal rate of 94 g of nitrate-N m^{-2} d^{-2}, a rate that is dramatically higher than either treatment wetlands or passive carbonaceous bioreactors. The IDS bioreactors have the potential to significantly reduce N discharge from agricultural drainage lines. They also offer a direction for future research on emerging bioreactors technology as a component of improved water quality at both watershed and basin scales (Hunt et al., 2008).

Nitrate is a widespread contaminant found in both ground and surface waters, and is often introduced into the environment via fertilizer application on farm fields. Reducing adverse environmental impacts due to nitrate requires, at least in part, a better understanding of the processes that govern nitrate mobility in soil, particularly anion exclusion. A laboratory investigation by ARS scientists in Columbus, OH, indicated that soil water ionic strength had a much greater influence than nitrate concentration on the anion exclusion processes affecting soil nitrate mobility. Results from this study can be used to improve computer models employed to predict nitrate movement through the soil profile, thereby allowing better nitrate fertilizer application management scenarios to be developed, which minimize adverse nitrate impacts on the environment (Allred, 2007; 2008; Allred et al., 2007a; 2007b).

In the arid western US, elevated concentrations of toxic elements such as selenium and arsenic are commonly found in agricultural drainage waters. Thus disposal of these polluted waters continues to be an environmental concern. ARS scientists in Parlier, CA, examined the salinity, chemical characteristics, and biogeochemistry of selenium and arsenic in drainage waters from agricultural fields, and in an evaporation basin facility used for the disposal of agricultural drainage in the Tulare Lake Drainage District. Water parameters, including redox, dissolved oxygen, dissolved Fe and sulfur species, and speciation of selenium and arsenic, were determined in water columns as well as spatially in evaporation basins. This information is critical for evaluating the potential environmental impacts of agricultural production systems where drainage disposal is required (Gao et al., 2007a; 2007b; 2007c; Herbel et al., 2007; Lin et al., 2010; Ryu et al., 2010). .

Agricultural water pollution control by drainage ditches is directly related to water residence time in the ditches, but these channels must also provide water drainage. Working with scientists from Mississippi State and Arkansas State Universities, ARS scientists at Oxford, MS, showed that low concrete weirs could be used to manage ditches for improved hydraulic residence time with minimal impacts on water drainage. Results showed that ditches with weirs reduced higher amounts of dissolved inorganic phosphate (71% vs. 66%), total inorganic phosphate (60% vs. 12%), nitrate-N (96% vs. 76%) and ammonium (-47% vs. -53%) than ditches without weirs. These results provide a foundation for future research on ditch weir design, maintenance, and the benefits of controlled drainage strategies for landowners (Kröger et al., 2011a; 2011b).

Theme 3: Tools and models for assessing impacts of drainage water management

Synthesizing research findings into tools or models to aid in making management and policy decisions is the ultimate goal of ARS' natural resource research. The selected accomplishments highlight efforts in improving the Root Zone Water Quality (RZWQM) and the Drainage Model (DRAINMOD). Although not reported here, there are also continuing efforts to improve the Soil Water Assessment Tool (SWAT) and the Agricultural Non-Point Source Pollution Model (AGNPS).

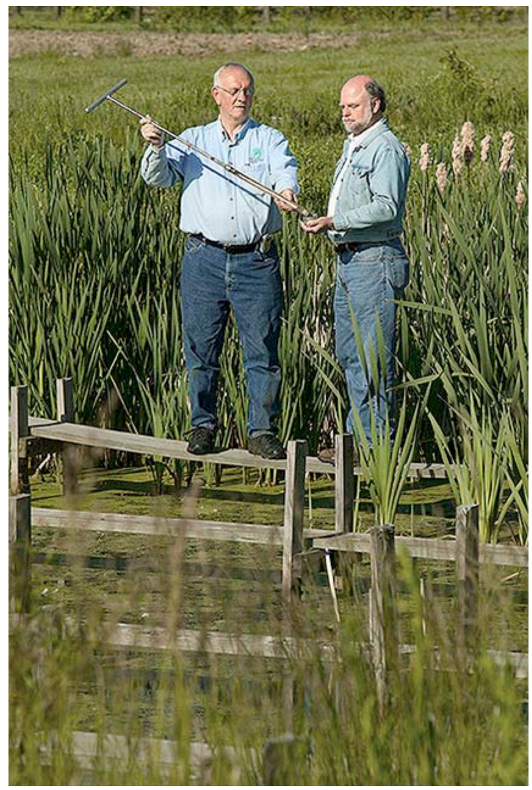
The selected accomplishments here are associated with Product 4: Decision support systems that include environmental and economic effects associated with DWM systems.

Selected Accomplishments under Theme 3 of Problem Area 3

To simplify assessing the benefits of drainage water management (DWM), ARS scientists at Ames, IA, Ft. Collins, CO, and Tucson, AZ, collaborated to parameterize and test a multiobjective decision support tool to assess economic-environmental tradeoffs. The RZWQM model was parameterized using field data from the Nashua research site and the DevTreks budgeting tool (www.devtreks.org) used quantify the effects of management on soil/slope groups and the tradeoffs assessed using the Facilitator decision support system. The approach could be scaled to become an operational N management tool integrating field measurements, expert opinion, and simulation models to more systematically address N management in tile-drained agriculture (Heilman et al., 2012).

Control of subsurface drainage can reduce nitrate losses to drain tile flow, but the effects can vary with different N application rates and weather conditions. ARS scientists in Ames, IA, and Fort Collins, CO, used the Root Zone Water Quality Model (RZWQM2) to investigate the long-term effects of controlled drainage. Changing from free to controlled drainage reduced measured annual N loss in tile flow by 12%. Long-term RZWQM2 simulations suggest that N loss might be reduced by 39% through controlled drainage and decreased N application rates, with minimal decreases in corn yield. This research will help agricultural scientists better understand the potential role of controlled drainage in reducing N losses from tile drained fields (Ma et al., 2007; Fang et al., 2011).

The subsurface drainage simulation model, DRAINMOD, developed at North Carolina State University (NCSU), is commonly used to assess different subsurface tile drainage designs. Recent upgrades to DRAINMOD (DRAINMOD-N2) have focused on the addition of water quality components for nutrient management and environmental impact assessment. DRAINMOD-N2 predicts drainage flow and nitrate loss, but lacks the needed routines to adjust for water table depth fluctuations caused by rainfall events or the lack of rainfall, during the simulated season. ARS scientists in Houma, LA, developed a water table fluctuation feedback-control subroutine for DRAINMOD, comparing the ability of the original and modified models to predict drainage volume, relative crop yield, and nitrogen loss. Simulation results for seasonal and automatic adjustment of the drain outlet water level for controlled-drainage systems were nearly the same, reducing drainage volume by about 35%, and nitrate loss by an average of 30%, when compared to conventional (uncontrolled) drainage systems. However, both automatic control of dual controlled-drainage and sub-irrigation systems reduced drainage by about 50%, saving 70% of the water needed for sub-irrigation while reducing nitrate loss by 45% compared to seasonally controlled drainage systems. The water table fluctuation subroutine has been incorporated into the DRAINMOD models and is now used widely.



Soil scientist Norm Fausey (left) and Ohio State University extension agricultural engineer Larry Brown discuss features and treatment efficiency of a constructed wetland receiving agricultural drainage water.

Ground penetrating radar (GPR) is a non-destructive and efficient subsurface drainage water management tool that is potentially useful to farmers and land improvement contractors for finding buried agricultural drainage pipes and evaluating their functionality. A field study was carried out by ARS scientists in Columbus, OH, to determine the GPR pipe response effects due to the GPR antenna orientation relative to drain line directional trend. Under dry soil conditions, a GPR antenna orientation perpendicular to the drain line was found to provide the best GPR drainage pipe response, while conversely, under wet soil conditions, a GPR antenna orientation parallel to a drain line provided the best GPR drainage pipe response. This information can be employed to optimize GPR field survey procedures, based on shallow hydrologic conditions, for the purpose of improving GPR drainage pipe location and functionality assessment capabilities (Allred and Redman, 2010; Allred, 2011).

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Problem Area 4: Integrated Soil Erosion and Sedimentation Technologies

Soil erosion, sediment movement, and deposition processes involve the interactions of land management practices with climate, soil, and landscape properties. Because erosion affects soil properties progressively over time, and generally results in decreased soil quality and reduced resistance of agricultural systems to stress, soil erosion control is essential for sustainable agricultural production systems. Sediment generated by soil erosion has costly, negative, off-site impacts on downstream channel evolution, flooding, water, and air quality. Better erosion control technologies and improved decision support systems for planning and assessment are needed. Managing local effects on a field, farm, or channel, as well as off-site impacts at larger watershed and landscape scales, are both critically important.

Theme 1: Improved science for targeting erosion control and assessment

To properly control erosion, it is necessary to know where the sediments came from and the dominant processes that moved the sediments on the landscape. ARS' erosion research is now more focused on identifying the dominant processes that move sediments on the landscape. Recent findings show that subsurface flow is a critical factor in causing ephemeral gully formation and stream bank erosion. Using environmental tracers for source tracking (i.e., to identify where the sediments come from) is another noted accomplishment.

The selected accomplishments are associated with Product 1: Database and predictive relationships for erosion and sediment transport caused by concentrated flow in irrigation furrows, ephemeral gullies, and edge-of-field gullies; Product 2: Decision support tools and databases for sediment loads, yields, and off-site impacts considering fractional sediment transport and deposition, geomorphic aspects of stream evolution, and reservoir/pond sedimentation for purposes of quantifying landscape scale erosion rates; and Product 4: Improved tools for assessment of soil susceptibility to erosion including spatial, temporal, topographical, vegetative, and management effects.

Selected Accomplishments under Theme 1 of Problem Area 4

Runoff and erosion are key factors affecting water distribution on the landscape, and consequently, rangeland sustainability. Scientists from Tucson, AZ, analyzed 34 years of precipitation, runoff and sediment data collected from 8 small (1.1 to 4.0 ha) semi-arid rangeland watersheds in southern Arizona. Annual precipitation averaged 400 mm y^{-1}, with half of the total rainfall occurring from July through September. Runoff depth was, on average, about 10 % of annual precipitation depth. Ten percent of rainfall events produced over half of the total sediment yield. Maximum 30 minute precipitation intensity was the primary factor affecting runoff, while runoff was the best predictor of sediment yield. In some watersheds, fire and drought may have significantly altered the hydrologic sediment response, but the lack of continuous monitoring of vegetation complicates the interpretation of both fire and grazing management effects (Polyakov et al., 2010a; 2010b).

Sediment is a major pollutant in many watershed streams. Identification of sediment sources is critical to providing cost-effective management for these watersheds, thereby reducing sediment pollution. Using sediment identification techniques, ARS scientists in Tucson, AZ, determined that three sub-watersheds in the Walnut Gulch Experimental Watershed (WGEW) contribute 86% of the total sediment load from the watershed. Sixty-five percent of the stable carbon isotope leaving the watershed comes from shrubs that dominate the vegetation in these three sub-watersheds. Using these sediment identification techniques, land managers and landowners can now determine areas where they should focus their limited resources to produce the greatest reduction in sediment loads (Rhoton et al., 2008; 2011).

Accurate quantification of erosion is an important component of developing tillage practices that minimize soil and associated nutrient losses from agricultural fields. However tillage practices also turn and move soil material in the field, but current soil erosion prediction models do not account for soil translocation following tillage. ARS scientists at Oxford, MS, quantified the amount of soil translocated following tillage, taking into account slope gradients both parallel and perpendicular to the direction of tillage. The prototype model operates on a rectangular grid represented by a Digital Elevation Map (DEM) containing initial terrain elevations. The model represents a valuable future tool for quantifying the effects of agricultural practices on soil erosion and sedimentation at the landscape scale (Vieira and Dabney, 2009; Vieira and Dabney, 2011).

Sediments stored in lakes are a valuable archive that can be used to recover information on the erosion history of watersheds. Measuring the performance of costly watershed management practices is a difficult problem with far-reaching consequences. Intensive agriculture results in erosion rates that are many times those of undisturbed land; however, the return on funds used to correct erosion problems is largely unknown. In cooperation with scientists from the University of Mississippi, ARS scientists at Oxford, MS, dated sediments from five natural oxbow cutoffs in the Mississippi River alluvial floodplain, using naturally occurring radioactive substances present in the soil. Observed trends in sedimentation rates were then related to changes in watershed management practices. Compared to pre-management sedimentation rates, significant reductions in post-management sedimentation rates were observed in Roundaway (33%), Beasley (76%), and Wolf (81%) lakes. Results demonstrate the effectiveness of conservation practices used in these watersheds, and that radioisotope-based measurements can be used to detect changes in sedimentation in response to changes in land management over time-frames as short as 15 years prior to sediment core collection (Wren et al., 2011).

The effects of field edges and buffer strips on runoff flow patterns have been recognized, but quantification of these effects remains uncertain. ARS scientists at Oxford, MS, quantified the progressive development of small earthen berms at the margins of tilled fields, determined their influence on runoff flow patterns and sediment delivery, and developed computer modeling technology to predict these effects. In the absence of a berm, most runoff passed into and through near-contour vegetative buffers, but tillage with a tandem disk immediately adjacent to buffers quickly built a berm that diverted most of the runoff received during small storms. Once a berm had formed, more than half of storm-generated runoff flowed along the buffer rather than through it, even during the largest storms. Runoff flowing upslope of and parallel to contour buffers had a longer flow path with increased opportunity time for water infiltration, resulting in decreased runoff volume but no significant impact on sediment delivery compared to runoff passing through buffers. Runoff diverted by tillage berms may become concentrated at areas of flow convergence within agricultural fields, where a stable outlet must be provided to avoid gully erosion. These studies support current NRCS National Practice Standards design criteria for Vegetative Barriers (code 601), Filter Strips (code 393), and Contour Buffer Strips (code 332) (Vieira and Dabney, 2011; Dabney et al., 2012; Vieira and Dabney, 2012).

Hydraulic engineer Daniel Wren makes adjustments to the floating instrument platform used in Goodwin Creek Experimental Watershed near Batesville, Mississippi. The platform is used for data collection and development of acoustic technology for field measurement of sediment transport.

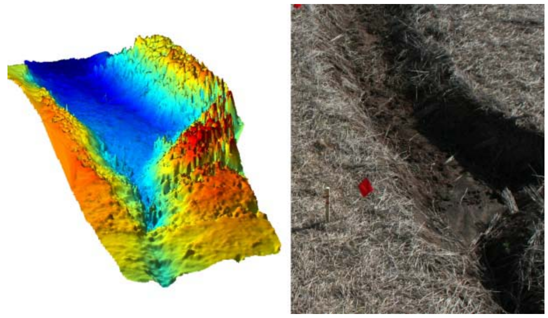
The majority of erosion research attributes gully erosion, often the dominant source of soil loss, to surface flow, while overlooking subsurface flow processes. ARS scientists at Oxford, MS, conducted mechanistic studies in the laboratory to document the role of preferential flow through large soil pores, termed soil pipes, on the development of ephemeral gullies, quantifying the conditions under which internal erosion of soil pipes can lead to the initiation of ephemeral gullies by tunnel collapse. The work provides guidance for incorporating subsurface flow processes into next generation models of gully erosion, and will form the basis for developing management strategies for controlling gully erosion under subsurface flow conditions (Wilson, 2009; 2011).

Sediment is one of the primary pollutants of surface waters in the U.S.; stream bank erosion has been identified as a significant sediment source. The use of riparian buffers to stabilize stream banks and reduce the loss of agricultural land and sediment loadings to streams has become a popular management technique, but accurately quantifying the reinforcing effects of vegetation on bank stability and sediment losses is difficult. To help managed stream bank erosion, ARS scientists at Oxford, MS, developed BSTEM, which is available free of charge on the Web. The Bank-Stability and Toe-Erosion Model has been used throughout the U.S., and in many places overseas, to analyze stream and gravitational forces, as well as the effects of seepage erosion, fluvial erosion and above- and below-ground riparian vegetation biomass, on bank stability and bank-face erosion (Wilson et al., 2007; Cancienne et al., 2008; Chu-Agor et al., 2008, 2009). The uses field data on root strength and root distributions for a broad range of riparian species, applying these data to a type of fiber bundle reinforcement model used in structural engineering (Pollen and Simon, 2005; Pollen, 2007). A new dynamic version allows users to input years of daily river-stage data, allowing iterative simulation of the combined effects of hydraulic erosion and geotechnical stability. The new dynamic version incorporates a near-bank groundwater model that provides dynamic variations in pore-water pressure distributions and, therefore, bank strength, over the course of the simulation. The model serves as a tool for watershed managers to: 1) determine sediment loads from stream bank erosion; 2) determine potential sediment-load reductions using a range of mitigation strategies; and 3) design stable-bank configurations for stream restoration activities (Simon et al., 2011).

Accurately measuring sediment concentrations in streams draining agricultural watersheds is important for quantifying erosion losses, assessing the impacts of sediment on the dynamics of stream and river flow, and predicting sediment buildup behind dams and in reservoirs, but sediment measurements are both difficult and expensive to collect. In collaboration with the National Center for Physical Acoustics, ARS scientists in Oxford, MS, developed an acoustic technique for measuring fine (< 0.062 mm) sediment particles in water. This new technology enhances current capabilities for measuring suspended sediments in water, closing a gap in acoustic measurements of particles less than 0.062 mm in diameter. The technology: allows remote, autonomous deployment; is relatively inexpensive; and gives much more detailed information about sediment dynamics than traditional manual sampling techniques (Carpenter et al., 2010)

Stream restoration using the BSTEM model design.

Digital photogrammetry is the remote measurement of geometric or topographic information from digital photographs. ARS scientists at West Lafayette, IN, found that the availability of low-cost digital cameras makes photogrammetry a great tool for soil erosion assessment. In photogrammetry, reference markers of known coordinates are needed to provide the scale for the objects in the image. Working in farm fields in Kansas where ephemeral gullies were present, these scientists developed and field-tested a simplified process to derive the coordinates of reference markers using an object of known geometry, eliminating the need to use expensive surveying equipment and enabling soil erosion assessments to occur much more broadly worldwide. The technology is also being adopted by the Agricultural University of Vienna, Austria, and University of Ghent, Belgium, to facilitate research on soil roughness changes during rill development (Nouwakpo and Huang, 2012).



A field gully at Kansas and the digitized channel geometry created from photogrammetry using a consumer-grade camera.

Theme 2: Tools for assessing potential earthen embankment breach

USDA flood control dams provide livestock water, municipal water and wastewater, electric power, flood protection, irrigation, fish and wildlife habitat, recreation, sediment detention, and manure storage and treatment. Many of these dams are approaching their designed service life. ARS research efforts in this subject area focus on assessing erosion from earthen embankments and spillways, which can trigger a catastrophic dam failure. Also, an acoustic procedure to identify internal erosion inside the embankment is another noted accomplishment.

The selected accomplishments are associated with Product 3: Improved tools for evaluating the potential for earthen embankment breach due to erosion and deterioration due to wave action.

Selected Accomplishments under Theme 2 of Problem Area 4

Present and future USDA Small Watershed Dams will require assessments to determine hazard classification, population at risk, and emergency action plans, and for prioritizing rehabilitation of aging infrastructure. A physically based dam embankment failure predictive model is essential for conducting these in-depth assessments. In cooperation with the NRCS and Kansas State University, ARS scientists in Stillwater, OK, have developed the computer engineering application tool, WinDAM B. This application software allows engineers to evaluate embankment overtopping erosion, breach timing, breach location, breach failure, and flood discharge, for flood overtopping of homogeneous earthen embankments. This computer tool will be important in evaluating existing structures, with potential for determining hazard classification, developing emergency action plans, and reducing costs associated with rehabilitation (Hanson et al., 2011).

From an observation platform overlooking a test dam, hydraulic engineer Greg Hanson records the test for use in computer modeling.

The NRCS provides technical and financial assistance on the design and construction of nearly 11,000 flood control dams installed in 47 states since 1947; half of these will reach their planned service life by 2018. Stepped spillways offer a cost savings relative to other rehabilitation methods, but there are design issues that need resolution. Convergent stepped spillways are one potential configuration, but they result in increased flow depth near the training wall. Thus the height of the training walls to retain the flow in the spillway chute must be determined. ARS engineers at Stillwater, OK, developed an equation for estimating the dimension criteria of converging vertical sidewalls for convergent stepped spillways. This training wall height equation provide design guidance so that spillway function adequately, protecting the remainder of the embankment. Stepped spillways are also known to create bulked flow, an increase in flow depth due to developing air entrainment created by the steps. Engineers have developed energy dissipation relationships based on the location of the air entrainment inception point that may be used for the design of the training walls and stilling basins. As a solution to both rehabilitation and safety needs, stepped spillways will be placed in approximately 10% of the existing dam embankments. Thus this new 'design criteria' equation will help in the rehabilitation of more than 1,000 flood control dams (Hunt and Kadavy, 2010a; 2010b).

Increasing the flow capacity of the numerous flood control dams that exist in small watersheds is a growing issue for rehabilitating these aging structures and maintaining their safety. NRCS engineers are using Roller-compacted Concrete (RCC) stepped spillways to increase flow capacity, thereby protecting these earthen dams from potential erosion. One important design issue is determining the dimensions of the vertical and sloped training walls needed when the spillway chute is required to be narrower at the bottom than at the top. Because RCC spillways cost several million dollars to build, research providing optimal design criteria for these spillways could save a significant amount of money. ARS scientists at Stillwater, OK, completed a series of generalized model studies that produced a series of equations to predict the appropriate dimensions of converging vertical and sloped sidewalls, to achieve maximum safe flow capacities in earthen dam spillways, thereby minimizing potential costs (Hunt et al., 2008).

Internal erosion by pipe flow is a leading cause of embankment failures and has been postulated to be a major cause of both landslides and gully erosion. Non-invasive methods are needed for identifying soil pipes and detecting when flow is occurring in these large soil pores and the resulting internal erosion that could lead to gully erosion and embankment failures. In cooperation with the National Center for Physical Acoustics, ARS scientists in Oxford, MS, carried out experiments in which flow through soil pipes under controlled laboratory conditions was monitored by both passive and active acoustic sensors. Internal erosion was measured as a function of pipe flow velocity, along with water pressure in soil surrounding the soil pipes. The study demonstrates the potential of acoustic velocity signals for monitoring dynamic and highly non-equilibrium conditions of soil pipe flow and internal erosion. Once fully tested and developed, such acoustic technologies could provide a non-invasive method for inspecting embankments and the early detection of pipe flow and internal erosion prior to failure (Wilson, 2009; 2011; Lu and Wilson, 2011).

ARS hydrologist Glenn Wilson (left), graduate student Raja Periketi (center), and Oklahoma State University scientist Garey Fox use a simulated streambank to conduct laboratory experiments of seepage erosion on streambank failure. Periketi is measuring the lateral extent of a mass failure caused by seepage erosion.

Theme 3: Erosion control techniques and strategies

The accomplishments reported here focus on field scale practices that have demonstrated erosion control benefits. One area of research that ARS scientists are known for is the use of soil amendments to improve water infiltration, reducing surface runoff and erosion. One notable accomplishment reported under this theme is that a small amount of ployacrylamide added into irrigation water can significantly reduce loss of water due to seepage.

The selected accomplishments reported below are associated with Product 5: Best Management Practices and design tools for in-field erosion control, gully and ephemeral channel erosion prevention, riparian corridor stabilization, and sediment retention structures; and Product 6: Models to predict irrigation-induced erosion using a common interface with shared databases: development, parameterization, and validation (surface, center pivot and set/move sprinklers).

Selected Accomplishments under Theme 3 of Problem Area 4

In the southern US, erosion and concomitant soil loss are common problems associated with cotton cultivation, particularly in sloping terrain. Standard approaches for growing cotton on sloping lands produce rates of erosion and sediment yield several times greater than the 7t/ha tolerance value. ARS scientists at Oxford, MS, completed a four-year study that included measuring water runoff and sediment yield from plots cultivated for cotton with conventional approaches, and from plots representing three innovative approaches to cotton cultivation in sloping terrain—various combinations of narrow row spacing, no-till, and grass hedges. Sediment yield from no-till plots with grass hedges was reduced by 94% relative to conventional tillage, while yielding an average of 0.2 t/ha of cotton more than conventionally tilled plots. These results will be useful in guiding future research on field-sized areas, with potential benefits for extension personnel, action agencies involved in water quality planning, and farmers (Cullum et al., 2007; Dabney et al., 2009).


An example of seepage erosion from a section of Goodwin Creek, Mississippi.

Knowledge of the 'carbon footprints' of various energy generation and use activities, including agriculture, has become an important environmental issue. ARS scientists at Coshocton, OH, studied the loss of dissolved organic carbon associated with runoff and erosion. In a system where a beef cow-calf herd was rotated weekly through 4 pastures during the grazing system, one pasture was used for winter feeding. Surface runoff was measured from each of these pastures throughout the year. Only the pasture used for winter feeding had runoff with measureable amounts of sediment, and those losses occurred during the winter feeding period. Because the cattle were constantly in this pasture during the winter months, the vegetative cover was reduced to less than 50%, increasing the potential for soil loss. Most of the sediment and carbon loss occurred during a few large, runoff-producing storms. On an individual storm event basis, there was no correlation between the amount of sediment lost and the organic carbon concentration of that sediment. Both dissolved organic carbon and sediment-attached organic carbon were lost in similar amounts on both an event and an annual basis. Losses of organic carbon (i.e., soil quality) from pastures, and thus the carbon footprints of pasture operations, can be reduced by using management practices, such as rotational stocking during the winter months, that reduce overall sediment losses (Owens and Shipitalo, 2009; Owens and Shipitalo, 2011).

Rock check dams are used across the western US for erosion control. These low-cost practices also provide a mechanism for increasing vegetation by altering soil moisture. However, there is a lack of data quantifying their impact on soil moisture distribution. ARS scientists in Tucson, AZ, found that, compared to control sites, significantly greater soil moisture content on channel banks were associated with both loose rock and wire bound check dams. The overall aim of the technology is to increase the potential for successful seedling emergence from ambient levels of grass seed in the lower part of the landscape near channels, which then will have the potential in wet years to expand across the landscape and increase rangeland production (Nichols, 2007; Nichols et al., 2012 in press).

Paper mills generate a large amount of a byproduct consisting of clay, lime, and fibers too short to make paper. Paper mill sludge (PMS) can improve reclamation of surface-coal mines where low pH and organic-carbon levels in the spoil cover material can inhibit re-vegetation. However when used at higher rates, PMS can adversely affect water quality. ARS scientists at Coshocton, OH, found that compared to standard reclamation practices, PMS application rates as high as 672 Mg/ha drastically reduced runoff and erosion and improved soil quality and plant growth, while not increasing loads of other pollutants in runoff. Results will help in establishing regulatory guidelines for PMS use and potentially increase applications of this by-product thereby helping to improve the reclamation of surface-coal mine spoils (Shipitalo and Bonta, 2008).

Water flowing in irrigation furrows can erode soil and transport sediment and associated nutrients off the field. In a field test conducted by ARS scientists at Kimberly, ID, a new starch/polyacrylamide amendment was compared against polyacrylamide-treated and untreated furrows, with respect to their abilities to reduce soil erosion and sediment transport in irrigation furrows. The new amendment—a blend of potato starch and polyacrylamide (PAM)—increased infiltration by 20%, and reduced soil erosion by 65%, as compared to untreated furrows. When applied at the same rate, PAM treatment increased infiltration by only 13%, but reduced erosion by 98%, as compared to untreated furrows. The new polysaccharide/PAM amendment can be used as an alternative to PAM for improving infiltration on furrow-irrigated fields. In addition to the erosion control benefits, PAM also increased dry bean yield by 14% and silage corn yield by 4.5%, which offset the cost of the practice to the producers (Bjorneberg and Sojka, 2008; Lentz and Sojka, 2009).

Jim Entry (left) and Dave Bjorneberg record sediment concentrations from furrow irrigation runoff samples. The clear sample on the right is from a PAM treated furrow.

Replacing surface irrigation with center pivot sprinkler irrigation is a common conservation practice to reduce irrigation induced runoff and soil erosion. However, runoff and erosion can still occur if center pivot sprinkler systems are improperly designed for the site conditions. Based on measurements of sprinkler droplet size and velocity, ARS researchers at Kimberly, Idaho, have shown that the conventional way of characterizing the application of sprinkler energy did not match potential runoff. Runoff can be minimized by having a large range of drop sizes in combination with low application rates. This information aids sprinkler selection and can be used to improve sprinkler design. Development of new ways to characterize sprinkler kinetic energy results in better designs for center pivot irrigation sprinklers (Bjorneberg et al., 2007; King and Bjorneberg, 2011).

Theme 4: Development of erosion prediction models and assessment tools

Probably the most well-known ARS science that has been turned into a technology used world-wide in natural resource management, is the development of Universal Soil Loss Equation-USLE. ARS researchers continue to improve the erosion science and control strategies and to incorporate the knowledge into erosion assessment technologies. Erosion models have also evolved from empirically based USLE-type concept to incorporate more physical processes.

The selected accomplishments related to erosion model development are associated with Product 7: Multi-scale modeling system to predict wind, water, and tillage erosion, and downstream impact of sediment movement on agricultural landscapes using a common interface with shared databases: development, parameterization, and validation.

Selected Accomplishments under Theme 4 of Problem Area 4

Because existing erosion models were developed for croplands, where hydrologic and erosion processes differ from those found on rangelands, accurate prediction of soil loss on western rangelands requires an erosion model specifically designed for rangeland applications. In a landmark paper on rangeland soil erosion modeling, ARS scientists from Tucson, AZ, describe the new Rangeland Hydrology and Erosion Model (RHEM), which can 1) model erosion processes under both undisturbed and disturbed rangeland conditions; 2) adopt a new splash erosion and thin sheet-flow transport equation developed specifically from rangeland data; and 3) link model hydrologic and erosion parameters with rangeland plant communities by providing a new system of parameter estimation equations based on 204 plots in 49 rangeland sites distributed across 16 western U.S. states. The Rangeland Hydrology and Erosion Model estimates runoff, erosion, and sediment delivery rates and volumes at the hillslope spatial scale, and at the temporal scale of individual rainfall events. Subsequent experiments conducted to generate independent data for model validation indicate the ability of RHEM to provide reasonable runoff and soil loss prediction capabilities for rangeland management and research needs, helping to sustain productive rangelands in the western U.S. in the face of changing land use and climatic fluctuations (Nearing et al., 2011).

In areas dominated by frozen soil conditions, where freezing, thawing, snow accumulation, and snow melting significantly affect soil loss, erosion prediction consistently performs poorly. Cooperative work between ARS scientists in West Lafayette, IN, Pullman, WA, and Washington State University, produced the updated Water Erosion Prediction Project (WEPP) model, version 2010.1. Released in January 2010, the model contains significant improvements in the prediction of soil freezing and thawing, snow accumulation, and runoff resulting from snowmelt. In validation studies using data from Pullman, WA, and Morris, MN, the new model performed significantly better than the previous version. The updated WEPP model will impact thousands of users throughout the U.S. and the world, providing better predictions of runoff, soil loss, and sediment yield from hillslopes and small field-scale watersheds. Users in areas experiencing substantial erosion from snowmelt on thawing soils should notice particularly better performance (Dun et al., 2010).

The shape of a river, and therefore the amount of material eroded from its boundary, are greatly affected by the presence of vegetation and the distribution of water in the riparian zone--the zone adjacent to the stream or river channel. ARS scientists in Oxford, MS, have developed new modeling components to accurately simulate: (1) the movement of water between a river and its riparian zone; and (2) the hydrologic and mechanical effects of vegetation on bank soil shear strength. These modeling components were integrated with the USDA-ARS computer models CONservational Channel Evolution Pollutant Transport System (CONCEPTS—a model of in-stream processes) and REMM (a model of riparian processes), and tested against two years of detailed data collected along a restored reach of Trout Creek in the Lake Tahoe Basin, CA. Simulations show that vegetation and bank orientation significantly affect soil water content in the bank, resulting in greater bank strength in summer and fall seasons. Bank strength, however, is significantly reduced in early spring, when melting of the bottom of the snow pack on the floodplain saturates the bank profile. The resulting model can better assess the impact of riparian zone management practices on stream bank erosion, providing an important tool for action agencies such as the NRCS, to evaluate the effects of edge-of-field practices at field or watershed scales (Langendoen et al., 2009).

An aerial view of a section of James Creek, in Mississippi, where channel incision has led to rapid bank erosion causing land loss and high suspended sediment loads within the water.

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Problem Area 5: Watershed Management, Water Availability, and Ecosystem Restoration

Agricultural lands, including crop, pasture, and range lands, comprise > 70% of the continental U.S. and play a dominant role in the management of the Nation's watersheds and water resources needed for human consumption, recreation, agriculture, industry, wildlife habitat, aquatic ecosystems, and the environment. The confluence of unprecedented demands for freshwater, rapidly changing land use to accommodate rural and urban growth and biofuel production, recurring droughts, and regional climatic variations, means that the Nation's freshwater resources, agricultural production, and ecosystems are under more pressure and at greater risk than ever before. Thus, there is a need to accurately quantify and manage our water resources to support these many uses across heterogeneous agricultural and urban landscapes. Watershed management based on multiple objectives that include water supply, water pollution, urban development, climate variability, recreation, ecosystem protection, and habitat restoration, is a complex task necessary not only to support the goals of the Clean Water Act and the Endangered Species Act, but also to address concerns of watershed coalitions, policy makers, and the public.

Theme 1: Production and management systems that improve water quantity and quality

ARS' natural resources projects are aimed towards developing field scale BMPs for both production and environmental benefits. Some accomplishments with the same objectives have been reported under Problem Area 1, Theme 2; Problem Area 2, Theme 5; Problem Area 3, Theme 1; and Problem Area 4, Theme 3; and Problem Area 6, Theme 1. In essence, no matter how water resources related research is divided or categorized, the development of BMPs is always the common goal of the research effort.

The selected accomplishments reported here are associated with Products 1: Best management practices (BMPs), assessment tools, and decision support systems for managing water quantity and quality within agricultural and urban landscapes; and Product 3: BMPs and assessment tools for determining economically and environmentally sustainable agricultural enterprises in South Florida.

Selected Accomplishments under Theme 1 of Problem Area 5

Particularly in arid and semi-arid regions, water is a limiting resource for crop production. Models can enable a systems approach to facilitate sustainable water management, but modeling spatial relationships in plant growth and yield at field-to-watershed scales requires accurate simulation of crop developmental responses across landscapes that vary in soil water availability. To address this need, ARS scientists at Fort Collins, CO, developed and released PhenologyMMS (Modular Modeling System) Version 1.2, and integrated its core science code into the Unified Plant Growth Model (UPGM). The PhenologyMMS software has subsequently received over 500 download requests from researchers, farmers, and agribusinesses, and numerous direct requests for additional information and explanation, including from the popular press. By helping to schedule farm crop management practices (e.g., irrigation) based on crop development stage, PhenologyMMS helps increase agricultural production while reducing adverse environmental impacts such as low water use efficiency (McMaster et al., 2011).

Soil maps describe the spatial range of the main soil series, and associated databases give values for the properties of these soils, without consideration of long term management effects. However over the long term, soil hydraulic properties can be affected by land management practices. In cooperation with researchers from the University of Missouri, ARS scientists at Columbia, MO, quantified soil hydraulic properties in two fields with the same soil type but very different long-term management histories. One field has been under continuous row crop cultivation for over 100 years; the other is a native prairie that has never been tilled. Soil from the row crop field was significantly more compact, less permeable, and had a lower water-holding capacity than the prairie soil. This research provides upper and lower boundaries for the hydraulic characteristics of this soil type that can be used to improve the accuracy of model simulations (Mudgal et al., 2010).

Soil-water storage and movement are the dominant factors controlling both crop production and agri-chemical movement in agricultural landscapes. In a rain-fed wheat field in semi-arid eastern Colorado, ARS scientists from Fort Collins, CO, quantified changes in soil-water content as a function of landscape position, to identify locations most likely influenced by lateral flows. While vertical processes appeared to control soil-water movement on hilltops, at lower landscape positions, soil-water dynamics were influenced primarily by unsaturated subsurface lateral flow as well as infrequent overland flow events. This study enhances our general understanding of soil hydrology in hill-slopes, providing data needed test data for watershed modeling to help improve assessment of both agricultural production for food security and the impact of conservation practices on environmental benefits in agricultural landscapes (Green and Erskine, in press).

In South Florida, the area planted in field crops and orchards has decreased dramatically during the past 10 years, while the area in floricultural crops has steadily increased. The effects of this shift in agricultural enterprise on water quality in the region are unknown. ARS scientists in Miami and Ft Pierce, FL, developed BMPs that reduce or mitigate nutrient leaching from horticultural and floricultural production systems, thereby enhancing water quality in South Florida. Research conducted at two nurseries, a foliage plant nursery and a bedding plant nursery, during irrigation/fertigation events, showed that significant amounts of nitrate-nitrogen can leave nursery production sites in runoff water associated with drip and overhead irrigation/fertigation practices. Rainfall events causing drainage through pots and surface runoff from the production areas may result in similar losses. These research findings benefit customers in the nursery industry, the fertilizer industry, and other commodity associations, by providing guidance on management practices that reduce the potential movement of nutrients offsite, and by developing growth media that utilize locally generated solid waste to enhance production efficiency while simultaneously ameliorating the negative impacts of solid waste collection sites (Wilson et al., 2010).

Hydrologist Reza Savabi (right) and technician Nicholas Cockshutt monitor soil moisture fluctuations near the Everglades National Park. This investigation is part of improving water management on agricultural areas.

Forage-based livestock systems are another water quality concern in Florida that have been implicated as major contributors to deteriorating water quality in many other parts of the US as well. Both fertilizers and manures represent sources of phosphorus that can be transported via hydrologic pathways, impacting surface and ground water quality. ARS scientists in Brooksville, FL, examined historical water quality parameters in three lakes located near beef cattle pastures, finding that properly managed beef cattle operations might not be major contributors to excessive nutrient loads (especially of P) in surface waters. Current fertilization recommendations for forage-based pastures in central Florida appear to offer little potential for negatively impacting water quality, while properly managed livestock operations appear to contribute negligible loads of nutrients (especially P) to surface water. Periodic application of additional P and other micronutrients may be necessary to sustain agronomic needs and to offset the export of nutrients due to animal production. Knowledge gained through this study helps improve the management of forage-based livestock systems in humid temperate and sub-tropical environments on similar soils (Sigua et al., 2011).


Soil scientist Gilbert Sigua uses a probe to measure levels of salinity, dissolved oxygen, conductivity, and temperature in Spring Lake, in Brooksville, Florida. The lake is located near forage-based cow-calf operations.

Long-term data bases are necessary to identify long-term trends and to develop models to describe the impacts of various land uses. The North Appalachian Experimental Watershed Research Station near Coshocton, Ohio, is another example of long-term data collection, where runoff, groundwater flow, and erosion data from agricultural watersheds have been recorded since the late 1930's. Water quality data have been collected from a variety of management practices since the early 1970's. Corresponding meteorological data are also available. Because the collection of long-term data requires a sustained investment of significant resources, data bases of this nature are comparatively rare. This information is useful to scientists who need long-term data bases for work such as development and/or validation of models or model components (Owens et al., 2009).

Theme 2: Habitat restoration and ecology

The ARS laboratory at Oxford, MS, has the only research team fully devoted to the assessment of habitats and aquatic ecology. Additional accomplishments associated with ecological assessment under the Conservation Effects Assessment Project (CEAP) are reported under Problem Area 1, Theme 2.

These selected accomplishments are associated with Product 2: Management tools and decision support information for restoration of riparian buffers, wetlands, and streams, and improvement of aquatic ecology.

Selected Accomplishments under Theme 2 of Problem Area 5

Over $1 billion are expended annually on stream restoration, but few projects are monitored following restoration, and scientists disagree on the most effective approaches to achieve various restoration objectives. ARS scientists in Oxford, MS, monitored streams for ten years after the surrounding watersheds were treated with standard erosion control practices. In addition, two stream reaches were treated with special features to restore fish habitat quality. Habitat restoration produced major shifts in the types and sizes of fish present—shifts that did not occur in non-treated stream sections. The study demonstrates that even watershed-scale application of traditional erosion control measures is not adequate to restore stream ecological integrity without identifying effective approaches to specifically address fish habitat deficiencies. This research will be beneficial to managers charged with both controlling erosion and restoring fish habitat and ecological integrity in streams draining agricultural watersheds (Shields et al., 2007; Shields, 2009)

Rivers and streams in intensively cultivated, low-relief watersheds often experience periods when dissolved oxygen concentrations fall below minimum levels set by state regulators. The ecological literature contains varying information about the effects of such conditions on fish. ARS scientists in Oxford, MS, showed that fish communities in the Big Sunflower River, MS, were sensitive to dissolved oxygen levels, with several species disappearing from collections obtained when oxygen levels were low. These results contribute to ongoing deliberations regarding requirements for modification of farming activities to improve stream water quality conditions in agricultural landscapes (Shields and Knight, 2011).

The ability of created wetlands to reduce nutrient, pesticide, and sediment loadings in agricultural runoff can be optimized by design and management, but addressing these priorities may result in wetlands that are less beneficial as habitats for aquatic vertebrates (e.g., fishes, amphibians, reptiles) that are exhibiting worldwide population declines. ARS scientists in Columbus, OH, documented differences in fishes, amphibians, and reptiles in two wetland types created by the wetland-reservoir-sub-irrigation system (WRSIS), using this information to develop design and management criteria to increase the ecological benefits of these agricultural water-recycling systems. Differences in amphibian abundance and species composition between WRSIS wetlands and reservoirs suggest their potential to provide habitats for different ecological communities, with wetlands favoring amphibian populations and reservoirs favoring fishes. However, this was not the case for ‘pond-type’ wetlands that, similar to reservoirs, favored fishes. To alleviate this problem, design and management criteria were developed to enable WRSIS wetlands to be managed as amphibian habitat, and reservoirs to be managed as fish habitat. These criteria can be used by federal, state, and private agencies when creating agricultural wetlands, to assist them meeting their conservation and restoration goals (Anderson et al. 2011).

Ecologist Scott Knight inspects and weighs a common carp while biologist Terry Welch records data. A wide range of fish species are collected from Beasley Lake in an effort to determine the overall health of lake ecology.

Agricultural pesticides are often removed from streams, lakes and wetlands by becoming attached to sediments and settling to the bottom, but the subsequent fate of these pesticides is often unknown. ARS scientists in Oxford, MS, found that after mixing sediment sampled from a wide range of aquatic environments adjacent to cultivated fields with water, and then exposing aquatic insects to this mixture for 28 days, pesticide compounds were found to move from the sediments into animal tissues. These findings will guide future studies of the movements and fate of such liberated pesticides in aquatic ecosystems (Smith et al., 2007).

Nutrients and herbicides often simultaneously enter lakes and streams in agricultural runoff, but it is not clear how mixtures of plant growth stimulators and inhibitors might alter algal growth in receiving waters. ARS scientists in Oxford, MS, used a new infrared microspectroscopy technique to assess the physiological response of individual algae from natural communities following their exposure to atrazine and nutrient mixtures. They found that because each species studied had unique reactions, overall algal community response depends on community composition. For example, nutrients inhibit the negative impact of atrazine in some species, while atrazine and nutrients both stimulate growth in others. This study developed an analytical method to bridge the gap between laboratory toxicity tests and field observations of algae, and can be used to develop predictions of how agricultural pollutants will alter aquatic microbial communities (Murdock and Wetzel, 2012).

Theme 3: Climate and climate change effects on the environment and hydrology

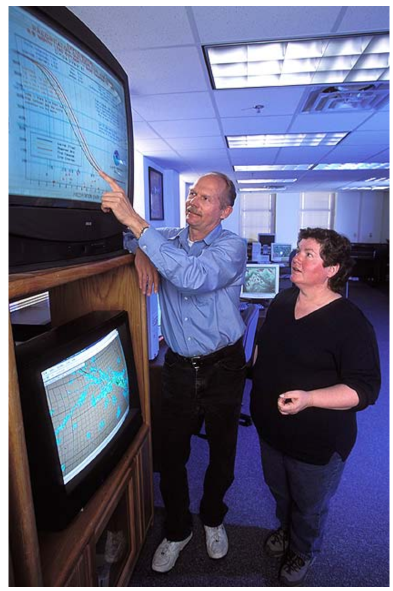
Climate drives the water cycle and energy exchange on Earth. The effects of climate and climate change on hydrology and agricultural production have received significant research attention, but there are still many challenges ahead. Selected accomplishments under this theme demonstrate the impacts of ARS climate related research on the carbon cycle, water yield, crop production and rangeland ecology.

These reported accomplishments are associated with Product 4: Improved watershed simulation, plant growth, and weather generation model components and data assimilation tools for water budget, water quality assessment, and flood and drought risk and impact assessment.

Selected Accomplishments under Theme 3 of Problem Area 5

Hydrologic shifts towards greater discharge have been observed in the Midwest, but it is uncertain whether this trend results from changes in agricultural land use or changes in climate. When evaluating simultaneous shifts in how energy (evaporative demand) and water (precipitation) were partitioned during a long-term, small-watershed experiment, the effects of land use (watershed treatment) and climate trend (time) became readily distinguishable. Applying this technique to four larger watersheds across the Midwest, an ARS scientist at Ames IA and an Iowa Department of Natural Resources hydrologist collaborated to show that increasing discharge was more attributable to climate change than to land-use change. Changes in land use, in particular increased soybean acreage, did show a shift towards increasing discharge that could be attributed to decreased crop water use. But since 1975, and after this change in cropping occurred, changing climate, in the form of increased precipitation and decreased evaporative demand, has been the dominant influence on watershed hydrology. This trend impacts issues such as Gulf of Mexico hypoxia, which expands as both nutrient losses and discharge increase. Results should be of interest to all groups interested in conservation effectiveness in the Midwest (i.e., conservation groups, policy developers, environmental and commodity groups), because increased discharge from agricultural watersheds due to climate change inherently increases the challenges of retaining agricultural nutrients within soils (Tomer and Schilling, 2009).

Agricultural systems models are useful tools for decision making and for optimizing agricultural management practices, but their usefulness could be greatly enhanced if future weather/climate could be forecast with sufficient lead time to allow adjustment of agricultural practices to predictable changes in weather and climate. ARS scientists in El Reno, OK, evaluated the utility of the National Oceanographic and Atmospheric Administration's (NOAA's) seasonal climate forecasts to aid in such decision making. The NOAA forecasts were found to have limited value for managing wheat-cattle production systems in Oklahoma. An alternative forecast method, based on the similarity between forecasted and historical precipitation, was tested for potential use with a newly developed wheat grazing model, but findings suggest that this methodology is an unlikely alternative to NOAA's seasonal climate forecast. Because investigations of new forecast methodologies have reaffirmed the limitations of producing seasonal climate forecasts that contain actionable information for agronomic decision-making in Oklahoma, this research alerts agricultural producers and managers in this state to use these seasonal climate forecasts with great caution (Garbrecht et al., 2010; Garbrecht et al., 2007; Schneider and Garbrecht, 2006; Schneider et al., 2005).



Hydrology engineer Jurgen Garbrecht and meteorologist Jeanne Schneider interpret the latest seasonal climate forecast issued by NOAA's Climate Prediction Center.

Multi-year precipitation variations impact water resources management and conservation. In this study, the existence and impact of multi-year precipitation variations on soil erosion, sediment transport, and watershed sediment yield were identified. The magnitudes of the impact of these variations on watershed runoff and sediment yield in the Southern Great Plains were demonstrated for several watersheds in southern Kansas and Oklahoma. Consideration of multi-year precipitation variations and associated impacts on watershed runoff and sediment yield reduces risk in water resource management and improves assessment of conservation needs to mitigate water quality and sedimentation problems in downstream water bodies. The visualization of multi-year precipitation variations has been adopted as a product by the Oklahoma Climatological Survey and used by local newspapers to illustrate the alternating and recurring drought and pluvial periods in the historical precipitation record. (Garbrecht, 2008; Garbrecht and Schneider, 2008; Garbrecht et al., 2007; Garbrecht et al., 2006; Zhang, 2006; Garbrecht et al., 2005)

The climate of the Southern High Plains may change during the current century, which could affect future cropping practices. Thus assessments of potential changes in climate, and how crop varieties can adapt to those changes, are needed. In collaboration with scientists from Kansas State University, ARS scientists in Bushland, TX, assessed the impact of climate scenarios on crop production using crop simulation models. Climate change models suggest that summer temperatures may increase by approximately 8^{o} F and summer precipitation may decrease. Crop simulation models indicate that sorghum production would decrease by 40-50% under these climatic conditions. Improvements in sorghum genetics and increased atmospheric carbon dioxide may prevent these yield losses (Lamm et al., 2010; Moroke et al., 2011; Baumhardt et al., 2011).

One of the most widespread changes currently occurring in the southwestern US is the encroachment of woody plants (shrubs and trees) into grasslands, affecting both water and nutrient cycling in these ecosystems. ARS scientists at Tucson, AZ, measured water and carbon dioxide exchange between a grassland experiencing woody plant encroachment by mesquite and the atmosphere over a four-year period, and determined how precipitation influenced these exchanges. Seasonal drought strongly influenced both water and carbon dioxide exchange. In contrast to current thinking, that woody plant encroachment might increase carbon sequestration, this particular grassland functioned as a net source of carbon to the atmosphere, the magnitude of which increased with increasing drought severity. Results highlight a complex relationship between vegetation change and climatic variation in precipitation that influences carbon sequestration in these water-limited ecosystems (Scott et al., 2009).

The distribution of post-storm soil moisture in arid lands is critical to understanding feedbacks between moisture distribution and vegetation growth. ARS scientists in Tucson, AZ, found that root-zone soil moisture was significantly higher between shrubs than under shrubs, due largely to greater root density there. Results contradict the commonly held hypothesis that there is a positive feedback between canopy cover and soil moisture that explains the stability of woody vegetation distribution patterns. This a key finding for modeling and management efforts related to desertification, suggesting that factors other than improved soil moisture status likely dominate the observed worldwide expansion of woody vegetation into arid and semiarid grasslands (Moran et al., 2010).

Previous studies of the impacts of climate change on hydrology have focused on how changes in precipitation and temperature affect runoff, with less emphasis on how plant water use (ET), the dominant source of water loss in many arid and semiarid watersheds, might change. In collaboration with university colleagues, an ARS scientist at Tucson, AZ, analyzed ET and weather data from three riparian sites located in a semiarid watershed in southern Arizona, and developed a simple model to estimate future plant water use (ET) rates based on climate model projections. Climate predictions for this region indicate that hotter and dryer weather conditions could increase plant water use, but actual ET rates at the studied field sites will remain largely unchanged due to plant mechanisms that constrain the loss of water from their leaves. However, the projected increase in the length of the growing season due to warmer temperatures will likely result in a greater annual riparian plant water use, potentially leading to greater groundwater deficits and decreased stream flow, further stressing water management institutions in semiarid regions (Serrat-Capdevila et al., 2011).

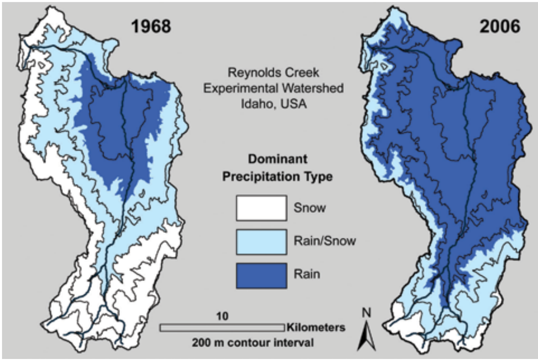
Severe drought can cause changes in plant community structure that, in turn, can result in differences in how water and carbon dioxide are cycled in ecosystems. ARS scientists Tucson, AZ, studied how the exchange of carbon dioxide between the atmosphere and a southern Arizona grassland responded to severe drought. When the drought ended, native grass species were replaced by an invasive African grass. The grassland was a source of carbon dioxide to the atmosphere during the drought, but became a sink for carbon dioxide when the drought ended and the exotic grass became established. When another dry growing season occurred after the invasion, the grassland still sequestered more carbon than it released to the atmosphere. Thus in some ecosystems and environments, invasive species appear to increase carbon sequestration, thereby improving soil quality and helping to mitigate increases in atmospheric carbon dioxide concentrations (Scott et al., 2010).

Site of the 90-square-mile Reynolds Creek Experimental Watershed in the Owyhee Mountains, about 50 miles southwest of Boise, Idaho.

With the overall goal of improving access to data on semi-arid rangelands, ARS scientists at Tucson, AZ, completed a multi-year project aimed at promoting analyses and interpretations of historic and current data for the Walnut Gulch Experimental Watershed. Although current data are being collected in easily–retrievable form, the historic data set required extensive transcription and compilation. The collection of geo-spatial referenced data describing rainfall, run-off, sedimentation, meteorology, soil hydrology, and vegetation changes is the most extensive data set in the world for a semi-arid area in a watershed greater than 10 km^2. A special section of the journal Water Resources Research (Moran et al., 2008) and the associated Web site (http://www.tucson.ars.ag.gov/dap/) describe 50 years of data collection and the most recent research results. These data are invaluable for developing and testing rangeland erosion and sediment yield models and assessment tools (Weltz et al., 2011; Nearing et al., 2011).

Although large quantities of potentially useful data are collected at various research sites, the additional work of making them intelligible and accessible often is not done. Data from multiple locations within the Reynolds Mountain East watershed for the years 1984 thru 2008, were tested, checked, corrected, gap-filled, and assembled into a continuous, 25-year hourly database by ARS scientists at Boise, ID, for both forcing and validating hydrologic models. As a result of this work, management agencies and other researchers will have the ability to perform detailed evaluations of different modeling approaches without being forced to collect very expensive data. This carefully crafted database is the most complete and comprehensive modeling data set in existence (Chauvin et al. 2011).

A variety of studies have found links between increasing temperatures, declining snow packs, and earlier stream flow in snow fed streams in the Western U.S., but in all of these studies, the linkages are based on observations collected from multiple locations and are thus somewhat indirect. ARS scientists in Boise, ID, analyzed 45 years of air temperature, snow, precipitation, and stream flow data measured at the same location, the Reynolds Creek Experimental Watershed (RCEW). Over the period of record, average air temperature has increased about 2^o C, snow disappears more than a month earlier at lower elevations, and while total annual precipitation has remained constant, the onset of stream flow now occurs earlier in the season. In the intermountain west where the vast majority of agriculture is irrigated, water allocations are based in part on water discharge in early spring following snowmelt, with the snowpack functioning as a reservoir to retain water in the upper portions of the watershed. Without building additional reservoirs, the earlier snowmelt and onset of stream flow means that less water will be available during the growing season to support irrigated agriculture (Flerchinger et al., 2007; Marks et al., 2008).



Warming trend means more rain, less snow in lower elevations.

Despite the observed warming trend from the recorded data at Reynolds Creek Experimental Watershed (RCEW), one question is whether the increase in temperature with no change in total precipitation would cause soil to dry out earlier in the year, resulting in increased drought and fire hazard. To examine trends in soil water content over the period during which this warming occurred, ARS researchers at Boise, ID, analyzed 32 years of biweekly soil water data for 4 sites within the RCEW representing very different environments. No trends in either average annual soil water content or the date of soil drying were observed at any of the 4 sites. Management practices for climate change mitigation cannot be based solely on simple projections of climate change to soil conditions and/or plant production (Seyfried et al., 2011).

Simulation models for snowmelt, runoff, stream flow, and soil temperature and moisture require coupling of surface and subsurface processes for energy and mass transfer. Both detailed, physically-based snow models and integrated hydrology models have been developed over the years, but never coupled in a way that calculated snowmelt. ARS scientists at Boise, ID, coupled the snow model, Isnobal, with the Penn State Integrated Hydrology Model (PIHM), and then ran this coupled model over the Reynolds Mountain East (RME) experimental watershed for the 2006 and 2007 water years. Though 2006 was very wet and warm, and 2007 was dry, the results show accurate predictions of snow deposition and melt over the catchment, soil moisture and temperature, ground water level, and stream flow, for both years. Doing the test over the well-instrumented RME basin enabled comprehensive evaluation of the ability to simulate the complex hydrologic state, storage, and fluxes from a mountain basin for the first time. Results demonstrate the feasibility of a physically-based approach to water supply management of snowmelt (Flerchinger et al., 2010).

Historical weather records over the last century show that the number of rainy days and the intensities of rain have been increasing. Using future precipitation as predicted by six different climate change models under three green-house gas emissions scenarios (high, medium, and low), ARS scientists at Tucson, AZ, examined projected changes in mean annual precipitation and the power of rainfall to cause erosion for the mid and latter part of the 21st century in Northeastern China, compared to observed conditions for the period 1960-1999. Rainfall erosivity increased by 91%, 71%, and 59%, respectively, under the three scenarios, suggesting severe detrimental impacts on soil and water resources. This research increases our understanding of how climate change may affect soil erosion, while pointing out the need for improved conservation strategies and land management practices to address future, non-stationary climatic conditions (Zhang et al., 2010).

A technician examines the snowfall collected in a precipitation gauge on the solar-powered telemetry system at the Reynolds Creek Watershed.

Theme 4: Remote sensing and in-situ technologies for water resource management

Accurate assessment water flux, particularly evapotranspiration (ET), is the key to understanding of the hydrologic cycle. Remote sensing provides and opportunity not only to help quantify the water cycle, but also to quantify different vegetative covers and land uses. Information derived from remote sensing is critical in documenting environmental change.

These selected accomplishments reported under Theme 4 are associated with Product 5: New remote sensing tools for terrain, ET, soil moisture, and water stress characterization and data interpretation methods for agricultural and rangeland environments; and Product 6: More accurate quantitative components of basin water budgets that consider ecosystem feedbacks affecting watershed states and fluxes and enhanced instrumentation (in-situ soil moisture, eddy-covariance, etc.) applications coordinated with ecosystem and biogeochemical observations.

Selected Accomplishments under Theme 4 of Problem Area 5

Drought-related reductions in agricultural productivity can have profound impacts on regional food security and global agricultural commodity markets. Our ability to mitigate these impacts is frequently limited by difficulties in accurately detecting the onset and severity of agricultural drought, particularly in underdeveloped regions of the world prone to food insecurity. To address this limitation, ARS scientists at Beltsville, MD, examined the microwave and thermal radiative signatures of agricultural landscapes undergoing drought, developing a series of satellite remote sensing tools to assess the availability of soil water in the root zone over large geographic regions. Compared to existing drought detection strategies based primarily on rainfall observations, these satellite-based strategies enable both the earlier detection of agricultural drought and a more detailed spatial description of its extent and severity. Eventually, these improvements will enhance our ability to mitigate the impacts of agricultural drought on global food markets, and to anticipate the social/political consequences of changes in food availability and price. Currently, these technologies, and/or the data sets they create, are being shared with operational drought monitoring activities at the USDA Foreign Agricultural Service, the National Oceanic and Atmospheric Administration, the National Environmental Satellite Data and Information Service, and the National Drought Mitigation Center (Anderson et al., 2011).

Accurate knowledge of vegetation condition is important for assessing agricultural production and forecasting yield. Satellites could collect this information, but conventional satellite-based vegetation sensors can only collect data during daylight and cannot "see" through clouds. Unfortunately, many parts of the world are plagued with almost constant cloud cover. ARS scientists at Beltsville, MD, developed a way to use microwaves to quantify vegetation condition regardless of weather, using currently operational satellites. Because microwaves are sensitive to properties of the entire canopy rather than just the leaves, microwave data can provide significant new information about vegetation condition and in many cases can "see" through plant canopies. Microwaves provide a complementary dataset to conventional satellite data that improves our capacity to monitor global agricultural productivity from space. This information has the capacity to improve the timeliness and reliability of crop condition assessments and yield forecasts made by USDA's Foreign Agricultural Service and other agencies both in the US and worldwide, with significant implications for improving international food security and agricultural adaptation to global climate change (Bolten et al., 2010).

Global soil moisture products are now being operationally generated from microwave-based satellite sensors by space agencies in the United States, Europe, and Japan. Validating these products is critical to potential users who typically require assurances concerning their accuracy and reliability. The disparity of spatial scales between what we are able to directly measure on the ground versus the coarse spatial resolution of the satellite sensors makes this a challenging task. In response to this challenge, soil moisture products were compared to in situ observations derived from spatially extensive ARS Experimental Watershed networks developed specifically for this purpose. These networks were based in the Little Washita (OK), Little River (GA), Walnut Gulch (AZ), and Reynolds Creek (ID) ARS Experimental Watersheds. Results indicate that each of the products evaluated had different performance statistics that depend on land surface characteristics. Nevertheless, it appears that satellite-based soil moisture products exhibit reasonable error bounds. For example, soil moisture retrievals derived from the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) instrument (on board the NASA Aqua satellite) were validated to within an accuracy of 0.05 m^3m^{-3} volumetric (i.e, the volume of water per unit volume of soil). Likewise, comparisons using the same set of ARS watershed soil moisture networks were used to provide an early indication that the European Space Agency Soil Moisture and Ocean Salinity (SMOS) mission - recently launched in late 2009 - is meeting its stated accuracy goal of estimating surface soil moisture to within an accuracy of 0.04 m^3m^{-3} (Jackson et al., 2010; Jackson et al., 2011).

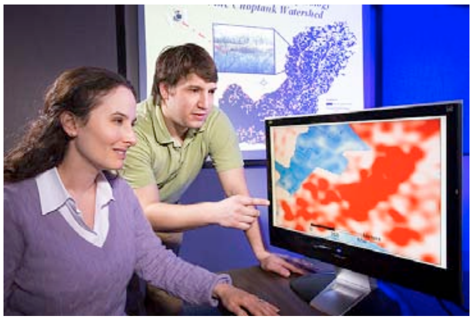
Better methods are needed for estimating water use in semiarid riparian systems so that regional water balances can be monitored and healthy riparian flows maintained. Working with the Universities of Arizona and Florida, ARS scientists in Tucson, AZ, explored using airborne and ground based LIDAR (LIght Detecting And Ranging) technology to improve water use estimates for a riparian system in Arizona. The LIDAR-derived estimates of canopy height, crown and trunk diameters, and canopy cover were used to quickly and accurately differentiate age classes of cottonwood trees in riparian areas in the San Pedro River Basin, near Benson, AZ. The LIDAR-derived canopy information will improve riparian corridor water use estimates in the Upper San Pedro Basin, with relevance to semiarid riparian systems in general. Accurate water use information is particularly valuable to regional water districts, so that efficient and timely releases of water can be made to maintain important urban, agricultural, and environmental flows (Farid et al., 2006a; 2006b; 2007).

Because of the link between atmospheric CO_2 concentrations and climate change, improved techniques for accurately quantifying CO_2 sources and sinks over large areas would be particularly useful. ARS scientists in Tucson, AZ, used a combination of satellite imagery, the Water Deficit Index, and Bowen ratio energy balance measurements to estimate daily net CO_2 fluxes from remotely sensed data. The approach could be used to map daily net CO_2 fluxes at the landscape scale, helping to better understand the contributions of semiarid grasslands to the global carbon cycle. This information will help improve estimates of carbon sequestration in grasslands, contributing to an increased understanding of global climate change (Holifield-Collins et al., 2008).

View of cotton field from helicopter showing reflectance tarps used in calibrating multi-spectral imagery equipment.

Soil texture and hydraulic properties are critical components of energy and water balance studies, but are not easily determined over heterogeneous regions. This study, conducted by ARS scientists at Tucson, AZ, in collaboration with the National Aeronautics and Space Administration (NASA) and the U.S. Army, used soil moisture estimates derived from satellite imagery to infer soil texture and hydraulic properties from a land surface model. This operational approach is useful for mapping soil information using available technology, to derive a better understanding of water availability in semiarid environments (Santanello et al., 2007).

Wetlands in agricultural landscapes are important because of their potential to remove agrochemicals before they enter aquatic ecosystems (e.g., Chesapeake Bay), where they can degrade both water quality and ecological communities. The majority of wetlands in the Chesapeake Bay Watershed are forested wetlands that are difficult to map and/or monitor using existing methodologies. ARS scientists at Beltsville, MD, used satellite-borne radar and air-borne lidar data to develop a new methodology to map forested wetlands at the watershed scale. Maps of forested wetland hydrology produced using radar and LIDAR data were well correlated with *in-situ* measurements of soil moisture and inundation. Next-generation wetland maps, produced by these remote sensing tools, provide a water quality management tool that can be used to quantify the proportionate contributions of various types of land uses to nutrient and sediment loads in the environment. These types of assessments are critical for calibrating models used by land managers and regulators in their efforts to improve the health of the Chesapeake Bay (Lang and McCarty, 2009).



Megan Lang and University of Maryland graduate student Robert Oesterling compare forested wetland maps for relationships between low (blue) and higher (white) elevations on one map and wet (red) and drier (white) spots on the other map. The maps were created with two remote-sensing technologies, one using laser light (LiDAR, or light detection and ranging), the other radio waves (SAR, or synthetic aperture radar).

Remote sensing has the potential to identify invasive weeds or shrubs that can have undesirable consequences (i.e., over-drafting limited water supplies or toxicity to grazing animals) for native plant communities. ARS scientists at Weslaco, TX, analyzed aerial photographs, applying spectral analyzing techniques to airborne hyperspectral images to successfully identify several different undesirable invasive plants. Successes include 1) Giant reed, an invasive weed found throughout the southern half of the US that presents a severe threat to agroecosystems and riparian areas; 2) Saltcedar, dense deep-rooted shrubs and trees that invade riparian areas and use excessive amounts of water; and 3) Broom snakeweed, a perennial shrub widely distributed across western North America that is undesirable due to its toxicity to livestock and its ability to reduce forage production). These results benefit natural resource managers and local, state, and federal government agencies by providing remote sensing technology to aid in the detection of invasive plant species over large geographic areas (Everitt et al., 2010).

During an aerial survey of streamside vegetation in Nevada, Joe Nance of Cloud Street Aerial Services, Fort Collins, Colorado, flies a light sport plane at about 300 feet while using a remote sensing package developed by ARS.

Land managers and policy makers across the globe need a regional-scale tool for measuring and inventorying soil salinity in agricultural fields where salt buildup can lower crop yields. A scientific team led by an ARS scientist at Riverside, CA, used Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery to assess and map soil salinity in 300,000 hectares of the Red River Valley (RRV) in North Dakota and Minnesota. Rising salinity levels in RRV soils have been linked to increases in precipitation and rising water tables due to climate change. Fifty-three percent of the observed variability in soil salinity measured *in situ* was correlated with a vegetation (crop) index derived from MODIS satellite imagery averaged over 7 years of data collection, and whether the land was eligible for inclusion in the CRP (a federal program that sets aside marginally productive land for conservation purposes). The observed relationship between soil salinity measured in the field and the satellite-derived vegetation (crop) index provides the NRCS with protocols and guidelines for mapping soil salinity over hundreds of thousands of hectares in the RRV, with applicability in other regions of the world as well (Lobell et al., 2010).

Leafy spurge (*Euphorbia esula*) is a noxious invasive weed species primarily occurring in the Northern Great Plains. Its yellow-green flower bracts are very distinctive and can be detected with imaging spectrometers flown in aircraft. The Weed Invasion Susceptibility Prediction (WISP) model predicts the distribution of leafy spurge over a landscape using geographic information systems (GIS). ARS scientists at Beltsville, MD, tested the WISP model for the distribution of leafy spurge near Devils Tower National Monument in Northeastern Wyoming using both field data and remote sensing data from NASA's Airborne Visible Infrared Imaging Spectrometer (AVIRIS). Each GIS data layer was compared to the remotely sensed classification and many of the variables used in the WISP model actually decreased accuracy. The improved potential distribution map was not only more accurate based on the field data, it also predicted considerably less land area that would be susceptible to invasion by leafy spurge. Remote sensing cannot detect the initial stages of invasion because the population densities are too low. Therefore, monitoring still must be done with field crews. Furthermore, hyperspectral remote sensing is expensive both for acquiring and for processing the data. By using remote sensing to determine the most probable areas that are susceptible to leafy spurge, monitoring on the ground will be much more efficient (Hunt et al., 2010).

Accurate measurements of ET (water use) are critical for determining the impacts of global climate change. Currently, the accuracy of ET measurements is limited by the lack of field-portable sources of precision water vapor standards. Field calibration of water vapor analyzers has always been a challenging problem for those making long-term flux measurements at remote sites. To remedy this, ARS researchers at St. Paul, MN, developed a field-portable mixing ratio generator with features that facilitate its use in water vapor isotope research. The temperature of water in the cell is monitored with a thermocouple and a pressure transducer is used to measure the cell pressure. A data logger uses this information to compute the mixing ratio in the cell and control the polarity and duty cycle of the power input to the Peltier block in order to drive the system toward the desired mixing ratio and to maintain it. Testing has shown that the unit is: 1) accurate over a broad range of mixing ratios; 2) able to compensate for changes in ambient pressure; and 3) stable for long periods of time. This information is useful to scientists for calibrating both conventional gas analyzers and water vapor isotope lasers for research applications, so that accurate measurements of evapotranspiration (water use), critical for determining impacts of global climate change, can be made (Baker and Griffis, 2010).

ARS pilot Michael René Davis flies the Cessna over the Jornada Range as researchers collect light-reflectance data.

Land surface fluxes and in particular ET are also strongly affected by variability in land surface properties (soil texture and land cover) and states (soil moisture and surface temperature) as well as overlying atmospheric conditions. The Large Eddy Simulation (LES) model has been fully coupled with a remote sensing-based land surface model for simulating the influence of land surface states and properties on exchange of heat, water vapor and momentum (wind energy) with the lower atmosphere. The model was applied to an agricultural study region in the Southern Great Plains for investigating in detail the spatial relationships between surface fluxes and near-surface atmospheric properties, and the potential errors in flux estimation due to homogeneous atmospheric inputs over heterogeneous landscapes. If air properties from a single weather station in a non-representative location within the landscape are applied uniformly over the domain, significant differences in surface flux estimation with respect to the LES output are observed. The spatial correlations of atmospheric properties with fluxes, the land cover properties, and surface states, were examined, and the spatial scaling of these fields analyzed, using a two-dimensional wavelet technique. The results indicate a significant local correlation of the spatial distributions of the air temperature, Ta, with the sensible heat flux, H, the specific humidity, q, with ET or latent heat flux, LE, and wind speed, U, with surface roughness, z0. A simple yet practical method has been proposed using remotely sensed observations and the land surface scheme, based on general linear expressions derived between Ta and H, q and LE/ET, and U and z0. This approach is recommended when only local weather station observations are available (Bertoldi et al., 2008).

While recent research suggests that tree cover in savanna systems improves under-canopy soil moisture, sustaining higher biomass in these locations, these under-canopy plant communities are often dominated by plants with well-developed drought-tolerant traits. By coupling measurements of soil water with whole-plant carbon and water fluxes, ARS scientists at Tucson, AZ, were able to show that understory soil water conditions, though less variable than between canopy spaces, were more limiting to plant carbon uptake. Thus higher soil water under savanna tree canopies appears to be a somewhat transient condition. Higher plant densities in these microhabitats appear to be associated with reductions in temperature and light stress due to shading, favoring plants capable of tolerating prolonged dry conditions. These findings are important in understanding controls to spatial patterns of productivity common to semiarid savanna systems (Hamerlynck et al., 2011).

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Problem Area 6: Water Quality Protection Systems

Nutrients and pesticides (insecticides, herbicides, fungicides) applied to agricultural fields, and pharmaceuticals (antibiotics and hormones) used in livestock production, can all move from their point of use into surface and ground waters, where their presence raises concerns about their impacts on aquatic and terrestrial ecosystems and human health. To evaluate fully the risks of using these chemicals and compounds in agriculture, there is a need to know their sources, transport behavior, fate, and biological impact at different concentrations and in different combinations in the environment. The ARS conducts research to better understand and predict the source, fate, transport, and environmental effects of nutrients, emerging contaminants, and inorganic ions. This work provides the basis for the development of best management practices across a range of climates, soils, and agricultural and urban settings. To better design and refine existing practices, new scientific information needs to be developed that clearly delineates how agricultural contaminants move and are transformed within the environment.

Theme 1: Nutrient management practices that minimize off-site transport

Agricultural management deals with two basic principles: 1) maximizing water and nutrient use efficiency; and 2) minimizing the threats of diseases and pests. At the most fundamental scale, plant roots obtain nutrients in the soil through the aqueous phase. Water in the root zone also carries nutrients and other pollutants to other parts of the ecosystem.

Under this Theme, selected ARS accomplishments in nutrient management are collected. The primary focus is on nitrogen (N) and phosphorus (P), but the use of animal manures is also included. These selected accomplishments are associated with Product 1: Scientific information regarding nutrient retention, transformation and transport processes, and field management techniques that reduce off-site nutrient movement; Product 2: Refinement and evaluation of P-based risk assessment tools at field, farm, and watershed scales; Product 3: Develop and refine sensors that detect variation in canopy nitrogen and water status and develop methods using these sensors for improved crop management and water quality; and Product 5: A Nitrogen Index (N Index) relative risk assessment tool that provides field guidance for potential movement of nitrogen via runoff, leachate, or gas emission from various landscapes and cropping systems.

Selected Accomplishments under Theme 1 of Problem Area 6

Manures from animal production systems are increasingly being used as sources of nutrients for agriculture. In contrast to surface application, injecting manure directly into the soil can have both environmental and economic benefits. In collaboration with colleagues at land grant universities in five mid-Atlantic states, ARS scientists at University Park, PA, Booneville, AR, and Auburn, AL, conducted research on new methods to incorporate manure directly into soil, as an alternative to the more common method of applying manure directly to the soil surface. By quantifying the benefits of injecting manures into soils with different technologies, researchers demonstrated the potential of new shallow injection technologies to: 1) lower odor to background levels within 3 hours of application; 2) decrease ammonia emissions by more than 70%; and 3) reduce P in runoff to levels comparable to soils that did not receive added manure. Relative to conventional methods, data from a field site on Maryland's Eastern Shore showed that phosphorus leaching losses were reduced by more than 40% with the manure injection technology. In addition, manure injection caused minimal soil disturbance, thus also reducing erosion in comparison with conventional tillage. The costs of purchasing and maintaining manure injectors were balanced or outweighed by improved use of manure nutrients by crops. As a result of this work, state and federal initiatives in the Chesapeake Bay watershed include plans to expand the use of manure injection technologies to more than 47,500 acres of agricultural lands. The USDA and university research team received the 2011 Mid-Atlantic Regional Educational Institution and Federal Laboratory Partnership Award, and their work has been cited in the Watershed Implementation Plans of four Chesapeake Bay watershed states--MD, NY, PA and VA (Maguire et al., 2011; Johnson et al., 2011; Brandt et al., 2011; Pote et al., 2011; Kibet et al., 2011).

ARS soil scientist Dan Pote observes as ARS technician Stephen Haller operates their invention, the Poultry Litter Subsurfer—the first commercially viable machine for applying dry poultry litter below ground.

Farmers can use fertilizers containing P to boost yields, but elevated P levels in streams and lakes are detrimental to water quality. The linkages between the amount of fertilizer applied to a watershed and the amount of P subsequently lost from the land ("loads") are poorly understood. Working with colleagues from the U.S. EPA and NRCS, ARS scientists at Oxford, MS, used the AnnAGNPS model computer simulations of an Ohio watershed to quantify the extent to which long-term high fertilization rates accentuate P loads leaving the watershed. Results of this analysis suggest that a "critical point" in soil P levels may exist beyond which P load increases dramatically. This finding is directly applicable to agencies and land managers implementing plans that include nutrient management practices and guidelines for agricultural watersheds (Yuan et al., 2011).

With traditional fertilizer management practices, it is not uncommon for less than 50% of added nitrogen (N) fertilizer to be taken up by growing corn crops. Real-time sensors can be used to increase nitrogen use efficiency in corn plants, providing the basis for matching corn nitrogen requirements with nitrogen fertilizer rates to maximize economic return and while minimizing N losses to the environment. ARS scientists at University Park, PA, showed that, compared with other methods of guiding N fertilizer rates, a canopy reflectance sensor provides recommendations that best match the economic optimum fertilizer rate. Besides producing more accurate N recommendations, the sensor provides immediate results that can be used to tailor fertilizer application rates to variable soil conditions within a field. While still new in Pennsylvania, this technology provides a way to improve N applications to corn, thus improving return for the farmer and reducing environmental losses in critical watersheds such as the Chesapeake Bay (Schmidt et al., 2010).

A similar effort using real-time sensors to manage nitrogen (N) application was conducted by ARS scientists at Lincoln, NE, in cooperation with University of Nebraska researchers. This research team developed equations to convert field variations in in-season readings from canopy reflectance sensors to variable N application rates across a field, producing a 15 to 40% savings in N compared to traditional practices. In addition, the new method requires only 2 or 3 sensors per 24-row applicator to monitor crop N status. As such, it should be relatively inexpensive to retrofit this technology to commercially available applicators (Bausch and Brodahl, 2011).

ARS hydrologist Tony Buda (far left) and Penn State University climatologist Paul Knight examine regional data they are using to develop a Web-based "fertilizer forecast," which will help farmers limit nutrient runoff by avoiding fertilizer applications before precipitation events. The program will use a range of weather variables, including the type of meteorological data Penn State associate professor Doug Miller and ARS soil scientist Peter Kleinman (far right) are studying in the background.

Managing N fertilizer is one of the many challenges facing farmers today. Establishing the economically optimal N rate (EONR) typically involves fitting an equation to yield versus N rate data and finding the point on the fitted curve where the profit from an incremental increase in yield just pays for the incremental increase in the cost of the added N fertilizer. While different types of equations have been fitted to yield-N rate data, a measure of the statistical reliability in the computed EONR is almost always lacking. ARS scientists at Ames, IA, demonstrated a new statistical method to compute EONR and its relative error that is applicable to most yield response equations, and then used this method to compare economically optimal N fertilizer rates for corn in a corn/soybean rotation among yield zones identified based on soil and landscape characteristics. Yield zones were generally demarked by slope position. Maximum yield was generally lower on the upper slope positions, but was a poor predictor of optimal N rate, which varied from 20 to 220 pounds per acre. Six years of central Iowa data indicate that N rates could be reduced by applying relatively less N fertilizer to lower slope positions, and more to upper slope positions. Dividing fields into yield zones may be a viable method for improving N fertilizer rates to corn, thereby reducing the potential for nitrate to be lost via surface and ground water flow. Helping researchers better design and interpret N fertilizer use efficiency experiments improves subsequent N management recommendations made to farmers, reducing fertilizer costs and improving water quality (Jaynes 2011; Jaynes et al., 2011)

Nitrate-N movement to tile drains represents an economic loss to farmers, and is a main cause of surface water and groundwater pollution in the Mississippi River Basin. Agroecosystem models have been widely used to evaluate management effects on N movement in tile-drained fields, but they do not accurately capture the variability of nitrate-N concentrations in tile drainage. ARS scientists at Fort Collins, CO, and Ames, IA, evaluated the performance of the RZWQM2, Ver. 2.0 in simulating the response of nitrate-N concentrations in tile drainage to different N fertilizer application rates, using a 16-year field study conducted in Iowa to evaluate the model. The RZWQM2 model accurately simulated the response of nitrate-N concentrations in tile drainage to N fertilizer rate, demonstrating that agroecosystem models like RZWQM2 can be used to help reduce both economic loss (through improved N management) and nitrate-N concentrations in surface waters (Qi et al., 2011b).

The sloping landscapes of the mid-Atlantic region have a distinct hydrology that can result in substantial differences in soil moisture availability during the growing season. ARS scientists at University Park, PA, demonstrated that improving N use efficiency by corn requires a better agronomic understanding of the interaction between soil moisture and nitrogen availability at a particular landscape position in the field. When soil moisture availability during the growing season is adequate, corn grain yield is directly related to N availability, but when soil moisture availability is low, N fertilizer has little effect on grain yield. Results support the ongoing improvement of precision N recommendations in sloping, mid-Atlantic landscapes, to minimize N losses to aquatic ecosystems that eventually drain into Chesapeake Bay (Schmidt et al., 2011).

ARS soil scientist Jorge Delgado (far left) and colleagues from Bolivia and Ecuador discuss the potential to use the Nitrogen Index and other nitrogen tools in those countries. Pictured with him are Ana Karina Saavedra Rivera (Bolivia), Luis Orlando Escudero López (Ecuador), and Carlos Marcial Monar Benavides (Ecuador).

Loss of soluble nitrogen and phosphorus from fertilizers to surface and ground waters is an unfortunate side effect of agricultural, turf, nursery, and home fertilizer use. A new fertilizer formulation strategy was developed by ARS scientists at Kimberly, ID, that employs chemical fixation and ion exchange, rather than encapsulation, to slow the release of N and P. In greenhouse studies, these patent pending formulations reduced N and P leaching losses by > 60%. The more than thirty industry enquiries received to date for joint development and licensing of this product, attest to the potential for commercial development of matrix-based fertilizer formulations to help reduce nutrient losses from fertilizer applications (Entry and Sojka, 2008).

Theme 2: Remediation of agricultural pollutants

The selected accomplishments reported here are associated with Product 4: New and improved technologies that remove nutrients from surface or subsurface waters; and Product 6: New knowledge and prediction capabilities of the physical, chemical, and biological processes affecting the retention, transformation, and transport of pesticides, pathogens, and pharmaceuticals and other contaminants and new management practices and tools for reducing their offsite movement.

Selected accomplishments related to on-site treatment of drainage water are reported under Problem Area 3, Theme 2.

Selected Accomplishments under Theme 2 of Problem Area 6

Farmers need low-cost, simple technologies to help reduce the export of excess nitrogen in subsurface drainage waters to sensitive aquatic ecosystems. Denitrifying bioreactors introduce solid carbon substrates into the flow path of contaminated water. ARS scientists at Ames, IA, summarized bioreactor design alternatives, effectiveness, and the factors limiting their performance. Bioreactors successfully removed nitrate in the field at rates of up to 22.0 g N m^{-3} d^{-1}. Removal rates varied with the design, the rate of water flow, and incoming nitrate concentrations. Bioreactors can also reduce the transport of veterinary antibiotics present in manure (e.g., sulfamethazine; enrofloxacin), and the herbicide atrazine, commonly applied to corn, without affecting denitrification rates. Denitrifying bioreactors are cost effective and complementary to other practices that can decrease nitrate loads to surface waters. This information will be of use to farmers and state and federal action agencies in setting priorities for the expenditure of conservation funds to improve surface waters affected by excess nitrate (Greenan et al., 2009; Ilhan et al., 2011; Jaynes et al., 2008; Shipper et al., 2010; Moorman et al., 2010).

Vegetative buffers are often used to reduce pollutant exports in waters draining from agricultural fields. Effective vegetative buffers require grass species that can capture nutrients before they run off the surface or leach to groundwater. In collaboration with scientists at the University of Missouri, ARS scientists at Columbia, MO, conducted a field study using five grass treatments (orchardgrass, tall fescue, smooth bromegrass, timothy, and switchgrass) compared to a bare ground control, to evaluate the ability of these grasses to remove nutrients, preventing their transport to shallow groundwater. All grass species except timothy reduced nitrate concentrations in shallow groundwater by ~99% compared to the control; switchgrass also reduced phosphate leaching by 60 to 74%. Grass treatments reduced soil nitrate levels by 41 to 91%. Because of their superior ability to reduce soil nitrate and nutrient leaching, switchgrass, smooth bromegrass, and tall fescue were the most suitable species for use in vegetative buffers. These findings provide important information to improve the design of vegetative buffers, increasing their effectiveness in nutrient removal (Lin et al., 2007a).

Uptake of P in vegetative buffers varies by grass species and P availability. Harvesting of buffer vegetation offers the opportunity to increase the supply of harvested biomass and remove nutrients that accumulate in buffers. Researchers found that reed canarygrass and switchgrass were better choices than smooth brome for P removal through biomass harvest. Switchgrass takes up more P from soil solutions initially high in P, but reed canarygrass performs best when low P solutions receive added P (simulating P inputs from runoff). Results support other recent evidence that species selection can be critical in determining the effectiveness of conservation practices such as vegetative buffers. This research should be of interest to agricultural producers, conservation planners, and policy makers seeking to improve buffer design and considering biomass harvest from conservation plantings (Kovar and Claassen, 2009).

In addition to the benefit of vegetative buffers in reducing nutrient runoff, the ARS research team at Columbia, MO, also studied the effects of forage species in vegetative buffers on pesticide degradation. The results showed that the majority of applied atrazine remained in the soil; only relatively small proportions of herbicide were leached to shallow groundwater (<15%) or taken up by plants (<4%). Grasses appear to enhance atrazine degradation in soil through their ability to increase microbial growth and activity in surface soil. Because of its ability to tolerate particularly high levels of exposure to atrazine, switchgrass is recommended for use in vegetative buffers designed to reduce atrazine transport to surface or ground waters. In a related study, ARS scientists in Miami, FL, demonstrated that switchgrass buffers were also effective in stopping the movement of endosulfan and its major degradation products down a 5 % slope. Since it provides the needed science for improving vegetative buffer designs to improve the protection of water resources impacted by row crop production, this research benefits both federal conservation agencies (e.g., NRCS) and state conservation departments (Lin et al., 2008).

Native grass buffers (including switchgrass and gammagrass) were found to be most effective in reducing atrazine, a widely used herbicide, in runoff.

Offsite transport of herbicides is a potential environmental problem. ARS scientists at St. Paul, MN, examined the impacts of six different biochars, activated charcoal, organoclay, and a biomass waste stream (olive mill waste), on the sorption and leaching of two herbicides [fluometuron and 2-methyl-4-chlorophenoxyacetic acid (MCPA)]. Amendments were added at 2% by weight to soil. Biochars are assumed to increase binding (sorption) of herbicides. However, in this study a biochar created by fast combustion (pyrolysis) of macadamia shells actually decreased observed sorption of the two herbicides in biochar-amended soil. Activated carbon resulted in complete sorption and no detectable leaching of the herbicides. Two of the biochars (a fast pyrolysis hardwood biochar and a slow pyrolysis hardwood biochar) increased observed sorption, but in the column study these two biochars resulted in increased leaching of the two herbicides. The organoclays also increased sorption but decreased leaching. These results indicate that the impact of biochar on herbicide transport is biochar specific; no general biochar behavior should be assumed. This finding could provide additional insight and direction in the focus of the benefits of biochar additions on improving water quality by sorbing agrochemicals. These results are significant to farmers and policy makers and will assist scientists and engineers in developing improved mechanisms of biochar additions for herbicide sorption to decrease agrochemical transport to groundwater (Cabrera Mesa and Spokas, 2011).

Bulk hardwood biochar prior to application on plots near Ames, Iowa.

South Florida's surficial aquifer provides potable water for nearly all of South Florida's rapidly growing population. Agricultural practices, which contribute to water quality impairment, have the potential to adversely affect the massive project focused on restoring South Florida's Everglades ecosystem. Investigations were conducted in southern Florida to assess risks to groundwater quality from atrazine used for sweet corn production in the region, and whether maintaining fields with a highly vigorous cover crop, Sun Hemp [Crotalaria juncea L.], during summer fallow periods, would reduce impacts. Results demonstrated that climatic and cropping patterns, relatively high dilution rates in the surficial aquifer, and high atrazine degradation rates in soil limit contamination levels as compared to other atrazine use sites. Measurements also showed that cover crop use leads to significantly lower contaminant levels in groundwater. Atrazine use presents a small, although potentially significant, risk to groundwater quality in southern Florida. The use of a cover crop like Sun Hemp during summer months, when fields are fallow, may be an effective mitigation measure. As a result of this research, growers are being strongly encouraged to plant cover crops, which have many other potential benefits (e.g., reduced nutrient leaching and wind erosion; improved soil quality) in addition to reducing herbicide leaching.

Along with arid region crop irrigation practices, farm field municipal sewage sludge and wastewater applications can each lead to the presence of heavy metals in surface runoff and subsurface drainage waters, which are then discharged into local streams, rivers and lakes. ARS scientists at Columbus, OH, conducted a laboratory study to evaluate the heavy metal removal capabilities of four iron based filter materials. Results indicate that each of the four materials removes some or most of these contaminants present in water. Consequently, filter systems containing iron based materials are an option for field removal of heavy metals found in agricultural surface runoff and subsurface drainage waters, thereby providing an environmental benefit to the public (Allred, 2010).

Agricultural drainage ditches are important components of water management infrastructure, but little is known about how these ditches affect water quality. ARS scientists in Oxford, MS, found that vegetated agricultural drainage ditches were effective in reducing insecticide levels. Depending on the insecticide evaluated, between 20 and 70% of the initial concentration was decreased between inflow and ditch outflow. Vegetations in the ditches played a significant role in reducing the pesticide levels. These findings will help refine technologies that use wetlands to ameliorate agricultural pollution, allowing more informed decisions regarding nutrient and insecticide best management practices (Moore et al., 2008; Moore et al., 2011; Werner et al., 2010; Lizotte et al., 2011).

Treatment strategies for agricultural runoff include constructed, natural, or restored wetlands as buffers between agricultural fields and nearby water sources. ARS scientists in Oxford, MS, found that the long-term growth patterns of live, caged mussels placed in a constructed wetland were affected by insecticides received in artificial runoff, and documented elevated releases of phosphorus during winter die off when a common wetland plant species was exposed to elevated levels of nitrogen and phosphorus. These findings will help refine technologies that use wetlands to ameliorate agricultural pollution, allowing more informed decisions regarding nutrient and insecticide best management practices (Bouldin et al. 2007; Kröger et al. 2007).

In a constructed wetland in Mississippi, agricultural engineer Bobby Cullum (left) collects water samples as ecologist Matt Moore uses a multimeter to record water quality to determine how well the wetland filters pollutants.

Wetlands may be used to trap and process pollutants in agricultural runoff, but little is known about the optimal types of aquatic vegetation for such remediation. ARS scientists at Oxford, MS, found that a constructed wetland reduced the initial toxicity of simulated storm-event agricultural runoff more than a similar sized holding basin without wetland plants. Simulated runoff was amended with two pesticides, diazinon and permethrin, and two nutrients, nitrogen and phosphorus. The study showed that plants were better at decreasing the effects of nutrients and pesticides within the first 5 hours, but no differences between the wetland and unvegetated holding basin were noted for longer periods. Nutrient and pesticide contaminated water had to be retained in the constructed wetland for 21 days to remove toxicity. These results are of interest to regulatory and other agencies and the pesticide industry by providing additional information to improve and sustain river, stream and lake water quality and overall environmental quality using wetlands as an effective conservation practice (Lizotte et al. 2011).

Theme 3: Quantifying agricultural chemicals and pathogens in the environment

The selected accomplishments are associated with Product 6: New knowledge and prediction capabilities of the physical, chemical, and biological processes affecting the retention, transformation, and transport of pesticides, pathogens, and pharmaceuticals and other contaminants and new management practices and tools for reducing their offsite movement.

Some accomplishments related to remediation efforts are reported under Theme 2 above. Also, accomplishments related to quantifying pesticides in the environment are also reported under Program Area 1, Theme 2.

Selected Accomplishments under Theme 3 of Problem Area 6

Especially in runoff-prone watersheds, herbicide contamination of surface waters remains an environmental problem. ARS scientists at Columbia, MO, analyzed 15-year (1992 to 2006) trends in five common herbicides in the Goodwater Creek Experimental Watershed (GCEW), and developed a simple index that explained annual variation in herbicide transport from planting progress, runoff events, and soil dissipation rate. Over this 15-year period, trends were apparent only for those herbicides that had been phased into or out of use (i.e., metolachlor, alachlor, and acetochlor). Despite substantial education and extension efforts in the region, especially for atrazine management, no trends were discernible for either atrazine or metribuzin. Combined with previously published research on the vulnerability of restrictive layer soils to herbicide transport, this work has resulted in widespread recognition among both other federal agencies (e.g., the U.S. EPA and the USGS) and atrazine registrants as to the critical nature of understanding spatial variations in atrazine contamination across the Corn Belt. Both agencies have expressed interest in the index, the EPA used the atrazine data during re-registration, and instead of applying the national Watershed Regressions for Pesticides (WARP) model in the region, the USGS has acknowledged the importance of restrictive soil layers by developing a new WAPR model (WARP-CB) specifically for use in the corn belt (Lerch et al. 2010a, b).

Runoff or irrigation return flows from agricultural lands can also contain harmful concentrations of pesticides. ARS scientists at Oxford, MS, found that aqueous diazinon and atrazine concentrations in water passing through a rice field decreased by approximately 80%. Based on current ecological economic values for water quality improvement, the water treatment value of the rice was almost triple that of its market value when harvested as a typical crop (based on current commodity prices). Such valuation of ecosystem services is necessary to stimulate implementation of sustainable practices (Moore et al., 2009a, 2009b; Kröger et al., 2009).

Accurately assessing the fate of herbicides and their metabolites in the environment requires the development of sensitive analytical techniques. In collaboration with University of Missouri researchers, ARS scientists at Columbia, MO, developed two new analytical methods for: 1) analyzing atrazine and its chlorinated metabolites in plants; and 2) the analysis of isoxaflutole (IXF) and its two primary metabolites in soils and plants. Both methods employ chromatography to separate the compounds of interest. Subsequent detection by mass spectrometry results in sub-parts per billion detection limits (1 to 2 orders of magnitude more sensitive than previously published methods). To demonstrate their utility, these methods were applied to measurements of plants or soils from a field experiment. Results showed that in forage grasses, ratios of metabolites to parent compounds were good indicators of the detoxification pathways and overall sensitivity to each herbicide. Scientists, regulators, and industry will benefit from the availability of these appropriately sensitive methods for measuring herbicides and their metabolites in plants and soils, improving understanding of their fate in the environment, and potentially leading to the development of vegetative buffers that more effectively prevent surface and ground water contamination (Lin et al., 2007a; 2007b).

The herbicide, Balance, is a relatively new product marketed as a substitute for atrazine, the most commonly used corn herbicide. Recent studies by ARS scientist in Columbia, MO, and at the University of Missouri, have shown that two of the Balance break-down products (degradates) are readily transported to shallow groundwater and, based on their chemical properties, are also likely to contaminate streams. One of the key mechanisms responsible for reducing the hydrologic transport of herbicides is their ability to bind to soil, a process referred to as sorption. The key objective of this study was to determine if soil iron and aluminum oxides can sorb the Balance degradates, diketonitrile (DKN) and benzoic acid (BA). Iron and aluminum oxides did show significant capacity to sorb both degradates, with slightly greater sorption to iron. Thus, metal oxides can help to reduce the transport of DKN and BA in acidic soils enriched with metal oxides, such as those common in the southern US. Land management agencies and growers can use this information to guide choices regarding the use of Balance to minimize its contamination of streams and shallow ground waters (Wu et al. 2011).

Herbicides present in untreated water can react with the chlorine used by water treatment plants for disinfection. In collaboration with the University of Missouri, ARS scientists at Columbia, MO, studied the breakdown of DKN, the herbicidal metabolite of the corn herbicide isoxaflutole (Balance), by chlorine. DKN has been shown to be both present in the surface waters of the major corn-growing states and to rapidly react with chlorine. Results showed that DKN was completely broken down by chlorine during the water treatment process, but that two potentially harmful products were formed: cyclopropanecarboxylic acid (CPCA) and dichloroacetonitrile (DCAN). Fortunately, levels were below those reported to cause toxic effects in humans or animals. This research identifies a potential human health issue associated with agricultural production, demonstrating that chlorination results in the complete breakdown of DKN, generating the potentially harmful breakdown products CPCA and DCAN, that appear to be present only at sub-toxic levels in affected drinking waters. Best management practices suggest routine CPCA and DCAN monitoring of chlorinated drinking water for the short term, and the development of techniques to remove these products from drinking water supplies over the long term (Lerch et al., 2007).

Aminocyclopyrachlor (trade name Imprelis) is a new herbicide from a new class of chemical compounds known as pyrimidine carboxylic acids. Although aminocyclopyrachlor has exhibited a number of positive stewardship attributes with very low impacts to mammals and the environment, not much is known about its fate in soil. ARS scientists at St. Paul, MN, characterized the binding of aminocyclopyrachlor to soil in 14 soils from the United States and Brazil exhibiting a range of pH, organic carbon, and clay content. Data suggest that although aminocyclopyrachlor would be very mobile based on its binding (sorption) coefficients, its potential for offsite transport may be overestimated. Because Imprelis does not readily desorb from soil, its potential mobility may be less than previously anticipated. Now scientists can better evaluate its potential mobility, information that is needed for aminocyclopyrachlor, particularly in light of reported possible damage to evergreen trees when applied to adjacent turf areas (Oliveira et al., 2011).

Runoff from a field planted with corn is directed into a grassed waterway where it passes through and over a series of compost-filled filter socks that help reduce levels of nutrients and herbicides.

Nitrogen, phosphorus, and herbicides associated with managed turf systems (e.g., golf courses) have been detected in both stormwater runoff and surface waters in urban watersheds. ARS scientists at St. Paul, MN, evaluated the effectiveness of management practices to mitigate the off-site transport of pesticides in runoff from turf managed as a golf course fairway. Relative to other commonly used cultivation methods, cultivation using hollow tine cores (HTCC) reduced the percentage of precipitation that became runoff. Likewise, the percentages of the applied herbicides dicamba, MCPP, and 2,4-D measured in runoff were lower from turf managed with HTCC. In cooperation with a private research organization, ARS scientists at Columbus, OH, quantified surface losses of both soluble and total nutrients from a managed turf system in Duluth, MN. Nutrients in surface runoff exhibited a seasonal trend, were detectable throughout the year, and routinely exceeded levels recommended to minimize algal blooms. This research provides quantitative information to inform decisions on turf management that can maximize chemical retention at the site of application, while minimizing environmental contamination and adverse effects associated with the off-site transport of chemicals in surface waters (Rice et al., 2010; King and Balogh, 2008).

ARS agricultural engineer Kevin King (right) and soil scientist Jim Balogh, of Spectrum Research, Inc., inspect a filter cartridge system being evaluated at a golf course tile drainage site. The cartridge system was donated by cooperating industry Kristar Enterprises, Inc.

Periodic flooding of soil causes substantial decreases in agricultural production in Midwestern U.S., but how short-term flooding affects the biogeochemistry of the root zone and subsequent plant growth has not been quantified. ARS scientists at West Lafayette, IN, performed a greenhouse study comparing corn grown with free drainage to that with a perched water table. Gypsum was applied with both reduction conditions. In the perched water table pots, corn roots died at or near the zone of low redox potential caused by the perched water table. This was alleviated by the addition of gypsum and the roots flourished throughout this zone. In addition, mercury (Hg) accumulations were 10-fold higher in plants grown with a perched water table, independent of gypsum addition. Results indicate that soil drainage is not only important for plant growth, but that applying gypsum to soils can prevent production losses due to flooding, but not the accumulation of Hg in plants (Acuna-Guzman, 2009).

Technicians Allan Knopf and Sharette Evans collect water samples from a pond that supplies irrigation water to Pacana Park in Maricopa, Arizona. In the laboratory, the pond-water samples are tested for presence of humanspecific Bacteroides molecular markers.

Accurate testing for the presence of fecal indicator bacteria (*E. coli* and enterococcus) is of high importance for treated wastewater, where water quality is assessed under a permitted system in which a high error rate could result in unnecessary use of disinfectant or an invalid violation of a discharge permit. ARS scientists in Maricopa, AZ, found that methods for Enterococcus identification in surface waters were robust, and that *E. coli* identification was highly accurate (less than 4% error rate), but misidentification rates of *E. coli* in reclaimed water approached 50%. Far higher false positive rates were observed in winter, raising the possibility that increased survival of competing bacteria in cooler waters may contribute to misidentification. This information will be useful in the development of improved *E. coli* identification methods. The work highlights the extreme importance of validation of microbiological results from selective media for accurate analysis of wastewater quality (Mclain and Williams, 2011).

Land application of bio-solids can introduce persistent, slow moving trace metals and other contaminants to the subsurface environment, affecting environmental quality and human health for decades. Safe use of bio-solids in agriculture requires accurate risk assessment of contaminant fate and transport. In collaboration with researchers in Sweden and Brazil, ARS scientists in Riverside, CA, developed a new contaminant transport model suitable for assessing the transport of slow moving contaminants in the root zone. The model has relatively modest data requirements, yet is more realistic than other root-zone models currently in use or proposed for use in bio-solid risk assessment. This new modeling tool will benefit both researchers and regulators who are charged with assessing the impacts of persistent contaminants in the root zone (Simunek and Van Genuchten, 2007).

Successful understanding and modeling of chemical transport in soils and groundwater is a precondition of risk-informed predictions of subsurface contaminant transport. Present day water quality models, though complex, are typically poor predictors of chemical transit times. However model abstraction is an emerging methodology for reducing the complexity of a simulation model while maintaining the validity of the simulation. The objective of this work was to use model abstraction techniques to characterize and understand flow and transport in soils in the presence of shallow groundwater. ARS scientists at Beltsville, MD, developed two case studies by carrying out two types of field tracer experiments at the USDA Optimizing Production Inputs for Economic and Environmental Enhancement (OPE3) field site, applying a sequence of model simplifications based on existing hydrologic models. Soil moisture, soil water potential, tracer concentrations in groundwater, groundwater levels, and weather data, along with ground-penetration radar surveys, electric resistivity monitoring, and dilution tests complemented borehole log data and laboratory hydraulic measurements to characterize soil heterogeneity. The invoked series of model abstractions showed the important role of subsurface heterogeneity in the vadose zone and groundwater, substantially improving the conceptualization of the subsurface (Yakirevich et al., 2009)

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APPENDIX 1

National Program 211 – Water Availability & Watershed Management

ACCOMPLISHMENT REPORT 2007 – 2011

Research Projects in National Program 211*

[By Action Problem Area]

Problem Area 1: Effectiveness of Conservation Practices.

3625-13000-009-00D
WATER QUALITY IMPROVEMENT FROM MANAGEMENT PRACTICES IN AGRICULTURAL WATERSHEDS – Tomer, Mark (P); Hatfield, Jerry; Jaynes, Dan; Kaspar, Thomas; Logsdon, Sally; Malone, Robert; and Moorman, Thomas; Ames, Iowa.

3625-12000-012-00D
ECOLOGICALLY-BASED SOIL MANAGEMENT FOR SUSTAINABLE AGRICULTURE AND RESOURCE CONSERVATION – Karlen, Douglas (P); Olk, Daniel; Logsdon, Sally; Hatfield, Jerry; Cambardella, Cynthia; and Kovar, John; Ames, Iowa.

1265-13610-027-00D
USING REMOTE SENSING & MODELING FOR EVALUATING HYDROLOGIC FLUXES, STATES, & CONSTITUENT TRANSPORT PROCESSES WITHIN AGRICULTURAL LANDSCAPES – Crow, Wade (P); Alfieri, Joseph; Anderson, Martha; Cosh, Michael; Gish, Timothy; Jackson, Thomas; Kustas, William; McCarty, Gregory; and Sadeghi, Ali; Beltsville, Maryland.

3622-12130-004-00D
DEVELOPMENT OF ALTERNATIVE PRACTICES FOR IMPROVED WATERSHED MANAGEMENT – Lerch, Robert (P); Baffaut, Claire; Kitchen, Newell; Kremer, Robert; Sadler, Edward; and Vories, Earl; Columbia, Missouri.

3604-13000-009-00D
ENVIRONMENTAL AND SOURCE WATER QUALITY EFFECTS OF MANAGEMENT PRACTICES AND LAND USE ON POORLY DRAINED LAND – King, Kevin (P); Fausey, Norman; and Smiley Jr, Peter; Columbus, Ohio.

5358-21410-002-00D
INTEGRATING PRODUCTION AND CONSERVATION PRACTICES TO MAINTAIN GRASS SEED FARM PROFITS – Griffith, Stephen (P); Whittaker, Gerald; Pfender, William; Banowetz, Gary; and Mueller Warrant, George; Corvallis, Oregon.

6218-13000-010-00D
HYDROLOGIC AND ENVIRONMENTAL IMPACTS OF CONSERVATION PRACTICES IN OKLAHOMA AGRICULTURAL WATERSHEDS – Starks, Patrick (P); Garbrecht, Jurgen; Moriasi, Daniel; and Steiner, Jean; El Reno, Oklahoma.

5402-13660-007-00D

OBJECT MODELING AND SCALING OF LANDSCAPE PROCESSES AND CONSERVATION EFFECTS IN AGRICULTURAL SYSTEMS – Ascough II, James (P); Ahuja, Lajpat; Dunn, Gale; Green, Timothy; Ma, Liwang; and McMaster, Gregory; Fort Collins, Colorado.

5368-13000-008-00D
SOIL AND WATER CONSERVATION FOR NORTHWESTERN IRRIGATED AGRICULTURE – Bjorneberg, David (P); Ippolito, James; Lentz, Rodrick; King, Bradley; Dungan, Robert; and Lehrsch, Gary; Kimberly, Idaho.

6208-13000-006-00D
MANAGING LIMITED IRRIGATION AND RAINFALL FOR CROP PRODUCTION IN SEMI-ARID ENVIRONMENTS – Baker, Jeffrey (P); Acosta-Martinez, Veronica; Gitz, Dennis; Lascano, Robert; Mauget, Steven; Van Pelt, Robert; and Zobeck, Teddy; Lubbock, Texas.

6408-13000-018-00D
INTEGRATED ASSESSMENT AND ANALYSIS OF PHYSICAL LANDSCAPE PROCESSES THAT IMPACT THE QUALITY AND MANAGEMENT OF AGRICULTURAL WATERSHEDS – Bingner, Ronald (P); Dabney, Seth; Kuhnle, Roger; Langendoen, Eddy; Rigby, James; Romkens, Mathias; Wells, Robert; Wilson, Glenn; and Wren, Daniel; Oxford, Mississippi.

6408-13000-020-00D
TECHNOLOGIES FOR ASSESSING SEDIMENT MOVEMENT & THE INTEGRITY OF FLOOD CONTROL STRUCTURES, STREAMBANKS, & EARTHEN POND-LEVEES & EMBANKMENTS – Kuhnle, Roger (P); Dabney, Seth; Langendoen, Eddy; Romkens, Mathias; Wilson, Glenn; and Wren, Daniel; Oxford, Mississippi.

6408-13660-006-00D
UNDERSTANDING AND PREDICTING THE IMPACT OF AGRICULTURE ON THE ENVIRONMENTAL INTEGRITY OF MANAGED WATERSHEDS – Locke, Martin (P); Bingner, Ronald; Cullum, Robert; Knight, Scott; Lizotte, Richard; Moore, Matthew; Rhoton, Fred; Romkens, Mathias; and Shields, Douglas; Oxford, Mississippi.

6206-13610-006-00D
DEVELOPMENT OF MODELS AND CONSERVATION PRACTICES FOR WATER QUALITY MANAGEMENT AND RESOURCE ASSESSMENTS – Arnold, Jeffrey (P); Harmel, Daren; Kiniry, James; Rossi, Colleen; and White, Michael; Temple, Texas.

6602-13000-025-00D
CONSERVATION EFFECTS ASSESSMENT IN THE SOUTH GEORGIA LITTLE RIVER – Bosch, David (P); Hubbard, Robert; Lowrance, Robert; Potter, Thomas; and Strickland, Timothy; Tifton, Georgia.

6602-13000-023-00D
LAND USE AND MANAGEMENT EFFECTS ON ENVIRONMENTAL PROCESSES AND HYDROLOGY IN COASTAL PLAIN WATERSHEDS – Lowrance, Robert (P);Bosch, David; Hubbard, Robert; Potter, Thomas; Stricklan, Timothy; and Truman, Clinton; Tifton, Georgia.

1902-13000-011-00D
INTEGRATED MANAGEMENT OF LAND AND WATER RESOURCES FOR ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY IN THE NORTHEAST U.S. – Kleinman, Peter (P);Bryant, Ray; Buda, Anthony; Church, Clinton; Dell, Curtis; and John Schmidt; University Park, Pennsylvania.

3602-13000-008-00D

CONSERVATION EFFECTS ASSESSMENT FOR THE ST. JOSEPH RIVER WATERSHED – Smith, Douglas (P); Heathman, Gary; Huang, Chi-hua; Norton, Lloyd; and Pappas, Elizabeth; West Lafayette, Indiana.

Problem Area 2: Irrigation Water Management.

5407-12130-006-00D
DRYLAND CROPPING SYSTEMS MANAGEMENT FOR THE CENTRAL GREAT PLAINS – Vigil, Merle (P); Nielsen, David; Mika, Maysoon; Benjamin, Joseph; and Calderon, Francisco; Akron, Colorado.

3625-11120-003-00D
BIOGEOCHEMICAL PROCESSES INFLUENCING FORMATION AND STABILIZATION OF SOIL ORGANIC MATTER AND SOIL STRUCTURE – Laird, David (P); Karlen, Douglas; Hatfield, Jerry; and Olk, Daniel; Ames, Iowa.

1265-13610-027-00D
USING REMOTE SENSING & MODELING FOR EVALUATING HYDROLOGIC FLUXES, STATES, & CONSTITUENT TRANSPORT PROCESSES WITHIN AGRICULTURAL LANDSCAPES – Crow, Wade (P); Alfieri, Joseph; Anderson, Martha; Cosh, Michael; Gish, Timothy; Jackson, Thomas; Kustas, William; McCarty, Gregory; and Sadeghi, Ali; Beltsville, Maryland.

6209-13000-013-00D
SUSTAINING RURAL ECONOMIES THROUGH NEW WATER MANAGEMENT TECHNOLOGIES – Brauer, David (P); Baumhardt, Roland; Colaizzi, Paul; Evett, Steven; Gowda, Prasanna; Howell, Terry; Lascano, Robert; Schwartz, Robert; Tolk, Judy; Van Pelt, Robert; and Zobeck, Teddy; Bushland, Texas.

3622-13610-002-00D
OPTIMIZING IRRIGATION MANAGEMENT FOR HUMID CLIMATES – Vories, Earl (P); Sadler, Edward; and Sudduth, Kenneth; Columbia, Missouri.

6657-13000-009-00D
MANAGING WATER AVAILABILITY AND QUALITY TO MAINTAIN OR INCREASE AGRICULTURAL PRODUCTION, CONSERVE NATURAL RESOURCES, AND ENHANCE ENVIRONMENT – Stone, Kenneth (P); Bauer, Philip; Hunt, Patrick; Ro, Kyoung; Ducy, Thomas; and Busscher, Warren; Florence, South Carolina.

5402-13220-003-00D
IRRIGATION AND PRECISION MANAGEMENT STRATEGIES TO SUSTAIN AGRICULTURE WITH LIMITED WATER SUPPLIES – Trout, Thomas (P); Bausch, Walter; Shaner, Dale; and Wiles, Lori; Fort Collins, Colorado.

5368-13000-008-00D
SOIL AND WATER CONSERVATION FOR NORTHWESTERN IRRIGATED AGRICULTURE – Bjorneberg, David (P); Ippolito, James; Lentz, Rodrick; King, Bradley; Dungan, Robert; and Lehrsch, Gary; Kimberly, Idaho.

6208-13000-006-00D
MANAGING LIMITED IRRIGATION AND RAINFALL FOR CROP PRODUCTION IN SEMI-ARID ENVIRONMENTS – Baker, Jeffrey (P); Acosta-Martinez, Veronica; Gitz, Dennis; Lascano, Robert; Mauget, Steven; Van Pelt, Robert; and Zobeck, Teddy; Lubbock, Texas.

5347-13000-002-00D
REUSE OF TREATED MUNICIPAL WASTE WATER FOR IRRIGATION – Williams, Clinton (P); and McLain, Jean; Maricopa, Arizona.

5347-13660-006-00D
REMOTE SENSING FOR CROP AND WATER MANAGEMENT IN IRRIGATED AGRICULTURE – Hunsaker, Douglas (P); French, Andrew; and Thorp, Kelly; Maricopa, Arizona.

5347-13000-015-00D
WATER MANAGEMENT IN ARID IRRIGATED AGRICULTURE – Bautista, Eduardo (P); and Strelkoff, Theodore; Maricopa, Arizona.

5302-13000-010-00D
WATER MANAGEMENT TO IMPROVE PRODUCTIVITY AND PROTECT WATER QUALITY – Ayars, James (P); Banuelos, Gary; Gao, Suduan; and Wang, Dong; Parlier, California.

5310-13210-009-00D
SALINITY AND TRACE ELEMENT MANAGEMENT FOR CROP PRODUCTION IN IRRIGATED AGRICULTURAL SYSTEMS – Grieve, Catherine (P); Riverside, California.

5310-12130-008-00D
MINIMIZING AIR & WATER CONTAMINATION FROM AGRICULTURAL PESTICIDES – Yates, Scott (P); and Skaggs, Todd; Riverside, California.

5310-61000-013-00D
SALINITY AND TRACE ELEMENTS ASSOCIATED WITH WATER REUSE IN IRRIGATED SYSTEMS: PROCESSES, SAMPLING PROTOCOLS, AND SITE-SPECIFIC MANAGEMENT – Suarez, Donald (P); Corwin, Dennis; and Goldberg, Sabine; Riverside, California.

5310-61000-014-00D
IMPROVED KNOWLEDGE AND MODELING OF WATER FLOW AND CHEMICAL TRANSPORT PROCESSES IN IRRIGATED SOILS – Skaggs, Todd (P); and Bradford, Scott; Riverside, California.

5436-13210-005-00D
ECOLOGICALLY-SOUND PEST, WATER AND SOIL MANAGEMENT STRATEGIES FOR NORTHERN GREAT PLAINS CROPPING SYSTEMS – Evans, Robert (P); Allen, Brett; Jabro, Jalal; Lartey, Robert; Sainju, Upendra; Stevens, William; and Caesar, Thecan; Sidney, Montana.

3640-31000-006-00D
DESIGNING FORAGES WITH IMPROVED CELL WALL DIGESTIBILITY AND GREATER INTAKE POTENTIAL – Jung, Hans Joachim (P); St. Paul, Minnesota.

6402-12130-003-00D
DEVELOPMENT OF SUSTAINABLE PRODUCTION SYSTEMS AND WATER MANAGEMENT TECHNOLOGY FOR THE MID SOUTH – Sassenrath, Gretchen (P); Stoneville, Mississippi.

6602-13000-023-00D
LAND USE AND MANAGEMENT EFFECTS ON ENVIRONMENTAL PROCESSES AND HYDROLOGY IN COASTAL PLAIN WATERSHEDS – Lowrance, Robert (P);Bosch, David; Hubbard, Robert; Potter, Thomas; Stricklan, Timothy; and Truman, Clinton; Tifton, Georgia.

6602-13000-025-00D
CONSERVATION EFFECTS ASSESSMENT IN THE SOUTH GEORGIA LITTLE RIVER – Bosch, David (P); Hubbard, Robert; Lowrance, Robert; Potter, Thomas; and Strickland, Timothy; Tifton, Georgia.

6612-13000-002-00D
PROTECTING WATER QUALITY AND MITIGATING DROUGHT IN THE SOUTHEASTERN USA – Fisher, Dwight (P); Franklin, Dorcas; Endale, Dinku; Schomberg, Harry; Sharpe, Ronald; Reeves, Donald; and Jenkins, Michael; Watkinsville, Georgia.

Problem Area 3: Drainage Water Management.

3625-13000-009-00D
WATER QUALITY IMPROVEMENT FROM MANAGEMENT PRACTICES IN AGRICULTURAL WATERSHEDS – Tomer, Mark (P); Hatfield, Jerry; Jaynes, Dan; Kaspar, Thomas; Logsdon, Sally; Malone, Robert; and Moorman, Thomas; Ames, Iowa.

6410-13000-010-00D
INTEGRATED WATER, SOIL, AGROCHEMICAL, AND CROP MANAGEMENT SYSTEMS FOR THE SUSTAINABLE PRODUCTION OF BIOFUELS IN HUMID ENVIRONMENTS – White Jr, Paul (P); Johnson, Richard; Richard, Edward; and Viator, Ryan; Houma, Alabama. (Formerly Baton Rouge, Louisiana.)

3604-13000-008-00D
MANAGEMENT AND TREATMENT OF DRAINAGE WATERS FOR WATER QUALITY PROTECTION AND SUSTAINABILITY OF AGRICULTURAL PRODUCTION IN THE MIDWEST U.S. – Allred, Barry (P);Fausey, Norman; SmileyJr, Peter; and Vantoai, Tara; Columbus, Ohio.

5402-13660-007-00D
OBJECT MODELING AND SCALING OF LANDSCAPE PROCESSES AND CONSERVATION EFFECTS IN AGRICULTURAL SYSTEMS – Ascough II, James (P); Ahuja, Lajpat; Dunn, Gale; Green, Timothy; Ma, Liwang; and McMaster, Gregory; Fort Collins, Colorado.

5302-13000-010-00D
WATER MANAGEMENT TO IMPROVE PRODUCTIVITY AND PROTECT WATER QUALITY – Ayars, James (P); Banuelos, Gary; Gao, Suduan; and Wang, Dong; Parlier, California.

3640-12130-005-00D
PROTECTING SURFACE AND GROUND WATERS IN EMERGING FARMING SYSTEMS OF THE NORTH CENTRAL UNITED STATES – Koskinen, William (P); Baker, John; Feyereisen, Fary; Rice, Pamela; Spokas, Kurt; and Venterea, Rodney; St. Paul, Minnesota.

1902-13000-011-00D
INTEGRATED MANAGEMENT OF LAND AND WATER RESOURCES FOR ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY IN THE NORTHEAST U.S. – Kleinman, Peter (P);Bryant, Ray; Buda, Anthony; Church, Clinton; Dell, Curtis; and John Schmidt; University Park, Pennsylvania.

Problem Area 4: Integrated Soil Erosion and Sedimentation Technologies.

1265-12130-002-00D
ASSESSING CLIMATE, SOIL, AND LANDSCAPE PROCESSES AFFECTING AGRICULTURAL ECOSYSTEMS – McCarty, Gregory (P); Jackson, Thomas; Crow, Wade; Reeves III, James; Alfieri, Joseph; Daughtry, Craig; and Anderson, Martha; Beltsville, Maryland.

5362-1361—007-00D
RANGELAND ASSESSMENT, MANAGEMENT, AND RESTORATION – Hardegree, Stuart (P); Clark, Patrick; and Pierson Jr, Frederick; Boise, Idaho.

6625-12000-002-00D
SOIL CONSERVATION FOR SUSTAINABLE SUGARCANE PRODUCTION – Glaz, Barry (P); Canal Point, Florida.

5402-13660-007-00D
OBJECT MODELING AND SCALING OF LANDSCAPE PROCESSES AND CONSERVATION EFFECTS IN AGRICULTURAL SYSTEMS – Ascough II, James (P); Ahuja, Lajpat; Dunn, Gale; Green, Timothy; Ma, Liwang; and McMaster, Gregory; Fort Collins, Colorado.

5368-13000-008-00D
SOIL AND WATER CONSERVATION FOR NORTHWESTERN IRRIGATED AGRICULTURE – Bjorneberg, David (P); Ippolito, James; Lentz, Rodrick; King, Bradley; Dungan, Robert; and Lehrsch, Gary; Kimberly, Idaho.

5368-12000-009-00D
DEVELOP AND IMPROVE STRATEGIES FOR MANAGEMENT OF IRRIGATED AGRICULTURAL CROPS AND SOILS – Lentz, Roderick (P); Ippolito, James; Tarkalson, David; Dungan, Robert; Lehrsch, Gary; and Leytem, April; Kimberly, Idaho.

6208-66000-001-00D
AIR QUALITY ISSUES RELATED TO AGRICULTURAL OPERATIONS AND PROCESSES – Holt, Gregory (P); and Pelletier, Mathew; Lubbock, Texas.

5445-11120-001-00D
SOIL RESOURCE EVALUATION OF MANAGEMENT SYSTEMS TO ENHANCE AGROECOSYSTEM SUSTAINABILITY – Liebig, Mark (P); Kronberg, Scott; Phillips, Beckie; Nichols, Kristine; and Tanaka, Donald; Mandan, North Dakota.

5430-11120-008-00D
PARTICULATE EMISSIONS FROM WIND EROSION: PROCESSES, ASSESSMENT, AND CONTROL – Tatarko, John (P); Casada, Mark; and Wagner, Larry; Manhattan, Kansas.

5347-13000-002-00D
REUSE OF TREATED MUNICIPAL WASTE WATER FOR IRRIGATION – Williams, Clinton (P); and McLain, Jean; Maricopa, Arizona.

5347-13000-015-00D
WATER MANAGEMENT IN ARID IRRIGATED AGRICULTURE – Bautista, Eduardo (P); and Strelkoff, Theodore; Maricopa, Arizona.

3645-11000-003-00D
SOIL CARBON CYCLING, TRACE GAS EMISSION, TILLAGE, AND CROP RESIDUE MANAGEMENT – Johnson, Jane (P); Jaradat, Abdullah; Weyers, Sharon; and Gesch, Russell; Morris, Minnesota.

6408-13000-018-00D
INTEGRATED ASSESSMENT AND ANALYSIS OF PHYSICAL LANDSCAPE PROCESSES THAT IMPACT THE QUALITY AND MANAGEMENT OF AGRICULTURAL WATERSHEDS – Bingner, Ronald (P); Dabney, Seth; Kuhnle, Roger; Langendoen, Eddy; Rigby, James; Romkens, Mathias; Wells, Robert; Wilson, Glenn; and Wren, Daniel; Oxford, Mississippi.

6408-13000-020-00D
TECHNOLOGIES FOR ASSESSING SEDIMENT MOVEMENT & THE INTEGRITY OF FLOOD CONTROL STRUCTURES, STREAMBANKS, & EARTHEN POND-LEVEES & EMBANKMENTS

– Kuhnle, Roger (P); Dabney, Seth; Langendoen, Eddy; Romkens, Mathias; Wilson, Glenn; and Wren, Daniel; Oxford, Mississippi.

5356-13210-002-00D
CROPPING SYSTEMS AND PRECISION LAND MANAGEMENT IN DRYLAND PACIFIC NORTHWEST – Long, Daniel (P); Albrecht, Stephan; Gollany, Hero; Huggins, David; Young, Francis; Williams, John; and Wuest, Stewart; Pendleton, Oregon.

5348-12000-008-00D
EROSION PREDICTION TECHNOLOGY TO ENHANCE CONSERVATION PLANNING – McCool, Donald (P); Pullman, Washington.

5348-11000-005-00D
QUANTIFYING AND PREDICTING EMISSIN OF PM10 AND GREENHOUSE GASES FROM AGRICULTURAL SOILS – Huggins, David (P); Smith, Jeffrey; Kennedy, Ann; Albrecht, Stephan; Gollany, Hero; Long, Daniel; Williams, John; Sharratt, Brenton; and Wuest, Stewart; Pullman, Washington.

6217-13000-008-00D
ENGINEERING TOOLS FOR SAFE, EFFICIENT HYDRAULIC STRUCTURES AND CHANNELS – Hanson, Gregory (P); and Hunt, Sherry; Stillwater, Oklahoma.

6206-11120-004-00D
ASSESSING MANAGEMENT EFFECTS ON CROPS AND SOILS – Potter, Kenneth (P); Haney, Richard; Harmel, Robert; and Arnold, Jeffrey; Temple, Texas.

5342-12660-004-00D
SOIL EROSION, SEDIMENT YIELD, CONSERVATION STRUCTURES, AND DSS FOR SUSTAINABLE LAND MANAGEMENT ON SEMIARID RANGELAND WATERSHED – Stone, Jeffry (P); Goodrich, David; Hamerlynck, Erik; Heilman, Philip; Moran, Mary; Nearing, Mark; and Nichols, Mary; Tucson, Arizona.

6602-12610-004-00D
SOIL RESOURCES IN THE COASTAL PLAIN: PROCESS CHARACTERIZATION, MANAGEMENT IMPACTS & ASSESS. TOOLS – Potter, Thomas (P); Strickland, Timothy; and Truman, Clinton; Tifton, Georgia.

3602-12000-012-00D
COMMON MODULAR WIND AND WATER EROSION MODELING FOR CONSERVATION PLANNING – Flanagan, Dennis (P); West Lafayette, Indiana.

Problem Area 5: Watershed Management, Water Availability, and Ecosystem Restoration.

1265-13610-027-00D
USING REMOTE SENSING & MODELING FOR EVALUATING HYDROLOGIC FLUXES, STATES, & CONSTITUENT TRANSPORT PROCESSES WITHIN AGRICULTURAL LANDSCAPES – Crow, Wade (P); Alfieri, Joseph; Anderson, Martha; Cosh, Michael; Gish, Timothy; Jackson, Thomas; Kustas, William; McCarty, Gregory; and Sadeghi, Ali; Beltsville, Maryland.

5362-13610-008-00D
SNOW AND HYDROLOGIC PROCESSES IN THE INTERMOUNTAIN WEST – Seyfried, Mark (P); Flerchinger, Gerald; Marks, Daniel; and Pierson, Frederick; Boise, Idaho.

6619-13000-002-00D
OPTIMIZING FORAGE-BASED COW-CALF OPERATIONS TO IMPROVE SUSTAINABILITY OF BEEF CATTLE AGRICULTURE AND WATER QUALITY PROTECTION AND MANAGEMENT – Sigua, Gilbert (P); and Chase, Chadwick; Brooksville, Florida.

6209-13000-013-00D
SUSTAINING RURAL ECONOMIES THROUGH NEW WATER MANAGEMENT TECHNOLOGIES – Brauer, David (P); Baumhardt, Roland; Colaizzi, Paul; Evett, Steven; Gowda, Prasanna; Howell, Terry; Lascano, Robert; Schwartz, Robert; Tolk, Judy; Van Pelt, Robert; and Zobeck, Teddy; Bushland, Texas.

3604-13000-009-00D
ENVIRONMENTAL AND SOURCE WATER QUALITY EFFECTS OF MANAGEMENT PRACTICES AND LAND USE ON POORLY DRAINED LAND – King, Kevin (P); Fausey, Norman; and Smiley Jr, Peter; Columbus, Ohio.

5358-21410-002-00D
INTEGRATING PRODUCTION AND CONSERVATION PRACTICES TO MAINTAIN GRASS SEED FARM PROFITS – Griffith, Stephen (P); Whittaker, Gerald; Pfender, William; Banowetz, Gary; and Mueller Warrant, George; Corvallis, Oregon.

3605-13000-004-00D
EFFECTIVENESS OF WATERSHED LAND-MANAGEMENT PRACTICES TO IMPROVE WATER QUALITY – Bonta, James (P); Owens, Lloyd; and Shipitalo, Martin; Coshocton, Ohio.

6218-11130-004-00D
INTEGRATION OF CLIMATE VARIABILITY AND FORECASTS INTO RISK-BASED MANAGEMENT TOOLS FOR AGRICULTURE PRODUCTION AND RESOURCE CONSERVATION – Garbrecht, Jurgen (P); Schneider, Jeanne; Steiner, Jean; and Zhang, Xunchang; El Reno, Oklahoma.

6657-13000-009-00D
MANAGING WATER AVAILABILITY AND QUALITY TO MAINTAIN OR INCREASE AGRICULTURAL PRODUCTION, CONSERVE NATURAL RESOURCES, AND ENHANCE ENVIRONMENT – Stone, Kenneth (P); Bauer, Philip; Hunt, Patrick; Ro, Kyoung; Ducy, Thomas; and Busscher, Warren; Florence, South Carolina.

6618-13000-003-00D
INTEGRATED HORTICULTURAL PRODUCTION SYSTEMS FOR WATER QUALITY PROTECTION AND WATER CONSERVATION – Albano, Joseph (P); and Evens, Terence; Fort Pierce, Florida.

6208-13000-006-00D
MANAGING LIMITED IRRIGATION AND RAINFALL FOR CROP PRODUCTION IN SEMI-ARID ENVIRONMENTS – Baker, Jeffrey (P); Acosta-Martinez, Veronica; Gitz, Dennis; Lascano, Robert; Mauget, Steven; Van Pelt, Robert; and Zobeck, Teddy; Lubbock, Texas.

5347-13000-002-00D
REUSE OF TREATED MUNICIPAL WASTE WATER FOR IRRIGATION – Williams, Clinton (P); and McLain, Jean; Maricopa, Arizona.

5347-13000-015-00D
WATER MANAGEMENT IN ARID IRRIGATED AGRICULTURE – Bautista, Eduardo (P); and Strelkoff, Theodore; Maricopa, Arizona.

5347-13660-006-00D
REMOTE SENSING FOR CROP AND WATER MANAGEMENT IN IRRIGATED AGRICULTURE – Hunsaker, Douglas (P); French, Andrew; and Thorp, Kelly; Maricopa, Arizona.

6631-13000-003-00D
DEVELOPING TOOLS TO ENHANCE WATER QUALITY FROM AGRICULTURAL ENTERPRISES IN SOUTH FLORIDA – Savibi, M (P); Miami, Florida.

6631-13000-04-00D
ENHANCING WATER QUALITY FROM HORTICULTURAL AND FLORICULTURAL PRODUCTION IN SOUTH FLORIDA – Reed, Stewart (P); Miami, Florida.

6408-13660-006-00D
UNDERSTANDING AND PREDICTING THE IMPACT OF AGRICULTURE ON THE ENVIRONMENTAL INTEGRITY OF MANAGED WATERSHEDS – Locke, Martin (P); Bingner, Ronald; Cullum, Robert; Knight, Scott; Lizotte, Richard; Moore, Matthew; Rhoton, Fred; Romkens, Mathias; and Shields, Douglas; Oxford, Mississippi.

6408-13000-018-00D
INTEGRATED ASSESSMENT AND ANALYSIS OF PHYSICAL LANDSCAPE PROCESSES THAT IMPACT THE QUALITY AND MANAGEMENT OF AGRICULTURAL WATERSHEDS – Bingner, Ronald (P); Dabney, Seth; Kuhnle, Roger; Langendoen, Eddy; Rigby, James; Romkens, Mathias; Wells, Robert; Wilson, Glenn; and Wren, Daniel; Oxford, Mississippi.

6408-13000-020-00D
TECHNOLOGIES FOR ASSESSING SEDIMENT MOVEMENT & THE INTEGRITY OF FLOOD CONTROL STRUCTURES, STREAMBANKS, & EARTHEN POND-LEVEES & EMBANKMENTS – Kuhnle, Roger (P); Dabney, Seth; Langendoen, Eddy; Romkens, Mathias; Wilson, Glenn; and Wren, Daniel; Oxford, Mississippi.

3640-12130-005-00D
PROTECTING SURFACE AND GROUND WATERS IN EMERGING FARMING SYSTEMS OF THE NORTH CENTRAL UNITED STATES – Koskinen, William (P); Baker, John; Feyereisen, Fary; Rice, Pamela; Spokas, Kurt; and Venterea, Rodney; St. Paul, Minnesota.

6206-13610-006-00D
DEVELOPMENT OF MODELS AND CONSERVATION PRACTICES FOR WATER QUALITY MANAGEMENT AND RESOURCE ASSESSMENTS – Arnold, Jeffrey (P); Harmel, Daren; Kiniry, James; Rossi, Colleen; and White, Michael; Temple, Texas.

6602-13000-023-00D
LAND USE AND MANAGEMENT EFFECTS ON ENVIRONMENTAL PROCESSES AND HYDROLOGY IN COASTAL PLAIN WATERSHEDS – Lowrance, Robert (P);Bosch, David; Hubbard, Robert; Potter, Thomas; Strickland, Timothy; and Truman, Clinton; Tifton, Georgia.

6602-13000-025-00D
CONSERVATION EFFECTS ASSESSMENT IN THE SOUTH GEORGIA LITTLE RIVER – Bosch, David (P); Hubbard, Robert; Lowrance, Robert; Potter, Thomas; and Strickland, Timothy; Tifton, Georgia.

5342-13610-010-00D
HYDROLOGIC PROCESSES, SCALE, CLIMATE VARIABILITY, AND WATER RESOURCES FOR SEMIARID WATERSHED MANAGEMENT – Goodrich, David (P); Hamerlynck, Erik; Heilman, Philip; Moran, Mary; Nearing, Mark; Scott, Russell; and Stone, Jeffry; Tucson, Arizona.

6612-13000-002-00D

PROTECTING WATER QUALITY AND MITIGATING DROUGHT IN THE SOUTHEASTERN USA – Fisher, Dwight (P); Franklin, Dorcas; Endale, Dinku; Schomberg, Harry; Sharpe, Ronald; Reeves, Donald; and Jenkins, Michael; Watkinsville, Georgia.

6204-11660-007-00D
USING REMOTE SENSING AND GIS FOR DETECTING AND MAPPING INVASIVE WEEDS IN RIPARIAN AND WETLAND ECOSYSTEMS – Yang, Chenghai (P); and Fletcher, Reginald; Weslaco, Texas.

3602-13000-008-00D
CONSERVATION EFFECTS ASSESSMENT FOR THE ST. JOSEPH RIVER WATERSHED – Smith, Douglas (P); Heathman, Gary; Huang, Chi-hua; Norton, Lloyd; and Pappas, Elizabeth; West Lafayette, Indiana.

Problem Area 6: Water Quality Protections Systems.

3625-13000-009-00D
WATER QUALITY IMPROVEMENT FROM MANAGEMENT PRACTICES IN AGRICULTURAL WATERSHEDS – Tomer, Mark (P); Hatfield, Jerry; Jaynes, Dan; Kaspar, Thomas; Logsdon, Sally; Malone, Robert; and Moorman, Thomas; Ames, Iowa.

1265-13610-027-00D
USING REMOTE SENSING & MODELING FOR EVALUATING HYDROLOGIC FLUXES, STATES, & CONSTITUENT TRANSPORT PROCESSES WITHIN AGRICULTURAL LANDSCAPES – Crow, Wade (P); Alfieri, Joseph; Anderson, Martha; Cosh, Michael; Gish, Timothy; Jackson, Thomas; Kustas, William; McCarty, Gregory; and Sadeghi, Ali; Beltsville, Maryland.

1265-63000-001-00D
PREVALENCE AND DIVERSITY OF MANURE-ASSOCIATED PATHOGENS IN AIR AND WATER – Shelton, Daniel (P); Beltsville, Maryland.

6209-13000-013-00D
SUSTAINING RURAL ECONOMIES THROUGH NEW WATER MANAGEMENT TECHNOLOGIES – Brauer, David (P); Baumhardt, Roland; Colaizzi, Paul; Evett, Steven; Gowda, Prasanna; Howell, Terry; Lascano, Robert; Schwartz, Robert; Tolk, Judy; Van Pelt, Robert; and Zobeck, Teddy; Bushland, Texas.

3622-12130-004-00D
DEVELOPMENT OF ALTERNATIVE PRACTICES FOR IMPROVED WATERSHED MANAGEMENT – Lerch, Robert (P); Baffaut, Claire; Kitchen, Newell; Kremer, Robert; Sadler, Edward; and Vories, Earl; Columbia, Missouri.

3604-13000-008-00D
MANAGEMENT AND TREATMENT OF DRAINAGE WATERS FOR WATER QUALITY PROTECTION AND SUSTAINABILITY OF AGRICULTURAL PRODUCTION IN THE MIDWEST U.S. – Allred, Barry (P);Fausey, Norman; SmileyJr, Peter; and Vantoai, Tara; Columbus, Ohio.

3605-13000-004-00D
EFFECTIVENESS OF WATERSHED LAND-MANAGEMENT PRACTICES TO IMPROVE WATER QUALITY – Bonta, James (P); Owens, Lloyd; and Shipitalo, Martin; Coshocton, Ohio.

5402-13660-007-00D

OBJECT MODELING AND SCALING OF LANDSCAPE PROCESSES AND CONSERVATION EFFECTS IN AGRICULTURAL SYSTEMS – Ascough II, James (P); Ahuja, Lajpat; Dunn, Gale; Green, Timothy; Ma, Liwang; and McMaster, Gregory; Fort Collins, Colorado.

5402-12130-007-00D
IMPROVING SOIL AND NITROGEN MANAGEMENT SYSTEMS FOR SUSTAINING LAND AND WATER QUALITY – Halvorson, Ardell (P); Delgado, Jorge; Follett, Ronald; Hunter, William; and Manter, Daniel; Fort Collins, Colorado.

5440-12130-010-00D
CROP AND SOIL MANAGEMENT SYSTEMS FOR WATER QUALITY PROTECTION AND AGRICULTURAL SUSTAINABILITY – Wienhold, Brian (P); Schmer, Marty; Jin, Virginia; and Varvel, Gary; Lincoln, Nebraska.

6408-13660-006-00D
UNDERSTANDING AND PREDICTING THE IMPACT OF AGRICULTURE ON THE ENVIRONMENTAL INTEGRITY OF MANAGED WATERSHEDS – Locke, Martin (P); Bingner, Ronald; Cullum, Robert; Knight, Scott; Lizotte, Richard; Moore, Matthew; Rhoton, Fred; Romkens, Mathias; and Shields, Douglas; Oxford, Mississippi.

5310-13210-009-00D
SALINITY AND TRACE ELEMENT MANAGEMENT FOR CROP PRODUCTION IN IRRIGATED AGRICULTURAL SYSTEMS – Grieve, Catherine (P); Riverside, California.

5310-61000-013-00D
SALINITY AND TRACE ELEMENTS ASSOCIATED WITH WATER REUSE IN IRRIGATED SYSTEMS: PROCESSES, SAMPLING PROTOCOLS, AND SITE-SPECIFIC MANAGEMENT – Suarez, Donald (P); Corwin, Dennis; and Goldberg, Sabine; Riverside, California.

5436-13210-005-00D
ECOLOGICALLY-SOUND PEST, WATER AND SOIL MANAGEMENT STRATEGIES FOR NORTHERN GREAT PLAINS CROPPING SYSTEMS – Evans, Robert (P); Allen, Brett; Jabro, Jalal; Lartey, Robert; Sainju, Upendra; Stevens, William; and Caesar, Thecan; Sidney, Montana.

3640-12000-007-00D
FARMING PRACTICES FOR THE NORTHERN CORN BELT TO PROTECT SOIL RESOURCES, SUPPORT BIOFUEL PRODUCTION, AND REDUCE GLOBAL WARMING POTENTIAL – Venterea, Rodney (P); Feyereisen, Gary; Spokas, Kurt; and Baker, John; St. Paul, Minnesota.

3640-12130-005-00D
PROTECTING SURFACE AND GROUND WATERS IN EMERGING FARMING SYSTEMS OF THE NORTH CENTRAL UNITED STATES – Koskinen, William (P); Baker, John; Feyereisen, Fary; Rice, Pamela; Spokas, Kurt; and Venterea, Rodney; St. Paul, Minnesota.

6206-13610-006-00D
DEVELOPMENT OF MODELS AND CONSERVATION PRACTICES FOR WATER QUALITY MANAGEMENT AND RESOURCE ASSESSMENTS – Arnold, Jeffrey (P); Harmel, Daren; Kiniry, James; Rossi, Colleen; and White, Michael; Temple, Texas.

6602-13000-023-00D
LAND USE AND MANAGEMENT EFFECTS ON ENVIRONMENTAL PROCESSES AND HYDROLOGY IN COASTAL PLAIN WATERSHEDS – Lowrance, Robert (P);Bosch, David; Hubbard, Robert; Potter, Thomas; Stricklan, Timothy; and Truman, Clinton; Tifton, Georgia.

6602-13000-025-00D

CONSERVATION EFFECTS ASSESSMENT IN THE SOUTH GEORGIA LITTLE RIVER – Bosch, David (P); Hubbard, Robert; Lowrance, Robert; Potter, Thomas; and Strickland, Timothy; Tifton, Georgia.

1902-13000-011-00D
INTEGRATED MANAGEMENT OF LAND AND WATER RESOURCES FOR ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY IN THE NORTHEAST U.S. – Kleinman, Peter (P);Bryant, Ray; Buda, Anthony; Church, Clinton; Dell, Curtis; and John Schmidt; University Park, Pennsylvania.

6612-13000-002-00D
PROTECTING WATER QUALITY AND MITIGATING DROUGHT IN THE SOUTHEASTERN USA – Fisher, Dwight (P); Franklin, Dorcas; Endale, Dinku; Schomberg, Harry; Sharpe, Ronald; Reeves, Donald; and Jenkins, Michael; Watkinsville, Georgia.

3602-13000-008-00D
CONSERVATION EFFECTS ASSESSMENT FOR THE ST. JOSEPH RIVER WATERSHED – Smith, Douglas (P); Heathman, Gary; Huang, Chi-hua; Norton, Lloyd; and Pappas, Elizabeth; West Lafayette, Indiana.

APPENDIX 2

National Program 211 – Water Availability & Watershed Management

ACCOMPLISHMENT REPORT 2007 – 2011

Publications

Abdu, H., Robinson, D.A., Seyfried, M.S., Jones, S. 2008. Geophysical Imaging of Watershed Subsurface Patterns and Prediction of Soil Texture and Water Holding Capacity. Water Resources Research, 44, Wood 18, doi:10.1029/2008WR007043.

Abraham, D., Kuhnle, R.A., Odgaard, A.J. 2011. Validation of bed-load transport measurements with time-sequenced bathymetric data. Journal of Hydraulic Engineering. 137(7):723-728.

Abrahamson Beese, D.A., Radcliffe, D.E., Steiner, J.L., Cabrera, M.L., Hanson, J.D., Rojas, K.W., Schomberg, H.H., Fisher, D.S., Schwartz, L., Hoogenboom, G. 2005. Calibration of the root zone water quality model for simulating drainage and leached nitrate in the Georgia Piedmont. Agronomy Journal. 97:1584-1602.

Accinelli, C., Koskinen, W.C., Becker, J.M., Sadowsky, M.J. 2008. Mineralization of the Bacillus thuringiensis Cry1Ac endotoxin in soil. Journal of Agricultural and Food Chemistry. 56:1025-1028.

Acosta Martinez, V., Dowd, S.E., Bell, C., Lascano, R.J., Booker, J.D., Zobeck, T.M., Upchurch, D.R. 2010. Microbial community composition as affected by dryland cropping systems and tillage in a semiarid sandy soil. Diversity. 2(6):910-931.

Agam, N., Kustas, W.P., Anderson, M.C., Li, F., Colaizzi, P.D. 2008. Utility of thermal image sharpening for monitoring field-scale evapotranspiration over rainfed and irrigated agricultural regions. Geophysical Research Letters. 35, L02402, http://dx.doi.org/10.1029/2007GL032195.

Agam, N., Kustas, W.P., Anderson, M.C., Li, F., Neale, C. 2007. A vegetation index based technique for spatial sharpening of thermal imagery. Remote Sensing of Environment. 107:545-558.

Agam, N., Kustas, W.P., Anderson, M.C., Norman, J.M., Colaizzi, P.D., Howell, T.A., Prueger, J.H., Meyers, T.P., Wilson, T.B. 2010. Application of the Priestley-Taylor Approach in a Two-Source Surface Energy Balance Model. Journal of Hydrometeorology. 11:185-198.

Agrawal, S.G., King, K.W., Fischer, E.N., Woner, D.N. 2011. Phosphate removal by and permeability of industrial byproducts and minerals: Granulated blast furnace slag, cement kiln dust, coconut-shell activated carbon, silica sand, and zeolite. Journal Of Water Air And Soil Pollution. DOI 10.1007/s11270-010-0686-4.

Agrawal, S.G., King, K.W., Moore, J.F., Levison, P.W., McDonald, J. 2011. Use of industrial byproducts to filter nutrients and pesticides in a golf green's drainage water. Journal of Environmental Quality. 40:1273-1280.

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Appendix 3

National Program 211 – Water Availability & Watershed Management

Accomplishment Report 2007 – 2011

Action Plan 2006-2010
[By Problem Area]

Problem Area 1 Effectiveness of Conservation Practices

Inputs/Resources	Outputs/Products	Outcomes
Product 1 Leaders Columbia, MO: J. Sadler) El Reno, OK: J. Steiner **Product Locations** Ames, IA, Columbia, MO, Oxford, MS, Temple, TX, Tifton, GA, University Park, PA, and W. Lafayette, IN **Cooperators** NRCS, ARS Office of Information Officer (OICO), and USGS	1. A data system to organize, document, manipulate and compile water, soil, management, and socio-economic data for assessment of conservation practices	**Short term*** Comprehensive and consistent data sets will be developed across the 14 watersheds. The data sets will support testing and validation for models being developed under product 3 and 5 below. **Long term**** The data system will be used for cost-efficient assessments of environmental effects of conservation practices on agricultural lands.

Inputs/Resources	Outputs/Products	Outcomes
Product 2 Leaders Ames, IA: M. Tomer Oxford, MS: Martin Locke **Product Locations** Ames, IA (202), Beltsville, MD, Columbia, MO, Columbus, OH, El Reno, OK, Kimberly, ID, Lubbock, TX, Oxford, MS, Temple, TX, and W. Lafayette, IN **Cooperators** NRCS, CSREES, FSA, Agriculture and Agri-Food Canada, USGS, and Soil and Water Conservation Districts	2. Water quality, water quantity, soil quality, and ecosystem effects of conservation practices at the field, farm, and watershed scales	**Short term** Environmental effects of conservation practices will be quantified for the 14 watersheds. **Long term** More effective conservation practices will be developed for use in future USDA conservation programs.
Product 3 Leaders Oxford, MS: R. Bingner Temple, TX: J. Arnold Tifton, GA: T. Strickland **Product Locations** Ames, IA, Columbia, MO, El Reno, OK, Oxford, MS, Temple, TX, Tifton, GA, University Park, PA, and W. Lafayette **Cooperators** NRCS, EPA, USGS, and Texas Agric. Exp. Station	3. Validate models, quantify uncertainties in model output, and conduct analyses with models at field, farm, and watershed scales	**Short term** Models will be modified, tested and validated for application to the assessment of the effects of conservation practices. **Long term** Validated models will become the primary tools used to conduct a national assessment of the environmental benefits of USDA conservation programs.

Inputs/Resources	Outputs/Products	Outcomes
		The assessments will have a major impact on the development of future USDA conservation programs.
Product 4 Leaders Corvallis, OR: G. Whittaker West Lafayette, IN: C. Huang **Product Locations** Columbus, OH, Temple, TX, and W. Lafayette, IN **Cooperators** NRCS, ERS, The Ohio State University, Pennsylvania State University, and Purdue University	4. Policy-planning tools to aid selection and placement of conservation practices to optimize profits, environmental quality, and conservation program efficiency	**Short term** The research will provide socio-economic data from selected watersheds relative to the adoption and economic value of USDA conservation practices. Tools will be provided that enable optimal choices of the selection and placement of conservation practices. **Long term** The results of this research will enable socio-economic issues to be included in the national assessment of the effects of USDA conservation programs.
Product 5 Leaders Fort Collins, CO: L. Ahuja Oxford, MS: M. Romkens **Product Locations**	5. Regional watershed models that can be used to quantify environmental outcomes and conservation practices in major agricultural regions **Product Users******	**Short term** Science-based watershed models will be provided that are capable of addressing processes that are of importance to specific regions.

Inputs/Resources	Outputs/Products	Outcomes
Ames, IA, Temple, TX, Fort Collins, CO, W. Lafayette, IN, Oxford, MS, and Tifton, GA **Cooperators** NRCS, EPA, USGS, and Colorado State University	Producers, COE, EPA, FSA, NRCS, USGS, Cooperative Extension Agents and Specialists, State and local agencies, land improvement contractors, community planners, and consultants	**Long term** This work will result in a new generation of modular based models that integrate scientific components of existing models and future models into an efficient, flexible system for use by the NRCS and other agencies in future national assessments or other applications.

* The short-term outcomes will be accomplished in the next five years.

** The long-term outcomes will not be fully accomplished in five years given current personnel and physical resources, but significant progress will be made.

*** These scientists are conducting research primarily in the ARS Soil Resource Management National Program (202) and ARS Global Change National Program (204).

**** Product users are for the entire problem area.

Problem Area 2 Irrigation Water Management

2.1: Irrigation Scheduling for Water Use Efficiency		
Inputs/Resources	**Outputs/Products**	**Outcomes**
Product 1 Leader Bushland, TX: T. Howell **Product Locations**	1. Quantification of evapotranspiration (ET) and crop coefficients under all constraints, including partitioning of ET components, regional variations, effects of tillage/irrigation methods, incomplete canopies, and deficit irrigation	**Short term*** Improved and more transportable crop coefficients and methods for adjusting those coefficients as a function of growing degree days, incomplete crop canopy and irrigation

Bushland, TX, Fort Collins, CO, Lubbock, TX, Maricopa, AZ, Parlier, CA, and Stoneville, MS (207) **Cooperators** ASCE/EWRI ET Task Committee, CSREES Multistate Research Coordinating Committee/Information Exchange Group, WERA202, "Climatic Data Applications in Irrigation Scheduling and Water Conservation"		method effects will be determined. **Long term**** Irrigation scheduling will be widely adopted for more effective use of water in irrigated agriculture.
Product 2 Leader Bushland, TX: P. Colaizzi **Product Locations** Beltsville, MD, Bushland, TX, Fort Collins, CO, Lubbock, TX, Maricopa, AZ, Stoneville, MS (207), and Tifton, GA **Cooperators** Kansas State Univ., New Mexico State Univ., Texas A&M Univ., Univ. of Arizona, Univ. of Idaho, NASA, and Bur. of Rec.	2. Remote sensing tools for ET and water stress predictions for field and farm district levels	**Short term** Tools will be developed that improve prediction of crop water use and plant stress at field to irrigation project scales. **Long term** Operational tools will be used by farmers, consultants and water districts to predict crop water use and plant stress to increase irrigation water use efficiencies and improve utilization of the Nation's water resources.

Product 3 Leaders Florence, SC: K. Stone Columbia, MO: E. Vories **Product Locations** Columbia, MO, Lubbock, TX, and Stoneville, MS (207) **Cooperators** CSREES project S1018 Irrigation Management for Humid and Sub-Humid Areas	3. Irrigation scheduling tools for humid and sub-humid regions, including crop coefficients, plant stress indicators, soil water sensing, and a rice automation/feedback irrigation system **Product Users****** Producers, NRCS, water districts, State and local agencies, State planning boards, and consultants	**Short term** Irrigation scheduling will be developed for major crops grown in humid and sub-humid regions. **Long term** Planners, water districts, and farmers will use advanced irrigation scheduling tools to improve crop water use efficiencies.
2.2: Managing Irrigation for Effective Water Use		
Product 4 Leader Maricopa, AZ: B. Clemmens **Product Locations** Bushland, TX, Kimberly, ID Maricopa, AZ, and Parlier, CA **Cooperators** NRCS and Bureau of Reclamation, Water Districts	4. Management tools and practices, and new technologies to make irrigation and water delivery systems more dependable, flexible, and efficient; and methods to quantify the impacts of these practices at field, farm, project, and watershed scales, including irrigation efficiency evaluation	**Short term** A knowledge base will be developed on intake/ infiltration parameters for various application methods to be used in the design of more efficient irrigation systems. Techniques and tools will be delivered for evaluating irrigation conservation practices and their impact at the field and watershed scale. **Long term** Farmers, consultants, water districts and NRCS will be able to improve the operation and management of irrigation systems at small and large scales through the use of these water management tools.

2.3: Improved Irrigation and Cropping for Reuse of Degraded Waters		
Product 5 Leader Riverside: D. Suarez **Product Locations** Maricopa, AZ, Parlier, CA, and Riverside, CA **Cooperators** UC Riverside, UC Davis, EPA, Bur. Rec, and NRCS	5. Guidelines for irrigating in urban and agricultural settings with degraded waters, and models and decision support systems for management of treated municipal wastewaters and other degraded waters in irrigation, including tools for determining the fate and transport of emerging contaminants and pathogens	**Short term** Guidelines will be developed for irrigating with degraded waters. **Long term** Tools will be made available to increase water supplies and make safer use of degraded waters in urban and agricultural settings.
Product 6 Leader Riverside, CA: C. Grieve **Product Locations** Parlier, CA, Riverside, CA, and St. Paul, MN (205) **Cooperators** Univ. of California Riverside, Univ. of California Davis, California State Univ., Fresno Tulare Lake Drainage District Imperial Valley Research Center, Brawley, CA, UC Berkeley, Panoche Drainage	6. New and improved crops that use degraded waters and/or phytoremediate soils, including identification of related biological components, and development of breeding lines and experimental germplasm **Product Users****** Producers, NRCS, water districts, State and local agencies, State planning boards, and consultants	**Short term** Biological processes will be identified for crop specific ion, salt or drought tolerance. **Long term** Specific crops will be available that tolerant to degraded water and soils.

District, Colorado State University, and University of Zurich, Switzerland		
2.4: Site Specific Technologies to Conserve Water, Nutrients, and Energy		
Product 7 Leaders Bushland, TX: S. Evett Sidney, MT: R. Evans **Product Locations** Ames, IA (202), Bushland, TX Columbia, MO, Florence, SC, Fort Collins, CO, Lubbock, TX, Maricopa, AZ, Riverside, CA, and Sidney, MT **Cooperators** NRCS, Universities: Colorado State Univ., Texas A&M, Univ. of Arizona, Univ. of Idaho, Utah State Univ., equipment manufacturers	7. Systems for spatially and temporally variable water, nutrient, and pesticide application based on soil-crop sensing and feedback **Product Users******** Producers, producer groups (corn, cotton, sorghum, wheat, etc.), irrigation equipment companies, NRCS, Bur. of Rec., universities	**Short term** Improved soil water and plant nutrient sensors will be developed for use in wireless mesh networked feedback control systems. **Long term** Tools will be developed for variable rate application of nutrients, pesticides, and water across fields, leading to conservation of water, nutrients, and energy for economically and environmentally sustainable enterprises; and feedback irrigation systems will be commercialized to increase water and nutrient use efficiency and reduce management time for economically and environmentally sustainable enterprises.
2.5: Cropping and Tillage Strategies to Best Use Limited Water Supplies		
Product 8 Leader Kimberly, ID: D. Bjorneberg **Product Locations** Akron, CO (202), Bushland, TX, Columbia, MO, Florence, SC, Fort Collins, CO, Kimberly, ID,	8. Tillage, irrigation, and crop management (including amendments and residue management) practices will be developed to improve crop water use efficiency in rainfed/irrigated cropping systems	**Short term** Cropping and tillage practices will be developed for improved crop water use efficiency in combined rainfed/ irrigated cropping systems. **Long term**

Lubbock, TX, Riverside, CA (202), Sidney, MT, Watkinsville, GA **Cooperators** Universities, e.g. Utah State, Texas A&M, Univ. of Idaho, and many others including those associated with CSREES project S1018, "Irrigation Management for Humid and Sub-Humid Areas"	**Product Users****** Producers, producer groups (corn, cotton, sorghum, wheat, etc.), NRCS, USGS, universities, water districts, State planning boards, and consultants	Crop and tillage systems will be adopted that optimize use of limited irrigation water supplies.

* The short-term outcomes will be accomplished in the next five years.

** The long-term outcomes will not be fully accomplished in five years given current personnel and physical resources, but significant progress will be made.

*** These scientists are conducting research primarily in the ARS Integrated Agricultural Systems National Program (207).

**** Product users are for each of subproblem areas.

Problem Area 3 Drainage Water Management Systems

Inputs/Resources	Outputs/Products	Outcomes
Product 1 Leaders Columbus, OH: N. Fausey St. Paul, MN: J. Baker **Product Locations** Ames, IA, Baton Rouge, LA, Columbus, OH, Fort Collins, CO, and St. Paul, MN **Cooperators:**	1.Guidelines for management practices that optimize soil, water, and economic benefits associated with surface and subsurface drainage water management (DWM) systems and wetland resources in humid rainfed areas With adoption of surface and subsurface drainage water management (DWM) systems in humid rainfed areas, tentative guidelines developed for improved agronomic, nutrient and pesticide management	**Short term*** Tentative Guidelines for agronomic, nutrient, and pesticide management practices will be made available to users of DWM systems. **Long term****

Inputs/Resources	Outputs/Products	Outcomes
Iowa State Univ. Louisiana State Univ., Univ. of IL, NRCS, Univ. of MO, North Carolina State Univ., Univ. of MN and Purdue Univ.	practices, and benefits or impacts assessed regarding water conservation, water quality, soil quality, economic factors, and management of combined areas of DWM systems and wetland resources	Expanded guidelines will be developed in short-term project to include other conservation practices, such as cover crops, buffer strips, tillage management, wetland diversions, etc., to enhance water quality benefits in surface waters and in coastal waters.
Product 2 Leaders Baton Rouge, LA: J. Fouss Parlier, CA: J. Ayars **Product Locations** Baton Rouge, LA Columbus, OH **Cooperators:** NRCS, Univ. of IL, The Ohio State Univ., North Carolina State Univ., and Univ. of MN	2. Design specifications of DWM systems for environmental benefits in the Midwest and West	**Short term** Design specifications for DWM systems will be developed for optimizing water quality benefits. **Long term** Design specifications for DWM systems will be developed for multiple environmental benefits.
Product 3 Leader Parlier, CA: J. Ayars **Product Locations** Parlier CA **Cooperators:**	3. Evaluation of the advantages and limitations associated with operation of DWM systems for irrigated areas	**Short term** Recommendations for operation of DWM systems will be developed for California. **Long term** Assessment and recommendations for use

Inputs/Resources	Outputs/Products	Outcomes
Bureau of Reclamation, U.C.-Davis, CA Dept. of Water Resources, NRCS, Water/Drainage Districts		of DWM systems will be developed for the West.
Product 4 Leaders Ames, IA: R. Malone Fort Collins, CO: L. Ahuja **Product Locations** Ames, IA, Baton Rouge, LA, Fort Collins, CO and University Park, PA **Cooperators** NRCS, North Carolina State Univ., and University of Minnesota **Other Problem Area #4** **Cooperators:** Drainage industry; producers; commodity organizations; and international organizations	4. Decision support systems that include environmental and economic effects associated with DWM systems **Product Users****** Producers, NRCS, Cooperative Extension Agents and Specialists, EPA, land improvement contractors, community planners, and consultants	**Short term** A DWM decision support system will be developed for benefit analysis in the Midwest. **Long term** A DWM decision support system will be developed for cost benefit analysis throughout the Nation. DWM guidelines will be developed to estimate the length of time required to obtain measurable water quality improvements at the watershed scale.

* The short-term outcomes will be accomplished in the next five years.

** The long-term outcomes will not be fully accomplished in five years given current personnel and physical resources, but significant progress will be made.

*** These cooperative scientists are employed by Land-Grant Universities.

**** Product users are for the entire problem area.

Problem Area 4 Integrated Soil Erosion and Sedimentation Technologies

Inputs/Resources	Outputs/Products	Outcomes
Product 1 Leader Oxford, MS: S. Dabney **Product Locations** W. Lafayette, IN, Oxford, MS, and Pendleton, OR **Cooperators** Oklahoma State Univ	1. Database and predictive relationships for erosion and sediment transport caused by concentrated flow in irrigation furrows, ephemeral gullies, and edge-of-field gullies	**Short term*** Predictive ability and databases will allow improved estimation of concentrated flow erosion from selected sites. **Long term**** Robust predictive ability and comprehensive database will provide reliable estimation of erosion and sediment transport caused by concentrated flow
Product 2 Leader Oxford, MS: R. Kuhnle **Product Locations** Oxford, MS and Tucson, AZ **Cooperators** Univ. of Mississippi, USBR, USGS, NRCS, USFS	2. Decision support tools and databases for sediment loads, yields, and off-site impacts considering fractional sediment transport and deposition, geomorphic aspects of stream evolution, and reservoir/pond sedimentation for purposes of quantifying landscape scale erosion rates	**Short term** Intermediate gains will increase ability to quantify landscape scale erosion. Science-based and cost-effective techniques will be developed to monitor changes in storage of aging reservoirs. **Long term** Ability to quantify landscape scale erosion and off-site impacts will be enhanced. Improvements to CONCEPTS will be developed for more accurate assessments of dam decommissioning/rehabilitation

Inputs/Resources	Outputs/Products	Outcomes
		impact at watershed and larger scales that will be used by Federal and State agencies.
Product 3 Leader Stillwater, OK: D. Temple **Product Locations** Stillwater, OK and Oxford, MS **Cooperators** NRCS, USACE (ERDC), USBR (WRRL), CEATI (DSIG), KSU (CIS), NRCS, and Univ. of Mississippi	3. Improved tools for evaluating the potential for earthen embankment breach due to erosion and deterioration due to wave action **Product Users** Producers, COE, EPA, NRCS, USBR, Cooperative Extension Agents and Specialists, State and local agencies, land improvement contractors, community planners, and consultants	**Short term** Improved predictive and preventive capabilities with regard to earthen embankment dam breach will be achieved. Science-based and cost - effective techniques will be developed to control erosion from streams and levees. **Long term** Ability to predict performance of existing structures and ability to improve designs based on simulation will be demonstrated.
Product 4 Leader West Lafayette, IN: C. Huang , D. Smith **Product Locations** Lubbock, TX (NP 202), Oxford, MS, and Pullman, WA	4. Improved tool for assessment of soil susceptibility to erosion including spatial, temporal, topographical, vegetative, and management effects	**Short term** Improved assessment of how climate, topography, and management affect erodibility and threshold velocities will lead to improved management systems and more reliable modeling of conservation effects at select locations. **Long term** Improved assessment of how climate, topography, and

Inputs/Resources	Outputs/Products	Outcomes
		management affect erodibility and threshold velocities will lead to improved management systems and more reliable modeling of conservation effects nationally.
Product 5 Leader Tucson, AZ: M. Nearing **Product Locations** Beltsville, MD (202), Kimberly, ID (211 and 202), W. Lafayette, IN, Lubbock, TX (202), Mandan, ND (202), Manhatten, KS (203), Oxford, MS, Pendleton, OR (202), Stillwater, OK, and Tucson, AZ **Cooperators** Oklahoma State University (BAE), NRCS, Engineering Division, Univ. Az. Ext. Service, and Malpai Borderlands Group	5. Best Management Practices and design tools for in-field erosion control, gully and ephemeral channel erosion prevention, riparian corridor stabilization, and sediment retention structures	**Short term** Design tools and practices for erosion prevention, water infrastructure improvements, and riparian corridor management will be developed to reduce sediment losses from fields and streams. Improved technology for design and rehabilitation of water resource structures will be developed. **Long term** Improved conservation practices will be developed for reducing sediment losses from fields, streams to lakes, and rivers. Engineering tools for design and rehabilitation of water resource structures will be completed.
Product 6 Leader Kimberly, ID: D. Bjorneberg	6. Model to predict irrigation-induced erosion using a common interface with shared databases: development, parameterization, and validation	**Short term** Field-scale single event models will be developed for improved

Inputs/Resources	Outputs/Products	Outcomes
Product Locations Fort Collins, CO, Kimberly, ID, and Maricopa, AZ **Cooperators** Producers, Industry, Consultants, University Extension, NRCS, Federal Agencies (COE, BLM, EPA, USGS,), State Agencies (DEQs), University of Mississippi	(surface, center pivot and set/move sprinklers). **Product Users****** Producers, NRCS, USGS, EPA, universities, soil and water conservation districts, State planning boards, farmers, ranchers, engineers, and consultants	predictions of irrigation-induced erosion. **Long term** Integration of irrigation-induced erosion model into a comprehensive decision support system for water erosion, wind erosion, tillage erosion, and sedimentation predictions will improve long-term conservation planning and impact assessments.
Product 7 Leader West Lafayette, IN: D. Flanagan **Product Locations** Boise, ID (205), Canal Point, FL (202), Lubbock, TX (202), Manhattan, KS (203), Morris, MN (202), Oxford, MS, Pendleton, OR, Pullman, WA (211 and 203) , Temple, TX (202), Tifton, GA(202), Tucson, AZ, and W. Lafayette, IN **Cooperators** Producers, Industry, Consultants, University Extension, Amendment Industry, Construction Industry NRCS-The Central National Technology Support Center, Ft. Worth, TX, NRCS-National	7. Multi-scale modeling system to predict wind, water, and tillage erosion, and downstream impact of sediment movement on agricultural landscapes using a common interface with shared databases: development, parameterization, and validation **Product Users****** Producers, NRCS, USFS, USGS, EPA, universities, soil and water conservation districts, State planning boards, farmers, ranchers, engineers, and consultants	**Short term** Integration of existing field-scale water, wind, and tillage erosion models will facilitate conservation planning on agricultural lands. Improved predictions of winter erosion processes, rangeland hydrology and erosion, tillage erosion, and wind erosion threshold velocities and dust emissions will improve resource protection. **Long term** Comprehensive decision support system that integrates water erosion, wind erosion, tillage erosion, and sedimentation predictions will improve long-term

Inputs/Resources	Outputs/Products	Outcomes
Water and Climate Center, Portland, OR, USFS, BLM, Other federal agencies (COE, EPA, USGS), State Agencies (DEQs), University of Mississippi, U of Arizona, Arizona State University, Purdue University, University at Buffalo, NY, Michigan Technological University, University of Nottingham, UK INTA, Argentina, and Mexico (INIFAP)		conservation planning and impact assessments.

* The short-term outcomes will be accomplished in the next five years.

** The long-term outcomes will not be fully accomplished in five years given current personnel and physical resources, but significant progress will be made.

*** These scientists are conducting research primarily in the ARS Soil Resource Management National Program (202), etc.

**** Product users are for the entire problem area.