USDA Agricultural Research Service
National Program 211 – Water Availability & Watershed Management
Action Plan 2016-2021

USDA Agricultural Research Service National Program 211

Water Availability and Watershed Management

Action Plan FY 2016-2021

Vision
Integrated, Effective, and Safe Water Resource Management

Mission
The mission the Water Availability and Watershed Management National Program is to effectively and safely manage water resources to sustain and increase agricultural production and water use efficiency while protecting the environment and human and animal health. The National Program accomplishes this mission by: (1) conducting fundamental and applied research on the processes that control water availability and quality for the health and economic growth of the American people; and (2) developing new and improved technologies for managing the Nation's agricultural water resources.

This will be achieved by characterizing potential hazards, developing management practices, strategies and systems to alleviate problems, and providing practices, technologies, and decision support tools for the benefit of customers, stakeholders, partners, and product users. Customers, stakeholders, partners, and users of this research include producers, landowners, consultants, manufacturers, State agencies, Cooperative Extension, USDA Agencies including the Natural Resources Conservation Service (NRCS), the Forest Service (FS), the Farm Services Agency (FSA), the Foreign Agricultural Service (FAS), and the Office of Risk Assessment and Cost-Benefit Analysis (ORACBA), and other Federal Agencies including the Environmental Protection Agency (EPA), the U.S. Geological Survey (USGS), the Centers for Disease Control and Prevention (CDC), the National Oceanographic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the Bureau of Land Management (BLM), the Bureau of Reclamation (BOR), the US Army Corps of Engineers (USACE), the National Park Service (NPS), and other action-oriented organizations and centers.

These advances in knowledge and technologies will provide producers, action agencies, local communities, and resource advisors with the practices, tools, models, technology and decision support systems they need to improve water conservation and water use efficiency in agriculture, enhance water quality, sustain and increase agricultural productivity and profitability, protect rural and urban communities from the ravages of droughts and floods, improve agricultural and urban watersheds, and prevent the degradation of riparian areas, wetlands, and stream corridors. The rationale for this program is that water is fundamental to life and is a basic requirement for virtually all of our agricultural, industrial, urban, and recreational activities, as well as the sustained health of the natural environment.

Relationship of this National Program to the USDA Strategic Plan
This Action Plan outlines research that supports two objectives in the USDA Strategic Plan for FY 2014-2018, both under Strategic Goal 2 – Ensure Our National Forests and Private Working Lands are Conserved, Restored, and Made More Resilient to Climate Change, while Enhancing Our Water Resources:

- Objective 2.2 – Lead Efforts to Mitigate and Adapt to Climate Change, Drought, and Extreme Weather in Agriculture and Forestry, and

- Objective 2.3 – Contribute to Clean and Abundant Water by Protecting and Enhancing Water Resources in National Forests and on Working Lands.

Relationship of this National Program to the 2014 USDA Resource, Education, and Economics (REE) Action Plan
This Action Plan outlines research that supports Goal 3 – Sustainable Use of Natural Resources, Subgoal 3A – Water Availability: Quality and Quantity in the 2014 REE Action Plan.

Relationship of this National Program to the ARS Strategic Plan
This Action Plan outlines research that supports Strategic Goal Area 2 – Natural Resources and Sustainable Agricultural Systems, Goal 2.1 – Integrated, Effective, and Safe Water Resource Management.

> **Performance Measure 2.2.1:** Develop technology and practices to promote improvement of integrated, effective, and safe water resource management.

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

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

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

Bay, and the Great Lakes. Clearly, new technologies were needed to allow agriculture to better manage both water quantity and quality.

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

Approach

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

Specific topics to be studied include: irrigation scheduling technologies for sustainability; drainage water management and control; field scale processes controlling soil erosion and the transport and fate of sediment and contaminants; understanding how to select, place, and combine conservation practices to achieve improvements in water quantity and quality in watersheds; improving conservation technologies to better protect water resources; ensuring conservation and agricultural management practices can increase agricultural profitability and resilience under changing climate and land use; development of tools and methods to improve water resource management; and improving watershed management and ecosystem services through large area, long-term field research, site characterization, and data dissemination in agricultural watersheds and landscapes. The overall goal is to provide solutions to problems in the utilization of the Nation's water resources.

This National Program is organized into four Components:

- Effective Water Management in Agriculture
- Erosion, Sedimentation, and Water Quality Protection
- Enhancing and Documenting the Benefits of Conservation Practices
- Watershed Management to Improve Ecosystem Services in Agricultural Landscapes

These Components were chosen after receiving input at a planning workshop designed to understand the problems and needs of our customers, stakeholders, and partners, and from other interactions with interested parties.

Cooperative research among ARS units will occur to develop the products and achieve the outcomes identified in this action plan. Cooperators from academia and other agencies will assist in the actual research and in outreach and technology transfer. Product users such as EPA, extension, NRCS, and USGS will work with us to ensure that we provide the information in the most useable formats for their organizations so that expected outcomes are quickly achieved.

As the name of this National Research Program, "Water Availability & Watershed Management", suggests, associated research addresses water resource issues and problems broadly and across a range of scales. Although it is often misinterpreted to mean water quantity only, the term 'Water Availability' was chosen because in its broadest sense, it refers to both water quantity and quality concerns. The first two program Components cover, through basic and applied research, water management for water availability and efficient water use in production agriculture (Component 1) and control of erosion, sedimentation, and water quality (Component 2).

As with many issues in natural resources, variations in scale are frequently important, and there is a long history of 'water-related' research, in ARS and elsewhere, that uses small watersheds as a model system to study water-related processes at larger scales. These experimental watersheds serve as platforms for collecting data at a variety of scales, for linking ground-based and remotely-sensed data, and for developing models that allow extrapolation of key hydrologic and related processes across both spatial and temporal scales. The watershed-scale research is divided into two Components, one that focuses specifically on the Conservation Effects Assessment Project (CEAP), and associated conservation research (Component 3), and a second (Component 4) that addresses a variety of other topics that are linked to the underlying small/experimental watershed model concept. Importantly, both irrigation and drainage practices are linked through this research to the watersheds in which they occur, ensuring that research on irrigation and drainage practices does not disregard broader environmental concerns. Both Components 3 and 4 are tied to long-term research involving close cooperation and information sharing between scientists involved with the ARS Long-Term Agro-ecosystems Research (LTAR) network. Research also contributes to the USDA Regional Biomass Research Centers, and the USDA Climate Hubs, which transfer information to help farmers, ranchers, and forest landowners adapt to climate change and weather variability. NP 211 research results will also be used to facilitate data synthesis and utilization in GRACEnet, REAP, and other ARS databases.

Because all NP 211 experiments and studies produce digital data that are used in long-term, multi-location research involving partners in many federal and state agencies and universities, data management is key to effective science in the present and future. Storage and curation of these data are essential to accessibility and usefulness of data to research partners and the public. Therefore, and pursuant to Presidential and OMB guidance (e.g., Presidential Memoranda M-13-13, OMB Circular A-130, OMB Memorandum M-06-02) that directs agencies to strengthen data management and accessibility practices, every project plan written for this action plan will include a data management plan (DMP). The DMP will include description of appropriate and useful metadata creation, means of data transmission and storage, a plan for crediting scientific contributions to data, and a plan for eventual disposition of data in a publically accessible repository. Projects that are involved in an ARS multi-location research (MLR) project may cite the DMP for the MLR project if such exists. An example is the Shared Data Plan referenced in the LTAR project plans.

As is characteristic of natural resource issues in general, water resources research often crosses artificial 'National Program' boundaries that are established primarily to facilitate program management. Water is the primary driver of all research conducted in NP 211, but it is impossible to address water research questions at any scale without considering associated factors such as soil, air, sustainability, climate change, greenhouse gas emissions, etc. Some NP 211 projects are contributing to research Components that are part of the Action Plans of other ARS National Programs; each of those projects carries a formal designation as contributing to one or two additional National Programs as appropriate. Other projects may address water-related research that involves soils (e.g., water-driven soil erosion), air quality (e.g., nitrogen cycling driven by water quality concerns that requires closing the nitrogen cycle, to achieve definitive results), climate change (precipitation is one of two key components that make up climate, and thus changes in the hydrologic cycle are intimately linked to climate change), but without addressing specific research Components in other National Program Action Plans. In the sections below, research activities that cross National Program boundaries either formally or informally have been placed in *italics* to make them readily identifiable to our customers, stakeholders, and other readers of this document, giving the reader a more complete picture of the scope of and interactions between ARS National Programs.

Planning Process and Plan Development
The National Program 211 Workshop was held in May 2015 at Beltsville, MD. Nearly 200 participants attended this workshop either in person or virtually, including producers, commodity and public interest group representatives, scientists from universities, and scientists and administrators from ARS and other Federal and State agencies. The problem areas in this action plan were formulated based on workshop inputs, and inputs from other activities such as USDA and interagency programs, committees, and meetings attended by our scientists and National Program Leaders. Recent reports from the National Academy of Science, National Science and Technology Council, and U.S. General Accounting Office were also considered as this Action Plan was developed.

ARS scientists used the program logic model to identify Outcomes desired by our customers and stakeholders, specific research products (Outputs) needed to achieve these outcomes, and the resources available to develop these products for each of the problem areas in this action plan. ARS scientists at each of the laboratories participating in NP 211 and other relevant National Programs will reference this action plan when developing project plans that describe the research they will conduct. Project plans provide detailed information on objectives, anticipated products or information to be generated, the approach that will be used, roles and responsibilities of ARS scientists and their cooperators, and timelines and milestones to measure progress of the research. All project plans are reviewed for scientific quality by an independent panel of experts in the field. ARS scientists will use input from the review panel to revise and improve their planned research.

Component 1 – Effective Water Management in Agriculture

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

Yet agriculture is subject to growing competition for water resources, and irrigation and drainage systems must be improved to deal with adverse environmental effects and inevitable reductions in water resources available for irrigated agriculture in some areas.

After thermoelectric generation, irrigation is the largest user of freshwater resources, accounting for 40% of water withdrawals overall and more than 70% in more arid regions such as the western USA. Surface and subsurface water allocation comprises a complex system of competing and interacting claims from agricultural, energy industry, tribal, environmental and urban interests, which increasingly leaves agriculture with less water, or with lower quality water, for food, feed, fiber, and biofuel production. Irrigated agriculture must respond with solutions that improve water use efficiency (amount of crop yield produced per unit of water consumed) and extend water availability through increased use of alternative resources, including urban treated wastewaters, recycled drainage waters, and other lower-quality waters such as from dairy, aquaculture, and animal feeding operations and commodity processing plants. New methods and management practices are required for safe and effective use of these sometimes lower quality alternative water resources. Economic forces are hastening the transfer of water from agricultural to urban areas and the subsequent decrease of irrigated area in the West. At the same time, irrigated acreage is increasing in the Midwest, Southeast and Mississippi Delta regions of Arkansas, Louisiana, Mississippi, and Missouri. Competition for water has caused conflicts in areas where water was typically abundant. In these sub-humid and humid climates, irrigation problems are frequently different from those in more arid climates, requiring new solutions that are not directly transferable from the irrigated West.

In all regions of the country, irrigation and drainage are now directly related to the environmental and public health and economic viability of the watersheds within which they operate. In the 17 states of the Western USA, the total annual farm gate value of production tied to irrigation exceeds $117 billion, and total economic impact exceeds $156 billion. In the Plains states, irrigated agriculture produces more than three times the net revenue per acre as dryland farming. Even as irrigated acreage in the West has declined due to drought and competition from other water users, irrigation has moved eastward into regions formerly considered to not need irrigation. Climate variability and the recognition that supplemental irrigation can stabilize crop yield and double water use efficiency compared with rain-fed agriculture have combined to motivate an 18% increase to >15 million irrigated acres in the Midwest over the last 15 years, and a >4% overall increase of irrigation in the South, including increases of >40% in Alabama, Georgia, Maryland, South Carolina and Tennessee, with a 27% increase to nearly five million irrigated acres in Arkansas alone. This eastern migration of irrigation improves crop yields to an average of 80% of potential yield compared with <50% of potential yield obtained when relying only precipitation; it thus stabilizes rural economies but brings with it a host of new management problems to be solved.

The quest for increased water and nutrient use efficiencies, and for water and food security for the nation and the world, requires solutions that improve water management for efficient agricultural production. Improved and new systems and technologies that automatically monitor crop responses to water and fertilization are needed to increase irrigation and nutrient use efficiencies and profitability, while reducing the adverse environmental consequences of irrigation and drainage systems, including reduction of greenhouse gas emissions. Improved understanding of how irrigation impacts ecosystem services, greenhouse gas production, and the related carbon credits market will impact irrigation management adoption rates. More precisely determining individual field and crop water needs will require better decision support systems (DSS), while advanced irrigation technologies are needed to automate these DSS tools to improve site-specific management within fields. Developing new sensors and sensor systems that improve measurements of soil water content and plant response is integral to developing these advanced DSS technologies. Electronic technologies exist that can be used to develop systems capable of providing continuous site-specific feedback to managers on when and how much to irrigate, drain, fertilize, and/or pump. Improved understanding of crop responses to water applications will help determine the timing and quantity of irrigation, to improve both yield and water use efficiency. Such understanding is also important to the development of water-efficient crop varieties that are an important component of both irrigated and rain-fed agriculture. New crop varieties will be a large factor driving water requirements in agricultural systems in the future.

There has been recent, renewed success in providing crop water use values to irrigation managers using the paradigm of a reference evapotranspiration multiplied by a seasonally adjusted crop coefficient (K_c). However, this success has generated demand for new knowledge of K_c for high-value horticultural, alternative, and biofuel crops. Demand is also growing for a K_c approach that transfers well across climatic regions, especially for application in humid climates. Important new work is aimed at developing tools for irrigation scheduling in humid and sub humid regions.

Beyond the scale of individual fields, there is a need for improved management and evaluation tools at farm, irrigation/drainage district, and watershed scales. These include assessment tools for managers and action agencies that encompass a range of problems, from methods of evaluating irrigation and drainage project performance and the impact of new technologies and Best Management Practices, to tools to assess the suitability of lower quality waters and needed amendments or other management options for their use, and new or revised irrigation district policies or regulations. Continued development of remote sensing applications will improve irrigation scheme assessments. Modeling tools for regional and national assessment of crop water use and water use efficiency are essential to improved policy formulation as well as management decisions in large basin and inter-basin water supply systems.

Drainage comprises the natural aspects of water moving down slope through swales, streams, and rivers as well as the use of constructed features, including terraces, grassed waterways, and surface and subsurface drainage systems (e.g., ditches and pipes), to manage water movement on and from the land. Constructed features are used on 120 million acres of cropland. Climate change predictions indicating warmer temperatures, more rainfall for the Midwest, and more extreme events for the nation add urgency to the need to develop innovative cropping and drainage water management (DWM) systems, technologies and guidelines. Surface and subsurface DWM systems are crucial for economic production and represent the best available technology for reducing offsite water quantity and quality impacts for both rain-fed and irrigated agriculture. Improved understanding of water use efficiency and the cost of implementing and maintaining on-farm storage of surface drainage water for irrigation are important in humid and semi-humid regions where groundwater sources are being depleted. Contaminants carried in runoff and subsurface drainage from cropland are often the major contributors to nonpoint source water quality problems in streams and other surface water bodies; development of new DWM systems shows considerable promise in reducing these pollutant loadings. Where it is not possible to apply DWM systems, alternatives include modified cropping practices, use of cover crops, bioreactors and other in-line treatment or filtration technologies. Diverting runoff and subsurface drainage waters through existing or constructed wetlands may prove effective for pollutant removal. Nutrient trading markets could be an incentive for land managers to adopt such technologies as has been done with other ecosystem services.

The decreasing supply of fresh water for irrigation, coupled with the increase of wastewater from urban areas and large livestock facilities, leads to the need for irrigation strategies and new crop species and varieties that work well with wastewaters as well as with saline and other alternative water resources not currently in use. Safe use of these waters requires new knowledge of the fate, transport, and control of emerging contaminants, pathogens, and potentially toxic elements, as well as assessment of soil salinity, management strategies, and crop selection for phytoremediation of degraded soils. Additional information is needed on leaching requirements, as current leaching guidelines appear unrealistically high, serving to unnecessarily discourage the use of brackish waters for irrigation and encourage excessive leaching. Studies are needed to evaluate the long term impacts of alternative water use on soil physical and chemical properties as well as on drainage water quality. Additionally, new crop varieties are needed that can be grown successfully with alternative water resources. Varietal improvements and crop selection should include consideration of ion imbalances, toxic elements, and tolerance to salinity, as well as to multiple stresses such as salinity and boron together. Resistance to the reuse for irrigation of water reclaimed from municipal treatment facilities and livestock operations has increased due to the detection of pharmaceutically active compounds and pathogens at very low levels. Monitoring is needed to determine if these constituents are naturally attenuated or accumulate in the environment.

Finally, as irrigation water supplies decline, an important pattern of rotation between irrigated and non-irrigated crops is emerging. Efficient use of the water resource in these cropping systems requires new tillage, irrigation, and crop management tools to reduce runoff and leaching, maximize the effective use of precipitation, and minimize water losses to evaporation. Tools are needed so that managers can evaluate choices between crops, irrigation amounts, or trading water to other users. Increased urban-agricultural water trading leads to the need to quantify the amount of water saved when fields are not irrigated, or are more efficiently irrigated so users receive accurate credit for traded water.

Research Needs. Customer needs were identified during the National Program 211 Workshop held in Beltsville, Maryland in May 2015, and through contacts with producer and commodity organizations, the irrigation and drainage industries, water and irrigation districts, water conservation districts, and federal and state action agencies. The needs of the various stakeholder groups were discussed relative to national and departmental priorities concerning climate change, future biofuel goals, and national food security. Five overall outcomes were identified:

- More effective management of water in agricultural irrigation, drainage and dryland/rain-fed systems;
- More dependable, flexible, and efficient irrigation water delivery and drainage systems at field, farm, and watershed scales;
- Conservation of water, nutrients, and energy for economically and environmentally sustainable enterprises;
- More effective use of precipitation, drainage and irrigation water, use of saline waters, and reuse of wastewaters; and
- Increased water use efficiency through improved tillage and residue management systems and crop development for salt tolerance and phytoremediation.

Research Plan

Problem Statement 1A: Irrigation Scheduling Technologies for Sustainability
Improving the efficiency of water use in production agriculture will be key to sustaining and expanding food and biofuel production in the face of increasing water demands for non-agricultural uses. Strategies pursued will include more accurate irrigation scheduling based

on weather data, plant- and soil-based sensor systems to guide and automate irrigation, deficit irrigation management and irrigated-dryland-rain-fed rotations to use scarce water supplies and precipitation more efficiently, site-specific irrigation systems to place water where it is most effective, strategies to reduce greenhouse gas emissions associated with various irrigation strategies, and integrated climate-crop-economic models to determine profitable and sustainable water use strategies.

Field studies will use soil water balance and weighing lysimeter methods to determine relationships between crop coefficients and plant properties (e.g., leaf temperature and reflectance, stomatal conductance, leaf water potential, etc.), as influenced by irrigation system application methods and management.

Plot, field, and watershed scale studies will characterize yield, quality, and crop water productivity of annual and perennial crops (e.g., peach, grape, citrus) under deficit irrigation, regulated according to crop stress & soil water sensing systems (ground, airborne and satellite based), or according to crop growth models based on assimilation of real-time and predicted weather, plant and/or soil water measurements. Crop rotation effects on water use and productivity will be evaluated. Multiple scale studies will evaluate remote sensing and related measurement techniques, and enhance understanding of the bio-pedo-physical processes regulating evapotranspiration (ET) to improve modeling of plant water use and stress. Field and simulation studies will examine the effects of crop rotations/sequences (water conservation during fallow), residue and moisture retaining tillage practices combined with partial pivot irrigation strategies (optimizing variable crop demand/timing and forecast weather), and alternate production practices (planting geometry, fertility management, harvested product).

Economic analyses will be made to identify optimal management strategies for a range of production and climate scenarios. Historical data will be analyzed to identify recent climate trends. Long term weather trends will be evaluated to identify alternative irrigation practices and methods and study their potential impacts over arid to humid regions.

ARS will conduct laboratory and field studies to develop and evaluate soil and plant water stress sensors, sensor networks, UAV-based sensing systems, and sensor-based feedback algorithms for estimating evaporation (E), transpiration (T) and ET, monitoring and control of irrigation and nutrient applications (including water level control), and drainage of annual and perennial crops (fruit, nut, landscape). In a multi-location joint effort, field and plot studies will be made of automation and control systems for site-specific irrigation and nutrient application systems; integrating sensor systems into decision support systems while evaluating spatial soil water status and plant stress and developing use of crop growth models for spatial irrigation.

Anticipated Products

- Crop coefficient (Kc or Kcb) and reference evapotranspiration (ETo) models that are reliable across regions and climatic zones, genotypes, and water deficit regimes. Real-time crop coefficients based on growth, as well as plant water and/or soil water status.
- Deficit irrigation management tools for a broad range of crops, including irrigation and timing strategies, automation and control systems, crop and/or irrigation rotations, crop growth models of the physical processes affecting crop yield & quality under water deficit conditions, and remote sensing-based monitoring of plant stress and water use.

- Multi-season and multi-crop integrated management and rotation tools for water management and use. Physiological and/or physical (e.g., soil water balance and energy balance) verification of associated tools.
- Integrated crop management and irrigation scheduling tools based on climatological information, crop and soil water modeling, and economic models.
- Plant & soil sensors and sensor systems as tools for irrigation, nutrient, water storage, and drainage management, and for mapping of surface and profile water contents and biotic and abiotic plant stress levels (low cost, reliable wireless sensors and algorithms, including water level sensing systems).
- Site specific irrigation (SSI) management tools (devices & algorithms to detect site-specific biotic and abiotic stresses, tied to irrigation control & scheduling systems for site-specific nutrient & water applications).

Potential Benefits

- Productivity and crop quality are maximized while water conservation and environmental protection are improved, because growers adopt more effective and user friendly irrigation scheduling protocols based on plant needs (determined using real-time crop coefficients and plant and soil water status sensing), especially where water resources are limiting.
- Limited water resources produce more crop yield through improved crop water use efficiency enabled by improved models and methods for irrigation scheduling and crop management using climatological and proximal and remote sensing information.
- Irrigation management time/cost are reduced and crop water productivity is improved by the development of integrated, commercially available plant and soil feedback systems that result in efficient full and regulated deficit irrigation.
- Overall efficiency of water use (both irrigation and precipitation) is increased to stretch limited water supplies through integrated management of irrigation supplies and rotation effects and use of improved crop development & growth models of the physical and physiological processes affecting crop yield and quality under water deficit conditions.
- Improved management of crop choices and identification of optimal irrigation strategies are enabled by the development/deployment of decision support tools that use climatological and proximal and remote sensing information and current or hypothetical price and cost conditions.
- Projection of future irrigation and/or crop choices based on climate trends over key growing regions results in significantly improved agricultural water use efficiency with no loss in productivity, food quality, or ecosystem services.
- Water and nutrient management is improved because new or improved sensor systems, networks, and algorithms are available for integration with irrigation, fertigation, and drainage systems, or for use directly in the field.
- An accurate, deep profiling soil water content sensor system, installable with minimal soil disturbance, is available for irrigation management and water use determination resulting in reduced water use through more accurate irrigation scheduling and improved management of crop water use when using alternative water resources.
- Improved evaluation of soil water sensing technology improves users' choice of sensors.
- Water and nutrient use efficiencies are improved, environmental impacts are reduced, and long-term scientific monitoring of variability and change is enhanced, because commercial irrigation-fertigation-drainage systems are now automated/guided by new or improved sensor systems.
- Crop production and water use efficiency are enhanced, and irrigation water use is reduced, through the development of tools for site-specific irrigation and nutrient application

- Irrigation management time is reduced, and crop water productivity is improved because integrated water management decision support systems are commercially available, including plant and soil feedback systems that are specifically tailored for site-specific irrigation management.

Problem Statement 1B: Water Productivity and Water Requirements at Multiple Scales

In the face of competing demands for water, including for biofuel production, knowledge of crop water productivity (water use efficiency) is essential to support decision-making at a variety of scales – on-farm, within irrigation and underground water management districts, for interstate and international water arrangements, and for policy makers and planners at all levels. Strategies will include: 1) plant-scale measurements of water productivity across diverse germplasm and varieties, including new drought tolerant varieties; 2) field-scale measurement of water use efficiency for multiple locations and crops in both irrigated and dryland/rain-fed farming systems; and 3) regional-scale approaches developed using remote sensing tools. Plant-, field-, and regional-scale approaches will be integrated with efforts to improve crop performance, detect plant stress, and estimate crop water use and productivity. In a multi-location joint effort, ARS will improve evapotranspiration algorithms, crop production functions and irrigation algorithms in ARS flagship models to better simulate water use efficiency under climate variations and with new conservation practices including on-farm storage of drainage waters for irrigation.

ARS will develop crop production functions, including impact of drought tolerance technology on production functions using field studies with various crop species and varieties. ARS will also use field studies to determine water productivity & sustainability of rangeland and cultivated biofuel crops in various climatic regions.

ARS will develop water-yield relationship for sprinkler irrigated rice using large-plot studies. New and existing data from field and plot studies on agronomic crops, horticultural crops, and biofuels will be summarized. ARS will establish water-yield relationships for companion crop systems.

ARS will conduct plot, field, and regional scale studies to model and measure ET and test spatial models of ET based on data from satellite and airborne (including UAV) remote sensing platforms, including investigating techniques for upscaling and downscaling ET estimates relevant to field scale applications and to ground-truthing the results, as well as watershed and regional scale estimation for comparison and integration into hydrologic and land surface models.

Anticipated Products

- Crop water productivity and water-yield-quality relationships for agronomic, biofuel, and horticultural crops.
- Improved model estimates of ET, particularly under precipitation and temperature extremes (e.g., drought).
- Remote sensing tools for field-to-regional scale ET and water use efficiency (WUE) estimation.

Potential Benefits

- Significant improvements in selection of sustainable cropping systems, factoring in water availability and water management practices, are made using a database of water use efficiencies and requirements for agronomic, horticultural and biofuel crops that is used by economists, planners and policy makers to estimate water productivity for different cropping and biofuel production scenarios.

- Growers and agricultural irrigation district managers improve crop water use efficiency by using tools for irrigation planning, scheduling, and crop stress detection that improve water use efficiency and which are based on reliable algorithms to estimate ET and WUE at various spatial resolutions and that are applicable to a wide variety of land cover types.
- Water use efficiency and sustainability are significantly improved in agricultural regions, where water availability from surface and groundwater sources is facing unprecedented limitations, through use of decision-making tools for agronomic, biofuel, and horticultural crop selection & production that are made available to and used by economists, producers, and district, regional, state, and federal managers and policy makers to address water productivity, harvest quality, and yield goals in the contexts of profitability and resource sustainability.
- Significant improvements in water use efficiency and agricultural sustainability in irrigated regions, including the Midwest, Midsouth and Southeast, result from operational field-scale and remote sensing-based ET and WUE models using airborne and satellite remote sensing platforms for water use assessment that are made available for irrigation scheduling, water balance/hydrologic modeling and water resource management decision making.

Problem Statement 1C: Irrigation Application Methods
As irrigation application through pressurized irrigation systems has increased to cover 65% of irrigated lands in the nation, water use efficiency has doubled; but in many areas irrigation is still applied using surface gravity-flow methods. Choice and design of appropriate irrigation application systems requires in depth understanding of the complex interactions of application method, cropping system, and the related energy, water and nutrient use efficiencies.

ARS will use field studies to understand the effects of irrigation application system (sprinkler, microirrigation and, where appropriate, gravity-flow systems) on energy balances, evaporative losses, transpiration, whole-field water use, and water and nutrient use efficiencies.

ARS will compare different production systems for rice (e.g., traditional flood, 0 grade, sprinkler), including comparing effects on greenhouse gas emissions. ARS will development and field test a model of surface irrigation-induced sediment and nutrient transport processes.

In field and plot studies, ARS will determine methods of estimating and measuring the effects of irrigation application method on soil and water conservation, including spatial and seasonal variability of infiltration properties.

Anticipated Products
- Irrigation application method comparisons in terms of water and energy use, water and nutrient use efficiencies, and BMPs for amelioration of deleterious factors: includes comparison of gravity, sprinkler and subsurface drip irrigation for major crops.
- Alternative, efficient methods for rice irrigation, (including BMPs for GHG, arsenic, and cadmium).
- Tools and software for evaluating, designing, comparing, choosing and improving water application methods in terms of water, nutrient and energy use and temporally and spatially variable soil and field characteristics, tied to the NRCS soils database in the absence of more site-specific data.

- Guidelines for the selection and application of soil & water conservation measures in irrigated systems and methods for quantifying their impact on soil, water, and energy resources.

Potential Benefits

- System design and decision-making are improved, because farmers, action agencies, and planners have access to assessments of crop water productivity and water losses as affected by choice of sprinkler, surface, and drip irrigation systems, resulting in improved WUE and decreased unnecessary off-site water movement.
- Subsurface drip irrigation lateral spacing and depth designs are optimized by farmers, action agencies, and vendors using a new design tool, resulting in improved germination, yield and profitability.
- Producers and action agencies justify converting to more efficient pressurized center pivot and microirrigation systems, resulting in decreased irrigation applications and increased water use efficiency, by using a decision support system to evaluate the impact of irrigation application methods and management practices at farm scale on water, nutrient and energy efficiencies and on profitability.
- Producers select the most profitable and sustainable irrigation system, given the constraints of water availability, soils, crops, energy costs and changing climate, by using new tools for evaluating and predicting the hydraulic performance of water application methods (sprinkler, drip, surface), linked to the NRCS soils database.

Problem Statement 1D: Dryland/Rain-fed Water Management

Water management in dryland and rain-fed farming systems is key to sustaining productivity and improving water use efficiency in the face of short- and long-term climatic stresses. Strategies for improving productivity and sustainability include no-tillage systems, crop selection and rotation, crop variety selection, planting geometry, and sequences of production that combine dryland/rain-fed farming with limited irrigation and grazing systems to maximize precipitation use efficiency.

ARS will conduct field research documenting yield, water productivity relationships, and soil water availability as affected by crop selection, planting decisions, tillage, harvested product, and rotational sequences that may include irrigated and livestock grazing production phases. Crop growth and agricultural systems models will be evaluated using collected field data. Alternative management practice effects on crop yield and water use efficiency will be simulated for projected and historical climates.

Anticipated Products

- Decision aids to determine optimal variety/crop, planting population/dates and crop sequences to maximize water productivity under dryland and rain-fed production systems
- Improved water production models that incorporate seasonal water stress on dryland crop yields for use across the southern and central Great Plains.
- Yield and overall water use efficiency relationships with soil water availability as affected by crop selection, rotation, and geometry, and sequences of irrigated-dryland-rain-fed-grazing production.
- Improved understanding and quantification of hydrological processes affecting spatial variability of soil water and crop/range production.

Potential Benefits

- Yield and profitability are improved by new dryland and rain-fed production strategies, including limited irrigation or rotation with irrigation, for a range of crops and regions.

- Evaporative losses are decreased and yields are increased with limited precipitation or irrigation using new or improved tillage practice recommendations.
- Water availability and yield are maximized across landscapes using new or improved soil-, crop-, and climate-specific tillage and cropping strategies (planting geometry crop rotation, sequences of dryland and irrigated production) recommendations under limited precipitation or irrigation.

Problem Statement 1E: Drainage Water Management and Control
In both rain-fed and irrigated regions of the nation, the application of surface and subsurface drainage systems has greatly increased the productivity of 120 million acres of farmland. During the past 150 years, surface ditches and subsurface drains have been widely installed across these regions to facilitate settlement and increase crop production. In many locations, subsurface drainage is required just to make agricultural production possible. In other areas, adding subsurface drainage can increase crop yields, reduce the risk of crop loss from excess water, decrease crop susceptibility to pests and diseases, and provide more uniform crop production amidst climate variability. But increased use of fertilizers and increased variability of precipitation in rain-fed regions requires new solutions for drainage water management. Strategies to reduce fertilizer and sediment movement from fields to waterways and to control and store drainage water for use in irrigation include new system design and management tools, water control and automation technologies, bioreactor designs for removing nutrients, and agronomic interventions such as wetland basins and cover crops. Expected demands for agriculture to provide food, feed, fiber, and fuel to an estimated 9.7 billion people by 2050 will require water management and control.

ARS will learn the effects of artificial drainage management and design, and in-field practice effects, on nutrient loss, nutrient use efficiency, and crop productivity. ARS will quantify the fate, transformation and loading potential of nutrients and antibiotics, under different landscape attributes and management scenarios, and the relative contributions between surface and subsurface transport pathways. This research will involve the use of novel tracers, field-scale evaluations of matrix-macropore interactions in tile-drained fields, and investigation of the impacts of electrostatic processes (anion exclusion/adsorption) on nitrate leaching through the soil profile. ARS will use field and model studies to examine the efficacy of cover crops on N and P loss reduction in tile drains.

ARS will conduct plot and field scale research to quantify capacity to mitigate nutrient and pesticide movement off site through use of vegetated agricultural drainage ditches as a management practice. Field and pilot test studies will be made of systems integrating bioreactors and chemically reactive porous media to remove both nitrate and phosphate from subsurface drainage waters, and any resulting nitrous oxide emissions. ARS will evaluate new and innovative in-field or edge-of-field treatment technologies, specifically for phosphorus and antibiotics, to minimize pollutant loading and transport in surface runoff and tile flow.

ARS will quantify water quality and quantity benefits of irrigation reservoirs, drainage water recycling, and tail-water recovery systems as a conservation practice in field- and watershed-scale research. ARS will identify and assess practices to increase water storage and recharge (both natural and artificial) in agricultural landscapes, and determine their impact on nutrients, sediments, water balance, and ecosystems.

ARS will determine the relationships between wave energy and embankment erosion, and assess the current state of impairment for existing reservoirs.

Hydrologic and crop yield data will be analyzed from field studies and remote sensing focused on controlled drainage and sub-irrigation water table management practices aimed at development and evaluation of climate change adjustment strategies for Midwest U.S. agriculture.

Anticipated Products

- Improved scientific knowledge of processes impacting nutrient transport, transformation, and losses within artificially drained agricultural settings, and of impacts on nutrient and water use efficiencies.
- Improved techniques for assessing sediments and pollutants in different hydrologic pathways, and improved prediction technologies.
- Quantification of the importance of electrostatic processes affecting nitrate leaching through the soil profile.
- Better tools for assessing environmental risks associated with nitrate fertilizer application on farm fields containing subsurface drainage systems.
- Improved understanding of biotic and abiotic processes involved in the remediation of nutrients and pesticides associated with agricultural runoff, leading to remediation practices.
- More efficient management practices utilizing vegetated drainage ditches.
- Tested systems using irrigation reservoirs coupled with tail-water recovery that improve water quality/quantity.
- Methods to identify opportunities for water storage and re-use in traditionally rain-fed agricultural regions.
- Recommendations for cover crop use to reduce nutrient loss.
- Decision support tools to assess the potential of denitrification bioreactors.
- Design guidelines for treatment systems, with combined bioreactor and chemically reactive porous media components that are an efficient, effective, and low- cost means of removing both nitrate and phosphate from drainage waters.
- Guidelines for drainage water management operations that best adapt to Midwest U.S. climate change scenarios, including predicted shifts in temperature and precipitation patterns, greater frequency of intense storms, and more severe and longer droughts in the summer.

Potential Benefits

- Assessment of the fate and transport of pollutants in space and time is improved using new, improved, and tested process-based erosion, nutrient transport and water quality models.
- Best management practice implementation is more focused and is more effective in reducing undesired nutrient transport and improving ecosystem services through identification of locations, landscape characteristics, and relevant management practices.
- Risk is reduced, and water quality and agronomic benefits and costs are improved, because producers and state and federal action agencies implement new or improved BMP recommendations across the Midwest.
- Improved yields and overall water and nutrient use efficiencies lead to lower costs and improved profitability through widespread adoption of new and enhanced BMPs for tile drained landscapes that minimize nutrient and water losses from agriculture
- New and innovative BMPs are used to increase water quality and water use efficiency through use of newly developed or improved strategies, tools and designs.
- Substantial improvements in water use efficiency, crop productivity, and water quality are realized through promotion and adoption of conservation practices including vegetated drainage ditches, tail-water recovery systems that improve

water quality, and treatment systems that reduce nitrate and phosphorus present in drainage water discharges.

- Unwanted nutrient fluxes to streams and lakes are reduced through increased adoption of bioreactors resulting from creation of a standard for sizing, construction and operation.
- Water availability is enhanced, and aquifer declines are stabilized or reversed, due to decreased use of groundwater to irrigate field crops resulting from implementation of conservation practices including drainage water and tail-water recovery systems.
- Risk is reduced, water quality improves, agronomic benefits increase, and costs decrease across the Midwest because producers and state and federal action agencies adopt fall-planted cover crop recommendations.
- The environmental quality of surface waters improves in agricultural areas due to the use of subsurface drainage best practices.
- Improved evaluation and implementation of levee protection options is enabled by use of worst-case guidelines for wave erosion of field-scale earthen levees. Improved placement and/or construction of levees is enabled by analysis of levee impairment and design.
- Farmers mitigate adverse environmental and crop production impacts of periods of excessive rainfall or drought through use of new drainage water management (DWM) guidelines and designs.
- Off field transport of nutrients is reduced through a significant increase of DWM systems in tile drained landscapes that results from tools and technologies developed to aid in the assessment, placement and design of DWM, sub-irrigation and water re-use systems.
- Agricultural production and the environment are sustained or enhanced, against a background of changing Midwest U.S. climate patterns, through the creation and adoption of improved practices for controlling and managing tile drained and sub-irrigated fields common to the region.

Problem Statement 1F: Alternative Water Resources for Irrigation

As the nation faces increasing water demand for non-agricultural uses and growing urban populations, agriculture must look toward developing alternative sources of irrigation waters, including recycled municipal, industrial and agricultural waters and lower quality natural water resources. Developing strategies for safe and effective use of these alternative water resources for agricultural production requires development of indicators for emerging contaminants and pathogens, assessment of persistence of these agents in treated waste waters, plant selection and breeding for tolerance to salinity and specific ions, and irrigation application and scheduling guidelines for effective, sustainable use of alternative water resources and the nutrients they contain.

ARS will conduct laboratory, small plot, field, and modeling studies of:

(i.) Emerging contaminants and pathogens, including antibiotic resistant pathogens and genes and the co-occurrence of antibiotics and specific antibiotic resistance in organisms, that may be associated with the use of alternative water resources for irrigation;

(ii.) Compounds and organisms that indicate past or current application of treated municipal waste water, and their environmental persistence;

(iii.) Plant response to, and crop production with, saline or brackish irrigation waters and drought conditions;

(iv.) *Genes related to crop salt tolerance, and the development of new varieties that have over-expression of those genes;*

(v.) Field assessment technologies for the impact of different saline, brackish, or recycled waters on soil properties, plant water and ion uptake, and plant growth;

ARS will use multiscale studies to evaluate, improve, and develop related integrated decision support tools.

Anticipated Products

- Identification and treatment of emerging contaminants and pathogens in waste waters used as alternative water resources for irrigation, including their persistence and/or accumulation in crops and soils.
- Assessment of the persistence and effects of emerging contaminants and pathogens from treated waste water in the environment.
- Plant identification, selection, & breeding for tolerance to salt, drought, and toxic ions.
- Water quality criteria for saline and reused water.
- Guidelines for crop selection and irrigation management & scheduling, including salinity assessment, leaching requirements, and management of toxic elements.

Potential Benefits

- Water availability and crop production are increased through use of alternative water resources resulting from new tools and recommendations for managing degraded and alternative water resources, which are established by identifying and quantifying agricultural production constraints and/or environmental impacts associated with excess salts, toxic trace elements, organic pollutants, and/or pathogens and emerging contaminants.
- Increased production of crops using brackish water resources results from phyto-management of toxic ions under saline and drought conditions, which is made possible through new plant species selections.
- Irrigation water requirements are reduced through revised leaching practice recommendations based on new knowledge and theory.
- More efficient use of nutrients in crop production is made possible by new/improved management guides/models for use of nutrients present in treated waste waters.
- Safe, effective, and sustainable use of alternative water resources is enabled through the creation of water reuse tools and concepts that integrate agronomic and environmental perspectives.
- The potential productivity of marginal lands and waters is increased due to the development of new salt and drought tolerant crops and plant varieties.
- More effective water management results from new and updated guidelines for: (i.) irrigation BMPs related to irrigation water salinity, nutrient content, potential toxic ions, and impact of saline and recycled waters on soil physical properties; and (ii.) the selection of plant species suitable for use with saline and degraded waters, for water-limited (drought) conditions, for biofuel production, and for phytoremediation.

Component 1 Resources

- Beltsville, Maryland
- Bushland, Texas
- Columbia, Missouri
- El Reno, Oklahoma
- Florence, South Carolina
- Fort Collins, Colorado
- Jonesboro, Arkansas
- Kimberly, Idaho
- Lubbock, Texas
- Maricopa, Arizona
- Parlier, California
- Riverside, California
- Stoneville, Mississippi
- Columbus, Ohio
- Tifton, Georgia
- St. Paul, Minnesota
- Temple, Texas
- Ames, Iowa
- University Park, Pennsylvania
- West Lafayette, Indiana
- Oxford, Mississippi

Component 2 - Erosion, Sedimentation, and Water Quality Protection

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

Excess pathogens, nutrients, sediment, and associated processes are among the top five causes of impairments for 303(d) listed waters, accounting for nearly half of the Nation's water quality concerns. Sediment generated by soil erosion can have costly impacts on downstream channel habitat and water quality, and reduce reservoir capacity. Erosion of embankments and levees can cause severe flooding and loss of life, while a large number of legacy dams in agricultural watersheds are in need of either rehabilitation or removal. Excess nutrients can accelerate the eutrophication of fresh and marine waters, causing shifts in species composition, noxious algal blooms, and hypoxia (i.e., oxygen depletion). High nitrate levels in drinking water are a human health concern in many parts of the U.S and the world. Due to the nutrient content of manure, the imbalance of P vs. N in relation to plant needs, and manure's potential to harbor pathogens and other compounds (e.g., pharmaceuticals, endocrine disrupting compounds), land application of livestock manures is a serious environmental concern. Because vectors of accumulation and loss include air, soil, and water resources, environmental concerns associated with manure generation and land application cross national program boundaries. Research in NP 211 focuses on the relationship between manure application and water quality.

Both pesticides (e.g., insecticides, herbicides, fungicides) and emerging contaminants such as the pharmaceuticals used in livestock production (e.g., antibiotics and hormones) can move from the point of application in agricultural fields to surface and ground waters, raising concerns about potential impacts on terrestrial and aquatic ecosystems as well as human health. These pollutants are often referred to as contaminants of emerging or environmental concern (CECs). To fully evaluate risks, we need to know the sources, transport behavior, fate, and ecological impacts of these agrochemicals, at different concentrations and in different combinations in the environment. To better design and refine best management practices that reduce risk, new scientific information is needed that clearly identifies and quantifies the processes involved in the transport, transformation, uptake, and sequestration of agricultural contaminants, as well as direct and indirect pathways of impact to terrestrial and aquatic ecosystems.

Research Needs. Improved ability to predict and manage the sources, transport, and transformation of contaminants must be based on a more thorough understanding of controlling processes. Effective and reliable control strategies and technologies can only be advanced through the development, collection, and application of scientific knowledge on underlying processes involved in the fate and transport of sediment, pathogens, and inorganic and organic contaminants including excess nutrients, pesticides, and pharmaceuticals. This is critical to continued science-based decision making for total maximum daily loads (TMDLs), establishing ecologically-based nutrient criteria, and watershed management strategies, as well as determining the site-specific performance of agricultural best management practices in improving water and soil quality, ecosystem health, and related ecosystem services.

Critical needs in erosion research include predicting the detachment and deposition of soil and sediments and developing tools for designing and safeguarding hydraulic structures. The size distribution and composition of sediment detached by sheet, rill, irrigation-induced, and gully erosion, and changes in sediment size and composition that occur during transport within agricultural fields, as well as through ditches, wetlands, lakes, and streams, remain poorly understood. Uncertainty about the location, size, and expression of ephemeral gullies in cropped fields confounds both the accurate prediction of erosion as well as conservation planning.

Research is also needed to quantify the role of climate, soil and landscape characteristics, land use, and management on the generation, movement, persistence, and cycling of water-borne contaminants. Decreased water quality causes a range of ecological impacts that affect downstream uses for water supply or recreation. Empirical relationships describing drivers of hypoxic events in agricultural water bodies, as well as stressor-response curves that link multiple stressor interactions to ecological impacts, are critically needed to predict effects of changing agricultural practices, contaminant mixtures, and climate on freshwater ecosystem health. Both new and existing knowledge must be synthesized and made available to scientists, producers, and action agency personnel so they can better understand the linkages between agricultural operations, water quality, and ecosystem services. This knowledge needs to be formulated into fact sheets, guidelines, mathematical algorithms incorporated into new or existing computer models, and the development and implementation of mitigation strategies to improve the management of our natural resources and reduce the impact of agriculture on water quality degradation. The application of this knowledge to targeting of conservation practices and assessment of their impacts at larger scales is described in Components 3 and 4 of this Action Plan.

There is a need for improved abilities to model sediment and contaminant transport, particularly at the landscape and watershed scale. Impacts of agricultural pollution can be detected downstream where streams or rivers are accessed for water supply or for recreational uses. Modeling of contaminant transport and ecological impacts requires integration of the research in Components 2.A to 2.D. Recent advances in hydrodynamic processes and topographic mapping at the watershed scale allow more detailed and mechanistic modeling of the hydrologic flow paths that underpin effective modeling efforts. In addition, hydraulic structures, such as earth embankments, dams, levees, and spillways, are integral components of an agricultural landscape. Many of these structures have passed their designed service life. Maintaining safe operation of these aging structures and developing tools for improved design and functionality are both critically needed.

Problem Statement 2A: Field scale processes controlling soil erosion, and the transport and fate of sediment and contaminants.

ARS will quantify the effects of management, rainfall and surface condition (distribution of vegetation, slope steepness and roughness) on surface and subsurface hydrology, concentrated flow dynamics, sediment detachment and transport processes (soil erodibility), and surface evolution (land degradation); including LiDAR studies to quantify runoff event scale, topographic change, and landscape evolution; development and use of ground based high-resolution time-lapse camera systems to autonomously monitor landscape evolution; and including the use of tracers and isotopes (i.e., existing ^{137}Cs, and geochemical fingerprints) to quantify erosion, sediment fluxes, deposition, and sediment sources at the landscape scale.

In order to assess soil erodibility for improved landscape management, ARS will determine soil physical and chemical properties under a variety of geographic and climatic conditions.

ARS will do geophysical mapping of soil pipe networks and remote sensing to monitor soil pipe collapse, including gullies, sinkholes, and flute holes; and quantification of internal erosion, transport, and deposition of soil particles and aggregates in soil pipes.
ARS will determine soil productivity potential on agricultural landscapes as a function of pervasive ephemeral gully erosion over various time and length scales, including field measurements of chemical, physical, and biological soil properties related to soil health with distance from ephemeral gullies.

ARS will develop acoustic measurement systems to quantify sediment flux. Erosion risk, conservation design, and placement will be determined utilizing remotely sensed data. ARS will develop and deliver updated erosion prediction technology to user agencies for conservation planning.

ARS will quantify the fate, transformation and loading potential of contaminants, specifically nutrients, sediment, pesticides, pathogens and antibiotics, in field and laboratory studies under different landscape attributes and management scenarios; including quantification of the relative contributions between surface and subsurface transport pathways, including groundwater recharge.

ARS will develop improved methods to measure antibiotic resistance and antibiotics in soil, and develop data sets and models that describe transport of contaminants and antibiotic resistance at field scale.

ARS will investigate water quality impacts of dairy manure application in a corn silage – alfalfa rotation.

Anticipated Products

- Relationships between landscape attributes (e.g., surface condition, subsurface hydrology, and soil properties) on erosion, sedimentation and landscape evolution.
- Improved field- and watershed- scale erosion process models.
- Improved quantification of ephemeral gully erosion and its impact on agricultural fields.
- Improved science and technology to quantify and monitor soil pipe development and internal erosion.
- New technologies (i.e., tracer, laser, acoustic, and imaging) to quantify erosion, deposition and sediment transport to provide more accurate assessment of soil erosion, deposition, and landscape evolution.
- Improved techniques for assessing sediments and contaminants in different hydrologic pathways.
- Tested methods and procedures for measuring pathogens and antibiotic resistance in agro-ecosystems, and measurements of these parameters across locations and over time.
- Improved models for bacterial persistence and transport.
- Databases for model calibration and evaluation, including data sets on seep water quantity and quality for two hydrologic contexts: clay pan soils and deep loess soils.
- Tested and improved process-based erosion and water quality models that can assess fate and transport of pollutants spatially and temporally.
- Agricultural best management practices that reduce the off-site transport of pathogens and antibiotic resistance.
- Identified ecosystem services from conservation agriculture.

Potential Benefits

- Crop yields are increased and production costs are reduced by keeping fertile soil and valuable nutrients in the field.
- Dredging and water treatment costs to remove downstream sediment and contaminants transported from agricultural fields to surface waters are reduced, aquatic organism exposure is minimized, and aquatic productivity is enhanced.
- Control and remediation strategies are better planned based on detection and prediction of potential erosion and pollution events and persistence of contaminants.
- Manure use guidelines and policy at the state and multi-state level will be more effective, maximizing agricultural benefits and minimizing environmental risk.
- The sustainability of agricultural systems is increased by a more accurate understanding of transport processes and implementation of BMPs.
- Off-site transport of sediment and contaminants to non-target soil and water resources is reduced via management practices or remediation strategies, resulting in improved environmental sustainability of agricultural systems and improved ecosystem health.

Problem Statement 2B: In-stream physical and biological processes controlling contaminant fate, transport, and effects.

ARS will develop integrated technologies for predicting total stream system sediment loads by size fraction, aggregated sediment transformation, and channel erosion as affected by reservoir sedimentation and dam removal impacts, on sediment loads and stream morphology in agricultural and rangeland watersheds. ARS will evaluate recent lake sedimentation rates in agricultural watersheds and relate sedimentation rates to watershed management practices.

ARS will develop improved methods to measure antibiotic resistance and antibiotics in water and will develop data sets and models that describe transport of contaminants and antibiotic resistance at the watershed scale.

ARS will characterize nutrients, pesticides, and emerging contaminants in agricultural watersheds and quantify in-stream processes associated with each. ARS will link edge-of-field P losses to in-field soil P concentrations, characterize P transport from edge-of-field P losses for typical fields in a watershed in relation to stream P transport; and quantify sediment-bound P as a function of stream order and sediment characteristics. ARS will quantify the effects of surface flow hydraulics and subsurface hydrology on dissolved phosphorus transport and the efficiency of different in-stream phosphorus removal strategies.

ARS will quantify relationships between environmental factors, microbial communities and fluxes of N_2 and N_2O from agricultural water bodies.

Anticipated Products

- Improved sediment transport algorithms that use surface roughness geometries as a scaling length for representing bed roughness and mixtures of sediment sizes, including methodologies to estimate scaling parameters from bed surface topography and sediment size.
- Improved computational modules to simulate grain sorting of mixed-size sediments for multi-dimensional computer models.
- Improved computational modules for multi-dimensional computer models to simulate the combined effects of bed and suspended load transport on stream morphology.
- Methodology and data on recent and seasonal sedimentation rates from sediment catchers installed in lakes of agricultural watersheds.

- Development of a comprehensive multi-dimensional river morphodynamics computer model to evaluate the impact of upland, instream, and reservoir rehabilitation measures on instream resources.
- Knowledge of seasonal variations in sedimentation rate for lakes in agricultural watersheds that can be related to cropping practices and other aspects of watershed management.
- Tested methods and procedures for measuring pathogens and antibiotic resistance in agricultural water bodies. Data on these parameters collected across locations and over time.
- Characterization of the current conditions of water bodies within agricultural watersheds.
- Improved fate and transport models, and survival and persistence data.
- Scale dependent phosphorus data.
- Improved capacity of APEX to predict P transport from high runoff potential soils (or soils with restrictive layers).
- Improved management strategies for phosphorus, including realistic expectations in terms of phosphorus load reductions.
- Enhanced understanding of the microbial communities involved in nitrification / denitrification processes in agricultural water bodies.
- Identification of the environmental factors associated with the release of the green-house gas nitrous oxide, in contrast to dinitrogen, in the denitrification process, and measurements of their fluxes from agricultural water bodies.
- Management practices that reduce the export of reactive N and nitrous oxide from agricultural ecosystems.
- Data for improved understanding of chemical and biotic exchange processes in streams exhibiting active exchange processes with adjacent subsurface volumes of sediment and porous space.

Potential Benefits

- Existing landscape-scale models will be improved by greater understanding of physical and biological processes controlling contaminant (sediment, excess nutrients, antibiotic, pesticide, etc.) fate and transport within agricultural watersheds.
- Resource managers' prediction capabilities are enhanced related to water quality outcomes of different management strategies within agricultural landscapes.
- Model predictions of contaminant transport and mitigation will be improved due to ability to assess chemical transport in streams exhibiting active exchange processes with adjacent subsurface volumes of sediment and porous space.
- Management practices will foster sustainable agriculture and forecasts for storage in reservoirs will be improved through more accurate quantification of landscape scale erosion in humid and semi-arid regions.
- Water management strategies that balance goals of reducing nitrogen runoff and greenhouse gas (nitrous oxide) emission, due to better understanding of factors controlling instream nitrogen processing.
- Downstream estuarine ecosystem quality will be improved while preventing further climate change impacts.
- Management decisions will improve the environmental sustainability of agriculture based on better assessment of production impacts of management practices guided by improved measurement and modeling of antibiotic resistance and contaminant occurrence and persistence (sediment, excess nutrients, pesticides, emerging contaminants, etc.).

Problem Statement 2C: Processes influencing the relationships between contaminants and aquatic ecosystems.
ARS will do field and experimental research to better understand the complex interactions between inputs of agricultural contaminants to freshwater ecosystems, hypoxia, and ecological responses in agricultural watersheds. ARS will develop cause-effect relationships for multiple stressor interactions needed to provide science-based decision tools to determine total maximum daily loads, nutrient criteria, and evaluate the effects of conservation practices. Field experiments will examine interrelationships among nutrients, pesticides, sediment, and aquatic population and community structure in agricultural watersheds. ARS will evaluate the influence of multiple environmental factors on ecosystem structure and function to obtain information to increase understanding of the ecological effects of conservation practices.

Anticipated Products
- Empirical relationships between limiting nutrients, carbon sources and inputs, hydrology, and temperature and the magnitude, duration, and frequency of hypoxic events in freshwater ecosystems.
- Empirical relationships between agricultural pollutant mixtures, habitat, and ecological responses in freshwater ecosystems.

Potential Benefits
- Alternative management options will restore healthy freshwater resources and ecosystem services by changing the amount and timing of harmful inputs based on better prediction of conditions causing freshwater hypoxia in agricultural watersheds.
- Restoration and management options available to producers and natural resource managers will enable maintenance of high quality agroecosystems based on improved understanding of the effects of dynamic agricultural contaminant mixtures and habitat on freshwater ecosystem quality and ecological responses to contaminant reduction strategies.

Problem Statement 2D: Development and testing of cost-effective measures to control the transport and fate of contaminants in agriculture, urban, and turf systems.
ARS will monitor and model water quality from replicated plots with varied tillage and cropping systems as part of the LTAR initiative. ARS will evaluate new and innovative in-field or edge-of-field treatment technologies to reduce contaminant concentrations and transport (e.g. phosphorus, antibiotics, sediment, other). The effectiveness of buffers (perennial grass) and cover crops to mitigate the impacts of agriculture on water quality will be assessed. A combination of field practices and treatment techniques to minimize pollutant loading and transport in surface runoff and tile flow will be evaluated. ARS will assess production and innovative management practices on nutrient cycling or nutrient and contaminant loss through surface and subsurface pathways.

ARS will determine how site preparation and placement of multiple plantings (grasses, forbs, shrubs, and trees) can mitigate the impacts of soil compaction on urban runoff and water use.

Lab/greenhouse/field studies will evaluate the persistence and transport of nutrients and contaminants from plant and animal protection products, amendments, or reused water in agricultural or horticultural systems, and the efficacy of management practices and remediation strategies to reduce contaminant concentration, availability and transport in agricultural or horticultural systems.

ARS research will be targeted at enhancing the efficacy of bioreactors. Research will improve design criteria for denitrifying bioreactors (NRCS Conservation Practice Standard 747), particularly at higher flows and low temperatures; evaluate microbial communities within denitrifying bioreactors to determine factors limiting denitrification and denitrification kinetics; improve the efficacy of denitrification bioreactors through the use of alternative carbon sources and the use of specialized sorbents for removal of phosphorus. Research will examine the potential for abiotic nitrate reduction with redox catalysts.

Anticipated Products

- Continuous, replicated, year-round data sets that inform models of multiple tillage and management systems.
- Quantified impacts of prevailing and innovative practices to control transport and fate of contaminants.
- Improved modeling of nutrient and contaminant losses from fields to surface waters.
- Data to support the conservation efficiency of proposed BMPs, and strategies, tools and designs for the implementation of new and innovative BMPs.
- Recommendations for residential plantings that reduce runoff, erosion, and chemical loss in agricultural watersheds.
- Management practices that reduce agrochemical (nutrient, pesticide, antibiotic, etc.) contamination levels in agricultural and turf run-off and/or drainage ditches.
- Data on the transport and uptake of contaminants in production products, their potential environmental and health risks, and management practices to reduce transport and risk.
- Recommendations to agricultural producers on management strategies to optimize yield with other ecosystem services (soil health, water quality, wildlife habitat).
- Updated NRCS Technical Standards for denitrifying bioreactors, based on improved knowledge of factors controlling denitrification rates.
- Data for decision making regarding the implementation of woodchip denitrification bioreactors and steel slag filters.
- Novel filter media that would reduce agrochemical (nutrient, pesticide, antibiotic, etc.) contamination levels in agricultural and turf run-off and/or drainage ditches.
- Prioritized practices for addressing natural resource water quality concerns.
- Databases to support modeling efforts.

Potential Benefits

- Selection of tillage and cropping systems will effectively maintain the quality of water resources and the sustainability of production practices using knowledge based on extensive monitoring datasets that are year-round and continuous.
- Water quality is improved while increasing both the productivity and sustainability of agricultural production systems through judicious use of cover crops and placement of buffers in the landscape.
- Urban horticultural ecosystems services improve (increasing habitat for wildlife and reducing negative impacts to water resources) based on following recommendations for urban planting that improve surface water quality and maintain water quantity of irrigation sources.
- Sustainability of agricultural and horticultural systems will increase based on identification of management practices and remediation strategies that reduce offsite transport and concentrations of excess nutrients and contaminants.
- Production efficiency will improve using management practices that help maintain nutrients and plant and animal protection products at their location of application.
- Management practices and remediation strategies will contribute to pollutant reduction goals of regulatory agencies.

Problem Statement 2E: New and innovative modeling and assessment tools to quantify sediment and contaminant transport on the landscape.
ARS will evaluate impact of alternative surface protection methods by constructing and testing physical models of earthen embankments and steep channels that simulate complex geometries and soil materials. Physical model studies in stepped chute facility will assess the hydraulic performance of alternative stepped chute design. ARS will develop non-invasive acoustic/seismic techniques to assess bank stability and potential for dam and levee failure, and acoustic methods for rapid assessment of soil water dynamics.
Models to assess embankment breaching and scouring around hydraulic structures will be developed.

ARS will develop a multi-scale water quality modeling approach using SWAT and APEX to quantify the impacts of local-scale management practices on large-scale water quality concerns. More robust wetland subroutines will be developed to allow improved assessment of wetland functions in agroecosystems and their impact on water quality. ARS will develop and use geospatial cropping / management system analysis tools (LAMPS, LMOD) and the AgES-Watershed model to assess the effects of water/wind erosion on sediment and chemical transport at field to watershed scales. The suite of CCHE models to assess erosion, sediment transport, and the fate of agro-chemicals in the environment will be improved.

ARS will test and interpret real time water quality sensors and develop protocols for their application in source identification and modeling.

Risk assessment methods, documentation, and tutorials, and assessment applicability will be developed for assessing post-fire impacts for the Rangeland Hydrology and Erosion Model.

Anticipated Products

- Improved Windows Dam Analysis Modules (WinDAM) simulation model that predicts erosion of complex embankment structures and allowable overtopping flows for alternative materials including articulated concrete blocks or riprap integrated with vegetation.
- Performance data and engineering design for alternative stepped chutes.
- Improved geophysical techniques to assess bank stability.
- Improved acoustic techniques to assess soil hydrology and shallow groundwater.
- Improved models to assess embankment breaching and scouring around hydraulic structures.
- Improved wetland function model that can be used to assess how wetland affects water quality and agroecosystems.
- Integration of a suite of water quality models (APEX, SWAT, CCHE1D, CCHE3D, and AgES-Watershed) and geospatial tools/databases (LAMPS and LMOD) that can be used to quantify sediment and chemical transport and to assess conservation effects.
- Field-tested real-time water quality sensors.
- Better tools to assess the impacts of management and fire on rangeland ecosystems.

Potential Benefits

- Potential for failure of hydraulic structures is minimized by improved hydraulic structure design and tools for ongoing monitoring and assessment of structural integrity.
- Sediment and contaminant losses in different farming systems are reduced due to better ability to predict the impacts of management practices.

- Production costs for farmers and land managers are reduced through more efficient cropping and management practices.
- Water control and conveyance structure lifetimes are extended due to new and better designs.
- Surface and ground water quality, water management, and ecosystem services are enhanced due to improved ability to predict the impact of management practices on the movement of sediment and contaminants on the landscape.

Component 2 Resources

- Ames, Iowa
- Columbia, Missouri
- El Reno, Oklahoma
- Oxford, Mississippi
- Reno, Nevada
- St. Paul, Minnesota
- Tifton, Georgia
- Tucson, Arizona
- University Park, Pennsylvania
- West Lafayette, Indiana
- Columbus, Ohio
- Florence, South Carolina
- Kimberly, Idaho
- Temple, Texas
- Beltsville, Maryland
- Fort Collins, Colorado
- Stillwater, Oklahoma

Component 3: Enhancing and Documenting the Benefits of Conservation Practices

Accountability for government expenditures necessitates that the cost of subsidized conservation practices be evaluated in comparison with the environmental benefits they provide. Beyond evaluation of existing practices, it is important to continue research to develop new practices to improve the benefits achieved with available funds. In addition, tools are needed that allow practitioners to optimize the placement and application of various conservation practices across diverse agricultural landscapes. The demands for information from ongoing research projects such as the Conservation Effects Assessment Project (CEAP), and regional initiatives such as in the Mississippi River Basin (MRBI) and the Chesapeake Bay (CBI), demonstrate the continuing need to assess and improve the benefits of conservation practices.

Multiple conservation practices are applied to a wide variety of agroecosystems and agricultural landscapes. However, the complex interactions of such practices within watersheds and at varying scales are difficult to quantify, and in some agricultural systems, new conservation approaches are needed to achieve water quality improvements. Advances in remote sensing and geographic systems analysis offer opportunities to position conservation practices on the landscape to achieve better effectiveness at the watershed scale. For many conservation practices, more complete information is needed on how they impact the transport pathways taken by water and contaminants and the processes involved in contaminant mitigation. In all watersheds where water quality improvements are being sought, the effects of practices on contaminant fluxes must be quantified.

Extremes of water availability pose critical problems that appear to be worsening as climate changes. Yield losses due to excess water and drought are the primary expense for Federal crop insurance programs. Both excess water and drought can occur in the same watershed in the same year, highlighting the need to develop conservation practices that increase the capacity to store water on the landscape during times of excess for subsequent use during times of need.

Experiments directly measuring the environmental benefits of individual conservation practices, as well as how those benefits are expressed at the watershed scale, are essential to provide the scientific basis to inform process modeling, but more importantly to evaluate the effectiveness of current conservation efforts at the landscape scale. Implementing these scientific advances will require collaborative partnerships through which model evaluation can occur in a variety of watersheds.

Research Needs. The evaluation of conservation practices in mixed land-use watersheds requires the integration of research and information from various scales. While decisions about the implementation of conservation practices are typically made at the small field or single crop scale; i.e., areas of uniform management where runoff and contaminant transport originate, watersheds integrate the numerous field-scale units across variations in land management, topography, geology, soils, and climate. When attempting to quantify the effects of conservation practices at the watershed or landscape scale, these combined effects pose significant scientific and technological challenges. Limited research and technology are available to describe the complex interactions of processes that occur as larger watersheds are monitored, causing difficulties in determining the downstream impacts of conservation practices on water availability and quality. To translate conservation effects from the field to the watershed scale, it is critical to understand how scales and processes interact.

While agricultural impacts on hydrology and water quality can be mitigated through a variety of in-field and field-edge conservation practices, strategies are needed that optimize both production and environmental endpoints for agriculture. Current knowledge used in conservation planning is focused at the field scale, but conservation science is beginning to produce tools to deploy conservation practices to achieve landscape-scale goals—an approach necessitated by the diffuse (i.e., non-point source) nature of the material flows involved. The concept of conservation targeting (i.e., precision conservation), which attempts to optimize conservation efforts at the landscape scale, requires the integration of diverse types of information, including a better understanding of key hydrologic and biogeochemical processes, to select and place practices on the landscape for maximum environmental benefit. Research is needed to develop and deliver precision conservation tools and guidelines that are scientifically defensible, affordable and socially acceptable, and which can improve watershed management and the resilience of agricultural systems. While much is known about the provisioning ecosystem services that agriculture provides (i.e., food, fiber, feed, and fuel), more quantitative data are needed to assess the impact of conservation practices on supporting and regulating ecosystem services within the context of water resource management (e.g., water quality and quantity, aquatic and wetland ecosystem function, and biodiversity). Within the context of both physical structures and climatic conditions, quantitative information on ecosystem services is needed to provide a cohesive national strategy to optimize available non-market ecosystem services in agricultural landscapes. Because applications have not been developed to predict how aquatic ecosystems or physical habitat respond to changes in agricultural watersheds resulting from conservation practices, watershed models (e.g., annAGNPS, SWAT) are limited, and new data collection and modeling efforts are needed to understand these responses. Research is also needed to identify and quantify unintended consequences of changes in management that can have significant lag times requiring longer-term assessments.

Agricultural soils, landscapes, and watersheds are most vulnerable to damage during extreme events, such as severe storms that can cause significant erosion and flooding, or prolonged droughts that reduce plant cover. Yet our knowledge of the effects of conservation practices was developed over a short and relatively recent time period. Most conservation planning and assessment tools utilize long-term averages of climate and contaminant transport, and are not designed to account for extreme events. Climate change and the dynamic nature of weather patterns raise questions about the effectiveness of current practices under climatic conditions outside those under which these practices were designed to be effective. Practices may need to be optimized to accommodate a broader range of weather and climate conditions, perhaps resulting in risk-based design tools or recommendations for worst-case scenarios.

The development of conservation practices to buffer extremes in water availability will require both models and measurements to determine the most effective ways to route excess water to surface and subsurface storage options, where it will later be available during periods of shortage. Though some basic principles may be similar, best practices will likely be quite different in diverse climates and landscapes such as the northern Corn Belt and the Mississippi delta. Measurements of the impact of such water management techniques on key soil properties and on regional hydrology (both streamflow and groundwater levels) must be accompanied by agronomic and economic assessments of overall impact on yield and profitability.

Land-use changes, such as the expected increase in the production of bioenergy feed stocks, pose challenges and present opportunities to enhance agricultural landscapes. For example, the harvest and removal of bioenergy feed stocks from Conservation Reserve Program (CRP) lands, buffers, or highly erodible lands may limit some of the diverse conservation benefits derived from these practices; such impacts need to be determined. Additionally, shifts from agricultural to urban land uses may diminish the resilience of associated natural systems under changing climatic conditions, and may require the development of new conservation practices and/or approaches for mixed, fragmented landscapes to maintain the functioning of hydrologic and water quality systems. Voluntary adoption of conservation practices depends in part on the economics of those practices in combination with incentives offered through conservation programs. The ARS has the technical expertise and experimental resources to quantify the physical and biological effects of conservation practices, but partnerships will be required to incorporate key social and economic drivers and consequences. Research is needed to combine information on the biophysical effects of conservation practices with their economic and social aspects, to improve the overall effectiveness of conservation program delivery. Past successful efforts (e.g., the Upper San Pedro Partnership) could serve as models for establishing similar partnerships across the ARS long-term agricultural research sites.

Problem Statement 3A: Selection, placement, and combination of conservation practices to achieve improvements in water quantity and quality in watersheds.
ARS will model conservation practice benefits, and develop decision support systems for watershed planning and assessment. Representation of conservation practice effects in soil erosion, water quality, and watershed models will be improved, as will the spatial representation of processes impacting conservation effectiveness in watershed models.

ARS will do research to understand water quality tradeoffs involved with practice selection and how to combine practices and thereby compensate for these tradeoffs. ARS will develop and improve criteria to optimize practice placement in fields and watersheds.

Remote sensing tools will be developed and used to assess soil and water resource conditions and agricultural practices.

ARS will improve the SWAT-APEX simulation scheme and use it to contribute to the Conservation Effects Assessment Project national assessment.

Anticipated Products

- Technologies and tools to identify strategies and options for the placement of conservation practices within and among fields and watersheds.
- Better models and modeling results that inform efforts to improve management of soil and water resources.
- Strategies and tools to manage soils, landscapes, and watersheds for multiple contaminants.
- Decision support systems and tools to evaluate conservation practices and policies at local and national scales.
- Estimates of the location, magnitude, impacts of, and control options for ephemeral gullies.
- Quantification of the role of morphological channel adjustment on watershed sediment load and pollutant transport and transformation.

Potential Benefits

- Watershed sediment loads are reduced due to precise and effective designs for gully and channel erosion control practices.
- New management strategies and resource policies are based on improvements in the quality of information obtained from resource assessments and watershed modeling.
- USDA conservation support incentives are justified based on reliable predictions of soil and water quality improvements from conservation practices and associated cost/benefit analyses.
- Water quality and other ecosystem services are improved because stakeholders implement new technologies for watershed planning and management.

Problem Statement 3B: Improve conservation technologies to better protect water resources: Development and testing of new designs, equipment, and materials.
Joint research with that of NP 212 will develop location-specific practices and equipment to apply and incorporate fertilizers, manures, and chemicals to minimize environmental losses and erosion that result in degraded water quality. Practices and management strategies to reduce losses of dissolved P to surface and subsurface waters will be developed.

ARS will improve monitoring in agricultural watersheds to assess effects of nutrient management (NRCS CP590), cover crops, and other practices (e.g., P index) on water quality in fields and watersheds.

Field and modeling studies of the efficacy of saturated buffers for the reduction of N and P losses to surface waters, emissions of nitrous oxide, and in-field storage of drain water will be done jointly with the research in Component 1, Problem Statement 1E.

ARS will study strategies and practices to enhance denitrification, reduce nitrate losses, and reduce gaseous NOx losses.

ARS will use field and modeling studies to enhance conservation of rangelands, pasturelands, and transitional urban-agricultural landscapes.

ARS will study practices to increase water storage and recharge in agricultural landscapes, and determine their impact on nutrients, sediments, and ecosystems.

Anticipated Products

- Contributions to the design and technical guidance for NRCS National and State Conservation Practice Standards. Examples: Surface intake filter practices (Conservation Practice Standard 640), denitrifying bioreactors (Conservation Practice Standard 747), saturated buffers (Conservation Practice Standard 739).

- Practices, knowledge, and models that improve our ability to attenuate all forms of nutrient pollution of surface and sub-surface waters in landscapes under cropped, grazed, and urban land uses.
- More effective and/or less expensive equipment and techniques to monitor water at field and watershed scales.
- Determination of the regional potential for N removal by denitrifying bioreactors, saturated buffers, and other practices.
- Techniques to identify opportunities for water storage and re-use in traditionally rain-fed and irrigated agricultural regions.
- Tested practices designed to reduce losses of dissolved phosphorus in surface runoff and drainage waters.

Potential Benefits

- Agricultural producers successfully reduce loadings of nutrients and other agricultural contaminants to surface waters.
- Improved monitoring techniques are used to document reductions in nutrient and contaminant loadings and resulting improvements in the natural resource base.
- Conservation strategies and environmental quality are improved using combinations of results from field-scale studies.
- Agricultural profitability, efficiency, and the natural resource base are improved due to greater water- and nutrient- use efficiencies.
- NRCS uses ARS products to document improvements in the delivery of their services to customers and stakeholders.

Problem Statement 3C: Ensure that conservation and agricultural management practices can increase agricultural profitability and resilience under changing climate and land use.

ARS will develop, maintain, and expand databases to assess changes in climate, land use, productivity, and water quality, including the STEWARDS and LTAR databases and downscaled (location specific) climate projections with synthetic weather data.

ARS will evaluate conservation practices through LTAR research.

ARS will show to what extent improved soil quality can improve hydrologic regimes and water quality in agricultural watersheds while improving agricultural productivity.

ARS will research issues regarding the maintenance and design life of conservation practices.

The impacts of possible future climate scenarios on conservation performance, including uncertainty analyses will be modeled.

ARS will model economic and social factors affecting conservation-practice decisions made on farms and in watersheds.

ARS will evaluate soil water dynamics of a variety of cropping systems at the landscape scale, including intensified rotations and perennials.

Anticipated Products

- Databases that provide information on long term trends and variation in climate and water resource conditions.
- Guidelines for the management / maintenance needs of a variety of conservation practices.

- *Model outputs that define water resource and ecosystem benefits, and the costs of improved soil management and conservation practices and systems now and into the future.*
- *Demonstrations that improved soil management and diversified rotations can increase the efficiency of agricultural water use and benefit production (joint with Component 1, Problem Statement 1D).*

Potential Benefits

- Measurable improvement in the ability of watershed models to predict watershed processes and environmental outcomes from management changes.
- Management and policy actions become better informed by long term data, helping society adapt to climate change.
- Resilient and adaptive management systems result from useful scientific products and enhanced scientific capacity provided by the Long-Term Agro-ecosystem Research network.
- Conservation's importance to the future of agriculture is more broadly recognized by the public and policy makers.

Problem Statement 3D: Link conservation practice performance to multiple ecosystem responses and services across agricultural landscapes and aquatic systems.

ARS will perform ecological assessments of watersheds, riparian zones, and aquatic systems to document agroecosystem effects on hydrology and water quality.

ARS will study landscape-based systems to enhance biomass-based energy production systems and conservation outcomes.

ARS will study wetlands and perennial vegetation in conservation practice installations to assess enhancement of habitat, carbon capture, and other ecosystem services.

ARS will model conservation practice performance interactions at the landscape scale.

Anticipated Products

- Improved agricultural management and conservation practices based on better understanding of the responses of ecological systems to management.
- Techniques, models, and tools to assess planning options that diversify agricultural production, vegetation, and conservation systems.
- Tools to improve and integrate the management of ecosystem services in agricultural settings.
- *Regional databases that describe soil and landscape conditions, and agricultural land-use trends, and benefit watershed assessment and planning.*

Potential Benefits

- Farm profitability and environmental quality in agricultural watersheds are improved due to more detailed knowledge of resource opportunities and vulnerabilities.
- Research guides adaptive management of multiple ecosystem services in agricultural regions.
- Ecosystem services from agricultural landscapes are expanded based on linkage of conservation practices to a variety of ecosystem services that informs management and policy.
- Biological diversity is sustained or enhanced in agricultural regions, supporting fisheries, migratory waterfowl, and other wildlife.

Component 3 Resources

- Ames, Iowa
- Beltsville, Maryland
- Columbia, Missouri
- El Reno, Oklahoma
- Fort Collins, Colorado
- Jonesboro, Arkansas
- Kimberly, Idaho
- Oxford, Mississippi
- Temple, Texas
- Tifton, Georgia
- University Park, Pennsylvania
- West Lafayette, Indiana
- Columbus, Ohio
- St. Paul, Minnesota
- Bushland, Texas

Component 4 - Watershed Management to Improve Ecosystem Services in Agricultural Landscapes

Agricultural watersheds, including crop, pasture, and range lands, cover more than 70% of the continental U.S. Eighty-seven percent of the nation's drinking water flows over or through agricultural lands. In parts of the western U.S., agriculture is the primary consumptive user of water while hydropower, an essential contributor to the electrical power grid, is the primary non-consumptive water user. Ecologically necessary stream flows also consume water; in California, for example, half of all water available is used to maintain ecological flows. In the 21st century, unprecedented demands for freshwater, rapidly changing land use, recurring droughts, regional climatic variations, and new demands for energy production on working lands will necessitate comprehensive approaches to agricultural water management, balancing trade-offs and multiple objectives.

Integrated watershed management considers the many ecosystem services expected of our agricultural landscapes. These ecosystem services include traditional demands for food, fiber, and fuel, as well as a clean and abundant water supply, improved wildlife habitat, greenhouse gas reduction, soil stabilization, recreational opportunities, reduced energy consumption, and reduction of urban wastes. Integrated watershed management is a complex task that supports regulatory goals, such as the Clean Water and Endangered Species Acts, but also addresses the concerns of farm communities, water districts, watershed coalitions, policy makers, and the general public.

The interactions among ecosystems in an agricultural landscape are regulated by land use and management decisions and the organization of landscape characteristics and features interacting with weather, climate, hydrology, and edaphic factors. The primary challenge remains the development and application of an integrated research approach that is explicitly designed to elucidate the integrity, production capacity, and resilience of ecosystems within and surrounding agricultural landscapes, and to clearly describe the quantities and pathways of energy, matter, and water exchange within and between ecosystems and among agricultural landscapes. Because water is one of the main connectors transporting material in agricultural landscapes, research that improves our understanding of water's flow paths through, and residence times within, these ecosystems as influenced by management will provide a better watershed-scale understanding of the processes controlling the provision of ecosystem services. Operating a national network of experimental watersheds and long-term agro-ecosystem research sites, the ARS is uniquely situated to address these questions. Among other things, long-term studies allow observation of changes that occur at different timescales, and the separation of annual weather variations from longer term climatic change. When combined with results from the other four components of this action plan, observations from these networks enable the development of integrated watershed management strategies for agriculture across broad regions of the continental United States.

Research Needs. Both fundamental process-oriented research and development of tools and methodologies are required to address and resolve issues related to water supply management and the provision of ecosystem services. Further research and model development are needed to improve comprehensive simulation models for water supply forecasting, watershed processes, plant productivity, and environmental response assessment under variable climate, changing land use, increasing urban activity, and ecosystem restoration efforts. Tools are needed to provide the relevant information for water management, assess and improve aquatic habitats, riparian buffers, wetlands, and streams, and to evaluate the utility of conservation practices for ensuring ecological integrity. The NRCS and action agencies have requested technologies and decision support systems that enhance our understanding of how variable and extreme weather, dam decommissioning, rehabilitation, and construction affect fluvial and ecological systems. Because the scale of this work is large relative to traditional, plot scale research, these scientific research activities, tool developments, simulation model investigations, conservation practice evaluations, and environmental enhancement efforts must be supported by new remote sensing tools and enhanced instrumentation for watershed-scale evapotranspiration and coupled carbon fluxes, soil moisture, snow accumulation and melt, water budgets, and water stress estimation, mapping, and interpretation. Investigations are needed to identify the existence and impact of regional climate variations on water availability and management, including the identification of drought risk and the occurrence of climate extremes. Also, the utility and applicability of climate forecasts for strategic and tactical planning in agricultural production and water resource management must be explored to take advantage of recent advances in climate/atmospheric sciences. Responses to these needs will be built on existing ARS expertise and offer an integrated research and development approach that enhances the beneficial utilization of land and water resources in agricultural landscapes, and meets today's need for competitive and multi-objective management of land and water resources.

In this problem area of the NP 211 Action Plan, ARS and USDA Experimental Watersheds, Ranges, and recently added LTAR network sites, provide a foundation for the multi-site research, analysis, and synthesis outlined herein. These multi-site projects will systematically test common hypotheses at locations across the continental United States, using long-term, high-resolution observations in time and space. This approach will enable broad scale interpretations and conclusions across a range of major agricultural production regions, biomes, and hydro-climatic zones. Note that several locations involved also take part in National Program 212 – Soil and Air, which contributes strongly to the LTAR network through its research focused on soil and air quality, which are inseparable in the physical world from water quality and dynamics in the soil, aquifers, streams and water bodies.

ARS customers have requested decision support tools that are user friendly, have broader applicability, are interoperable, and can provide multiple objective outcomes (water quantity, water quality, optimized crop yield, and provision of quantifiable ecosystem services that can be traded as commodities). The development and ongoing support of such tools requires applied research on how to monitor ecosystems at appropriate spatial and temporal scales, the design and deployment of data collection tools and sensors to track variations in process responses, and the translation of temporal and geospatial data trends into reliable indicators of agro-ecosystem resiliency and metrics of ecosystem services. Effective use of these tools requires the collection of long-term data; model improvement, calibration and application; and the development of national datasets that facilitate the use of model and user applications to synthesize agro-ecosystem service capacities into scalable management options.

Problem Statement 4A: Improve watershed management and ecosystem services through large area, long term field research, site characterization, and data dissemination in agricultural watersheds and landscapes
ARS will coordinate long-term watershed and LTAR data collection and databases to support research linking water resource trends with constraints to food/fuel/fiber production. The observational capability and data accessibility of ARS Experimental Watersheds, Ranges and LTAR sites will be improved. Long-term remote sensing data products over LTAR sites will be developed describing the evolution in ET, soil moisture and vegetation conditions over surrounding landscapes. ARS will analyze hydro-climatic trends across long-term ARS locations.

Field management databases for improved representation of nutrient and sediment sources will be developed.

ARS will determine the significance of historical trends in temperature and precipitation on watershed responses like runoff and ecosystem services.

Methodologies for the LTAR network will be further developed and improved.

Anticipated Products

- Publication and dissemination of agricultural water resource, watershed, and modeling data through the ARS Big Data Initiative.
- New biome-specific relationships between precipitation and annual net primary productivity.
- Historical ties between management, climate, water balance, and runoff from agricultural lands are elucidated.
- Standards to allow comparison of water balance budgets across ARS research sites.
- Long-term storm intensification trends at sub-daily resolution delineated by Multi Location (LTAR/ARS Experimental Watershed) Project.

Potential Benefits

- Critical agriculture related natural resource issues are addressed due to increased data and site accessibility facilitating multi-disciplinary research at ARS locations.
- New management strategies are available based on improved understanding of long-term environmental trends on agricultural lands.
- Critical agriculture related natural resource issues are solved using a national collaborative research network focused at ARS locations.

Problem 4B: Develop tools and methods to improve water resource management
In order to improve water management in response to drought and other climatic extremes, ARS will test and implement water supply models in snow reliant regions in conjunction with action agencies.

The applicability of different remote sensing techniques at different scales and environments for improved measurement of components of the water balance and integration with hydrologic models will be evaluated. ARS will measure and model energy balance in variable environments to improve larger scale hydrologic models.

High-resolution, remote sensing data sources will be evaluated to quantify watershed vegetation conditions.

National Weather Service dual-pole radar rainfall products over densely instrumented ARS observation infrastructure will be evaluated for short-term intensity and seasonal precipitation estimates.

New soil moisture measures (including COSMOS) will be evaluated with other soil moisture monitoring data under different land cover.

Anticipated Products

- Improved integrated model for managing water supply in snow reliant regions.
- More sophisticated process representation in hydrologic models based on more comprehensive data.
- Improved estimation of water budget components at watershed and basin scales.
- Methodological advances in remote sensing algorithm development.
- Integrated tools for better multi-scale (field-to-watershed) decision support for agricultural management practices.

Potential Benefits

- More efficient and effective management of water resources due to the availability and use of improved models.
- More effective agricultural water management resulting from enhanced understanding of scale-relevant hydrologic processes.
- Water resources are conserved in water-limited agricultural systems through more efficient and climate resilient management strategies.
- Adaptive management of agricultural lands in response to climatic extremes (e.g., drought, precipitation extremes) will greatly improve due to timely and robust information about surface moisture conditions.

Problem 4C: Measure and predict water-driven agroecosystem productivity and other ecosystem services

ARS will measure and model fluxes of carbon, water, and nutrients, under variable cover, soil, and management practices.

ARS will continue development and evaluation of ARS watershed and management simulation models to treat a broader spectrum of conditions, management scenarios, ecosystem services, economics, and crop production.

The effectiveness of in-basin agricultural and urban water conservation strategies will be assessed along with the feasibility of meeting anticipated agricultural and urban water demands, under projected climate scenarios and ecosystem services.

ARS will develop improved plant growth models and model parameter determination for rangelands and crops. Methods for estimating crop yield using remote sensing indicators of moisture stress and crop development will be improved.

ARS will identify landscape positions where accumulations of water and nutrients can enhance bio-fuel feedstock production and ecosystem services.

For sugarcane production for sugar or bioenergy, ARS will determine limiting water requirements for sustainable production, risks to ecosystem services, and best management practices for sustain-able production.

ARS will determine effects of fire on nutrient loss through erosion, biodiversity and streamflow generation.

Anticipated Products

- *Improved, accessible, water driven production models for cropland, range, and pasturelands.*
- *Improved understanding of the stocks and fluxes of carbon and nutrients and how they may be affected by water status and fluxes as mediated by climate change and management.*
- Science-based tools for national conservation policy development and environmental decision making for water management.
- Projections of lag times following conservation program implementation (e.g., legacy phosphorus controls on water quality response).
- Better understanding of the trade-offs associated with agronomic and conservation practice implementation for water management.
- *Improved understanding of the effects of brush management in western US rangelands on runoff quantity and quality (ecosystem services).*
- Understanding how changes in water availability have and will impact terrestrial carbon balance.
- *Improved understanding and modeling of rangeland runoff and erosion responses to fire.*
- *Effective techniques for implementing crop models over landscapes by incorporating gridded inputs from remote sensing and land-surface modeling to determine water flows and accumulations.*

Potential Benefits

- Agroecosystem productivity will be increased while minimizing negative impacts to the environment using newly available management tools.
- Carbon storage and nutrient retention in soil will be improved using new management practices.
- Erosion and storm runoff will be reduced while maintaining ecosystem services through use of improved post-fire management actions.
- Conservation of critical resources will be increased due to holistic management approaches resulting from better understanding of the coupled carbon, water and nutrient cycles in agricultural landscapes.
- *Grazing land productivity will be enhanced while retaining essential ecosystem services through use of more effective grazing animal management based on water resources.*
- *Climate forecasts will be improved due to a better understanding of the terrestrial carbon, water and climate feedbacks.*
- *Yield estimates and within-season decision making will improve using robust specifications of crop development limitations at landscape scale.*

Problem 4D: Impacts of climate and land-use change on water use and availability
Using multiple approaches, including simulation and remote sensing, ARS will evaluate eco-hydrologic impacts (e.g., on productivity, water partitioning, and sediment production) that result from on-going land cover changes and fire. AGWA/KINEROS will be improved and used to assimilate near-real time radar-rainfall data and burn severity images, to improve post-fire flooding and erosion estimates

Historical data and down-scaling from Global Climate Model (GCM) projections will be used to evaluate the eco-hydrologic impacts on productivity, water partitioning, and sediment production that result from observed or projected climate change, including extreme drought and ongoing warming. The eco-hydrologic effects of the observed rising of the rain-snow transition elevation will be measured and simulated. ARS will develop and test relationships between coarse scale GCM climate predictions and historical climate data for down-scaling of GCM climate predictions for application to smaller watersheds.

ARS will conduct multi-scale studies of remote sensing techniques for mapping drought and drought response and resilience. And, ARS will assess impacts of land and water management on water use using long-term, remotely sensed ET and soil moisture. Agricultural water conservation strategies will be developed to adapt to climate change.

ARS will determine how climate changes have altered rainfall characteristics and associated changes in runoff. Methods will be developed to incorporate climate change capabilities into weather generation models so that runoff and erosion modeling can incorporate climate change effects.

Anticipated Products

- Multi-scale assessments of how climate and land use changes affect water supply, nutrient dynamics, and productivity.
- Improved understanding of the differences between rain and snow in terms of hydrology, carbon dynamics, and productivity and management.
- BMPs for concentrating and spreading water and integrating dryland and irrigated cropping on the landscape.
- Understanding of environmental and productivity outcomes of Business-as-Usual (BAU) and Aspirational (ASP) agro-ecosystem production systems under climate change (at some LTAR sites).
- Effects of fire on rangeland and forest hydrology and erosion will be better simulated, leading to improved and more cost-effective post-fire interventions.
- *New methods to predict and take into account changes in land use, land management, or crop genetics in response to impacts of a changing climate on water availability.*

Potential Benefits

- Long-term water availability is improved with planning using new data sets and improved models for assessing climate change impacts on water availability and agricultural production.
- Stakeholder activities depending on water availability are sustained using new strategies and practices for managing water resources and water quality.
- Post fire rangeland and forest management for reduced erosion and fast recovery will be more cost-effective.
- More climate resilient production systems result from assessment of how climate and land use change affect water use and availability.

Component 4 Resources

- Ames, Iowa
- Beltsville, Maryland
- Boise, Idaho
- Columbia, Missouri
- El Reno, Oklahoma
- Fort Collins, Colorado
- Jonesboro, Arkansas
- Oxford, Mississippi
- Temple, Texas
- Tifton, Georgia
- Tucson, Arizona
- University Park, Pennsylvania
- West Lafayette, Louisiana
- Bushland, Texas
- Houma, Louisiana