National Program 211

Water Availability & Watershed Management 2021 - 2025

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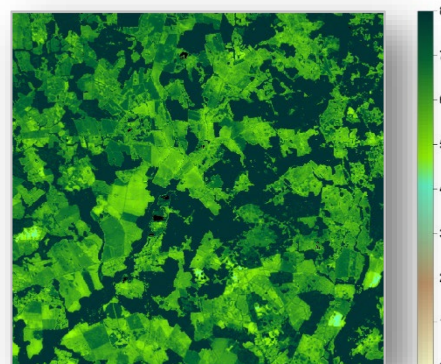

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USDA Agricultural Research Service National Program 211

Water Availability and Watershed Management Program Action Plan FY 2021-2025

Vision
Integrated, Effective, and Safe Water Resource Management

Mission
The mission of the Water Availability and Watershed Management National Program (NP 211) is to effectively and safely manage water resources to sustain and increase agricultural production and crop water productivity while protecting the environment and human and animal health.

Relationship of this National Program to the USDA Strategic Plan
This Action Plan outlines research that supports five objectives in the USDA Strategic Plan for FY 2018-2022.

- **Goal 1– Ensure USDA Programs Are Delivered Efficiently, Effectively, With Integrity and a Focus on Customer Service**:
  - **Objective 1.4** – Improve Stewardship of Resources and Utilize Data-Driven Analyses to Maximize the Return on Investment.
- **Goal 5 – Strengthen the Stewardship of Private Lands through Technology and Research**:
  - **Objective 5.1** – Enhance Conservation Planning with Science-Based Tools and Information
  - **Objective 5.2** – Promote Productive Working Lands
  - **Objective 5.3** – Enhance Productive Agricultural Landscapes
- **Goal 6 – Ensure Productive and Sustainable Use of our National Forest System Lands**:
  - **Objective 6.2** – Ensure Lands and Watersheds Are Sustainable, Healthy, and Productive.

Relationship of this National Program to the 2020-2025 USDA Science Blueprint
Theme 1 of the 2020-2025 USDA Science Blueprint is Sustainable Ag Intensification. The NP 211 Action Plan outlines research that supports Theme 1 objectives for Plant Production, Health, and Genetics. These include:

> **Objective 1** – Develop crop production systems and alternative strategies to intensify plant and forest production with continuous improvements and adoption of new technology and innovative practices while reducing environmental impacts.
>
> **Objective 5** – Evaluate the adoption and use of enhanced technologies and technology transfer for sensors, data analytics, and precision agriculture.

The NP 211 Action Plan outlines research that supports the work outlined in Theme 1 objectives for Animal Production, Health, and Genetics, research supports:

Objective 1 – Develop animal production systems and alternative strategies to maximize animal, human, environmental, and economic health to include continuous improvements, adoption of new technology and innovative practices while maintaining sustainability.

Theme 2 of the 2020-2025 USDA Science Blueprint is Ag Climate Adaptation. The NP 211 Action Plan outlines research that supports all the objectives included in both components for Theme 2, Landscape-Scale Conservation and Management and Climate Research and Resiliency. NP211 seeks to develop knowledge and tools to enable adaptation to climate change and weather variability, to improve the resilience of unmanaged and managed ecosystems, and optimize the sustainability of agricultural management systems.

Relationship of this National Program to the ARS Strategic Plan
Under the Science Goals outlined in the 2018-2020 ARS Strategic Plan, The NP 211 Action Plan outlines research that supports Goal Area 2, Natural Resources and Sustainable Agricultural Systems. Research projects and products primarily relate to Goal 2.1: Effectively and Safely Manage Water Resources to Sustain and Increase Agricultural Production and Water Use Efficiently While Protecting the Environment and Human and Animal Health. Scientists working on Goal 2.1 collaborate with those working on Goal 2.2, Goal 2.4, Goal 3.1, and Goal 3.2. These researchers are using the Conservation Effects Assessment Project (CEAP) and the Long-Term Agroecosystem Research (LTAR) platforms to identify new technologies and strategies and to address local, regional, and national agricultural related issues. NP211 will support Goal 2.1 through research in four components: (1) effective water management in agriculture; (2) erosion, sedimentation, and water quality protection; (3) processes, implementation, and impacts of conservation practices in agricultural watersheds; and (4) watershed management to improve ecosystem services.

Performance Measure for Goal 2.1: Develop technology and practices to promote and improve integrated, effective, and safe water resource management.

Introduction

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

The new Nation 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 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, and the United States became a major exporter of agricultural products. Concurrently, while agriculture became the largest consumptive user of freshwater, potential opportunities for optimizing agricultural production to conserve water supplies and improve water quality for all users remained relatively unexplored.

As the 20th century ended, the water resource situation in both the United States and the world began to change. Runoff and drainage from heavily fertilized fields increasingly threatened the aquatic health of our waterways and oceans. Key groundwater reserves were being depleted, water quality became increasingly degraded, and adverse climatic conditions such as drought were significantly reducing available freshwater supplies. At the same time, freshwater allocations began to shift among different users and needs. This included shifting supplies from agricultural to urban uses, reducing water supplies in reservoirs to maintain in-stream flows that ensure healthy aquatic ecosystems, and reducing water use for industry and energy production and increasing its use for recreation. Our shared freshwater supply was significantly reduced as it also became more variable and unreliable, and was increasingly insufficient to meet the needs and demands of an expanding population. Meanwhile, large-scale and complex water quality issues, such as hypoxia, eutrophication, and harmful algal blooms, began to degrade water quality in 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. They are increasing demands for water from our cities, farms, and aquatic ecosystems and increasing reliance in the eastern humid and sub-humid states on irrigated agriculture for stable crop and animal production and farm income. Water supplies are changing due to regional groundwater depletion, climate variability and change, and the need to tap alternative water resources. Advances in agricultural water management can provide important and unique contributions to the complex water management problems at regional and national scales. Science and engineering can develop new and emerging technologies that widen the range and effectiveness of options for future water management, 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 understanding these new technologies, assessing effectiveness and potential unintended consequences, and developing strategies for persuading water users and agencies to adopt the technologies determined to be most effective. Thus, the Nation can apply and use science and technology to protect, sustain, enhance, and manage our water resources, thereby improving human and ecological health while continuing to build a strong and growing economy.

The ARS Water Availability and Watershed Management National Program (NP211) addresses the highest priorities for agricultural water management: Effective water management; erosion, sedimentation, and water quality protection; the processes, implementation, and impacts of conservation practices in agricultural watersheds; and watershed management to improve ecosystem services. Research will also be conducted to determine the transport and fate of potential contaminants (sediments, nutrients, pesticides, pathogens, pharmaceutically active compounds, other organic compounds, salts, and trace elements) as well as to assess our capabilities to conserve and reuse waters in both urban and agricultural landscapes and watersheds. The overall goal is to provide solutions to problems in the utilization of the Nation's water resources. As a result of the planning process described in Appendix A, specific topics to be studied include:

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

Success 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 U.S. 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 U.S. 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 our agricultural, industrial, urban, and recreational activities, as well as the sustained health of the natural environment.

As suggested by the name of this National Research Program, "Water Availability & Watershed Management", associated research addresses water resource issues and problems broadly and across a range of scales. Although it is often misinterpreted to mean only water quantity, 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, effective water management in agriculture (Component 1) and control of erosion, sedimentation, and water quality (Component 2).

As with many natural resource issues, 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 model systems 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 Component 4, which focuses on the LTAR network and 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.

Importantly, this National Program emphasizes multi-location research projects that address water availability and management problem sets across scales, climate zones, soils, and agroecosystems. The most important of these are listed in Appendix B. Component 3 and Component 4 are both tied to long-term research involving close cooperation and information sharing between scientists involved with the 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. NP211 research results will also be used to facilitate data synthesis and utilization in Greenhouse gas Reduction through Agricultural Carbon Enhancement network

(GRACEnet), REAP (Resilient Economic Agricultural Practices), Sustaining the Earth's Watersheds - Agricultural Research Database System (STEWARDS), and other ARS databases. Because this national program develops a large amount of data that is valuable beyond the specific objectives and goals of any single 5-year action plan, there is an emphasis on data management as explained in Appendix C.

As is characteristic of natural resource issues in general, water resources research often crosses '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, and other components. Some NP 211 projects are contributing to research components that are part of action plans for 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 do not address specific research components in other national program action plans. In the sections below, numerous research activities cross national program boundaries either formally or informally.

Component 1: Effective Water Management in Agriculture

Human civilizations learned millennia ago that supplying adequate food and fiber required artificial manipulation of the natural hydrology through irrigation, water harvesting, and/or drainage. In the United States, irrigated agriculture produces 49 percent of U.S. crop market value on 18 percent of cropped lands. In all regions of the country, irrigation and drainage are now directly related to the environmental and economic viability of the watersheds within which they operate. In the 17 western U.S. states, 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. Irrigation is essential to the most highly productive, intensely managed, and internationally competitive sectors of our agricultural economy, and plays a key role in meeting growing national and global food, fiber, and energy needs. Surface and subsurface drainage are equally important to production agriculture . On approximately 120 million acres throughout the nation, removing excess water has resulted in reliable crop production. However, agriculture is subject to growing competition for water resources, growing pressure to safeguard water quality, and a clear need to adapt to alternative water resources. Irrigation and drainage technology and decision support systems must be improved to deal with adverse environmental effects and inevitable reductions in water resources available for irrigated agriculture in some areas.

Irrigated agriculture must respond with solutions that improve crop water productivity (CWP = amount of crop economic yield produced per unit of water consumed) and extend water availability through increasing the use of alternative resources, including treated urban wastewaters, recycled drainage waters, and other lower-quality waters such as those from dairy, aquaculture, animal feeding operations, and commodity processing plants. New methods and management practices are required for safe and effective use of these alternative water resources. Economic forces are hastening the transfer of water from agricultural to urban areas and the subsequent reduction of irrigated area in the West. At the same time, in the face of climate change and more frequent short-term (flash) droughts, irrigated acreage is increasing in the Midwest, East, Southeast, and in the Mississippi Delta regions of Arkansas, Louisiana, Mississippi, and Missouri. This eastern migration of irrigation helps stabilize rural economies but brings with it a host of new management issues to be solved; the 33 eastern states now comprise nearly 32 percent of the total 58 million acres of U.S. irrigated land. Competition for water has caused conflicts in areas where water was typically abundant in the past. 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 the most recent (2015) relevant USGS report, irrigation water withdrawals were 25 percent less than the high that occurred in 1980, even though irrigated area increased by 10 percent in that period. The decline was due to the installation of more water-efficient water application systems, including a 10 percent increase in the use of sprinkler systems and a 19 percent increase in the use of microirrigation. It also resulted from the irrigation declines in the 17 western states that have large water requirements and the increase of irrigation in the eastern states where irrigation may be needed only a few times per season. The wide adoption of pressurized irrigation systems has opened the door to more effective water management; these systems include variable rate irrigation (VRI) capabilities built into every new center pivot irrigation system. But the promise of pressurized systems to drive efficiencies has been hampered by the lack of user-friendly decision support systems that would allow producers to take advantage of pressurized irrigation's inherent capacity for control.

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 and adverse effects on water quality. 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, taking full advantage of the VRI capabilities already available in modern irrigation systems. 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 irrigation schedules and amounts that improve both yield and crop water productivity. Such understanding is also important to the development of water-efficient crop varieties that are an important component of both irrigated and rainfed 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 such as evapotranspiration (ET) to irrigation managers using the paradigm of a reference ET 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, as well as for K_c for new irrigation application methods. Demand is also growing for a K_c approach that transfers well across climatic regions, especially for application in humid climates. Important new work will be aimed at developing crop computer simulation models that more accurately calculate K_c and ET across a wide range of climate, weather, soil, crop, and irrigation application methods, including developing tools for irrigation scheduling in humid and sub humid regions.

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 beyond the scale of individual fields. There is a need for improved management and evaluation tools at farm, irrigation/drainage district, water resource district, and watershed scales. Assessment tools for managers and action agencies must address a range of problems. These include methods of evaluating irrigation and drainage project performance and the impact of new technologies and Best Management Practices (BMPs), 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, including ET estimation at scales from sub-field to districts to entire basins and watersheds. Modeling tools for regional and national assessment of crop water use and productivity are essential to improved policy formulation as well as management decisions in large basin and inter-basin water supply systems, particularly in the face of climate change. Agriculture must look toward developing decision support systems that are effective yet easy for farmers to apply. Increasingly, decision support systems involve wireless sensor systems in the soil, above ground, in the air, and in space that are integrated and provide an overwhelming amount of data that are useful for decision making but require automated methods, transparent to the end user, for turning the data into water management decisions. These automated methods all involve some model of the relationship between data and the soil-water-nutrient-plant-atmosphere system that drives agricultural production. Simulation models have now advanced to the point where they can be automated within decision support systems when they can be shown to be sufficiently accurate from field to regional scales. Accurate ET and crop yield data for the needed simulation model and decision support system assessment is key to success. Development of quality-controlled multi-year and multi-location datasets is equally necessary for model testing and improvement.

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 across and from the land. Constructed drainage features used on 120 million acres of cropland enable consistent high-yield production. Climate change predictions indicating warmer temperatures and more rainfall for the Midwest, and the increasing frequency of more extreme events for the nation increase the urgent 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 off-site water quantity and quality impacts for both rainfed and irrigated agriculture. Improved understanding of crop water productivity and the cost of implementing and maintaining on-farm storage of surface drainage water for irrigation are important in humid and sub-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 such as the 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. Groundwater depletion due to irrigation, even in humid and sub-humid regions, increases the need to identify optimal locations and approaches for managed aquifer recharge (MAR), develop better estimates of irrigation storage capacity, and test the viability of groundwater transfer to depleted aquifers using aquifer storage and recovery (ASR) technology

The declining supply of fresh water for irrigation, coupled with the increase of wastewater from urban areas and large livestock facilities, is generating the need for irrigation strategies, new crop species, and new crop varieties that can be produced successfully using wastewaters, saline waters, or 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 phyto-remediation of degraded soils. Additional information is needed on leaching requirements, because current leaching guidelines appear unrealistically high, 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 tolerances for combined stresses such as salinity and boron. Resistance to the reuse for irrigation of water reclaimed from municipal treatment facilities and livestock operations has increased due to the detection of very low levels of pharmaceutically active compounds and pathogens. Resource managers needs ways to monitor and manage these compounds to determine if these constituents are 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. The efficient use of water resources in these cropping systems requires new tillage, limited irrigation, and crop management tools to reduce runoff and leaching, maximize the effective use of precipitation, and minimize water losses to evaporation. Managers need tools to evaluate crop selections, identify suitable irrigation management, or assess the benefits of water trades with other users. Increased urban-agricultural water trading requires improved quantification of the amount of water saved when fields are not irrigated or are more efficiently irrigated so users receive accurate credit for traded water.

Research Focus

ARS NP 211 research will focus on several key topics. Successful adaptation to climate change effects on water availability and excess requires the following:

- More effective management of water in agricultural irrigation, drainage and dryland/rainfed systems, including development of easy-to-use, location specific sensors and sensor-driven decision support systems;
- Dependable, multi-scale quantification/prediction of crop water requirements, including for cover crops, deep-rooted and woody plants, and urban settings;
- More dependable, flexible, and efficient irrigation water delivery and drainage systems at field, farm, and watershed scales, including information on efficiency and productivity gains when converting from surface to sprinkler and microirrigation methods;
- Development and translation of more robust and reliable remote sensing tools for crop water use and soil water availability into easy-to-use grower-oriented tools for management;
- 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, drainage and other alternative water resources, including through managed aquifer recharge, above-ground storage, and predictions of snow pack contributions to water supply through computer modeling of the continuum from mountain to baseflow and streamflow, to aquifer and above-ground storage; and

- Increased crop water productivity through improved tillage and residue management systems and crop development for salt tolerance and phytoremediation.

Problem Statement 1-A: Develop Multi-scale Irrigation Management Technologies for Sustainability

Improving the effectiveness of water use in production agriculture will be key to sustaining and expanding food, feed, fiber, and biofuel production in the face of increasing water demands for non-agricultural uses. Knowledge of crop water productivity (CWP = economic yield per unit of crop water use; also known as 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. Quantification of CWP requires accurate methods to measure and estimate crop water use ET over multiple scales. Strategies to use scarce water supplies and precipitation more efficiently will include:

- More accurate and user-friendly irrigation scheduling based on weather data, plant and soil sensor systems;
- Satellite data fusion to guide and automate irrigation, deficit irrigation management and irrigated-dryland-rainfed rotations;
- Site-specific and VRI systems to place water where and when it is most effective;
- Easy to use decision support system for VRI management;
- Irrigation methods and management to reduce greenhouse gas emissions; and
- Integrated climate-crop-economic models to identify profitable and sustainable water use strategies.

Additional 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 crop water productivity for multiple locations and crops in both irrigated and dryland/rainfed 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, estimate crop water use and productivity, and integrate simulation models into decision support systems.

Anticipated Products

- Evapotranspiration (ET), crop coefficient (K_c or K_{cb}), and reference ET models that are reliable across regions, climatic zones, CO_2 levels, and water deficit regimes. Real-time crop coefficients based on remotely sensed vegetation indices, as well as plant water and/or soil water status.
- Integrated crop and irrigation management tools for a broad range of crops, including deficit irrigation and timing strategies, automation and control systems, modeling of physical processes affecting crop yield and quality under water deficit conditions and variable weather, and in-situ and remote sensing-based monitoring and modeling of plant stress and water use.
- Multi-season and multi-crop integrated management and rotation tools for water management and use and physiological and/or physical (e.g., soil water balance and energy balance) verification of associated tools.

- Improved cloud-based technologies for sensor data acquisition with APIs that allow sensor data to be used in off-site decision support systems, and remote sensing data products that can be integrated with irrigation scheduling algorithms.
- Improved soil water and plant sensors, and sensors for water level and stream channel characterization.
- Low-cost imaging sensors for estimating canopy cover, qualifying canopy temperature measurements, improving energy balance model outputs, and detecting diseased plants.
- New algorithms that incorporate spectral radiation data from ground-based and aerial platforms to assess crop water and nutrient stress.
- Data sets for crop model development and for electronic irrigation scheduling apps.
- Site specific irrigation (SSI) management systems using remote sensing-based ET and water balance tools and/or proximal sensors for biotic and abiotic stress detection.
- Decision support algorithms for VRI or site-specific water and nutrient applications.
- Remotely sensed crop water productivity maps at field to regional scales
- Multi-scale, ground truth models of crop stress, land surface and hydrology.

Potential Benefits

- Improved productivity, crop quality, water conservation, and environmental protection through grower adoption of 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.
- Reduced leaching of nutrients and salt loading to groundwater.
- Reduced costs of irrigation management and improved crop water productivity via development of integrated, commercially available plant and soil feedback systems that work with both full and regulated deficit irrigation.
- More efficient use of water inputs (both irrigation and precipitation) through integrated management of irrigation supplies and crop rotations.
- Improved management of crop selection and irrigation strategies via use of decision support tools based on the combination of weather-soil-plant sensing with price and cost conditions.
- Improved irrigation crop water productivity on a broad scale via commercial adoption of integrated crop and irrigation management tools.
- Improved water, irrigation, and nutrient management strategies and reduced environmental impact due to enhanced real-time data accessibility from continuous dam and reservoir performance monitoring, soil water content and plant monitoring, and new algorithms that enable better water storage management and better integration of fertigation, irrigation, and drainage management systems.
- Real-time reservoir water storage capacity evaluations will assist water resource managers with irrigation scheduling, design engineers with prioritization of dams for rehabilitation and/or decommissioning, and emergency managers with data necessary for flood forecasting and improved flood maps for emergency action plans.
- Improved crop water productivity, water storage capacities, and erosion control resulting from more robust algorithms for water management control systems and automated irrigation scheduling.

- Economic benefit from continued flood protection of the agricultural and urban landscape.
- Reduced water and fertilizer use via the development of tools for site-specific irrigation and nutrient application that enhance crop water productivity and nutrient use efficiency.

Component 1-A Resources
Beltsville, Maryland
Bushland, Texas
Columbia, Missouri
Columbus, Ohio
Davis, California
El Reno, Oklahoma
Florence, South Carolina
Fort Collins, Colorado
Houma, Louisiana
Jonesboro, Arkansas
Kimberly, Idaho
Lubbock, Texas
Maricopa, Arizona
Parlier, California
Riverside, California
Stillwater, Oklahoma
Stoneville, Mississippi
Tifton, Georgia
University Park, Pennsylvania

Problem Statement 1-B: Develop and Test Irrigation Application Methods, Components, and Management

As irrigation application through pressurized irrigation systems has increased to cover 67 percent of U.S. irrigated lands, crop water productivity has doubled; but in many areas irrigation is still applied using surface gravity-flow methods or older, less efficient pressurized systems. The choice and design of appropriate irrigation application systems requires in depth understanding of the complex interactions of application methods, cropping systems and the related crop water productivity, and energy and nutrient use efficiencies. Strategies employed will include:

- Studies to improve all application methods;
- Field-scale comparisons of application methods including microirrigation, sprinkler, spray and gravity-flow methods at multiple locations and with multiple crop species to determine relative irrigation efficiency, crop water use and crop water productivity of these systems on different soils and in different climatic environments; and
- Simulation modeling of systems to extend field-scale results to wider regions.

Anticipated Products

- Irrigation application method comparisons for major crops in terms of water and energy use, crop water productivity and nutrient use efficiency; BMPs for specific application methods.

- Alternative, efficient application methods for rice irrigation (including BMPs for GHG, arsenic, and cadmium reduction).
- Tools and software to evaluate, design, compare, choose, and improve 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 and water conservation measures in irrigated systems and methods for quantifying their impact on soil, water, and energy resources.

Potential Benefits

- Improved system design and decision-making that results in improved CWP and reduced unnecessary off-site water movement because farmers, action agencies, and planners have access to assessments of CWP and water losses as affected by choice of gravity, sprinkler, mobile drip or microirrigation systems, system components, and system management.
- Improved crop germination, yield, and profitability resulting from optimized subsurface drip irrigation lateral spacing and depth designs.
- Reduced irrigation applications and increased crop water productivity resulting from decision support systems that encourage converting to more efficient pressurized center pivot and microirrigation systems.
- Producers select the most profitable and sustainable irrigation system, given the constraints of water availability, soils, crops, energy costs and changing climate, due to availability of new tools for evaluating and predicting the hydraulic performance of water application methods (gravity, sprinkler, mobile drip, microirrigation) linked to the NRCS soils database.

Component 1-B Resources

Bushland, Texas
Columbia, Missouri
Fort Collins, Colorado
Jonesboro, Arkansas
Kimberly, Idaho
Maricopa, Arizona
Stoneville, Mississippi
Parlier, California

Problem Statement 1-C: Improve Management of Rainfed, Dryland, and Limited-Irrigation Water Use

Water management in dryland and rainfed farming systems is key to sustaining yields and improving water productivity under increasingly limited water supplies and in the face of short-term weather and long-term climate change stresses. Strategies for addressing this problem area include multi-location studies to measure outcomes of new management practices, and to improve models, remote sensing evaluations, and hydrological assessments, which are required to evaluate management strategies over a range of scales, soils and climates and under larger water and other abiotic stresses. Improved tillage and agronomic practices, crop rotations, crop trait selections, and limited irrigation water allocations under limiting water supplies are necessary to improve water productivity and sustainability.

Anticipated Products

- Improved understanding and quantification of hydrological processes affecting spatial variability of soil water and crop and range production (processes include lateral subsurface flow, surface run-on, effective precipitation, water storage as affected by soil horizonation and depth).
- Improved water production models and assessments that incorporate improved biological processes, remote sensing, water balance algorithms and multi-scale water and other abiotic stresses in time and space to assess crop ET, dryland/rainfed crop yields, and water productivity, including in agrovoltaic systems.
- Methods to improve overall irrigated and non-irrigated water productivity through evaluation and modeling of agronomic, crop and hybrid selection, and rotational strategies to allocate irrigation in time and space.
- More useful understanding of water use and tradeoffs of adding cover crops to water-limited systems under historical climate variability and projected climate change, including evaluation of effects of changes in soil biodiversity on plant water relations and crop productivity.
- Decision aids and remote sensing platforms to evaluate and determine optimal tillage and agronomic practices, crop selection, and rotational sequences to optimize CWP and profitability.
- Data on soil microbial and related crop water availability responses to management and precipitation regime for climate change models.

Potential Benefits

- Improved yield and profitability for a range of crops and regions via new dryland and rainfed production strategies, including limited irrigation or rotation with irrigation, based on precision water management decision support with improved modeling.
- Decreased evaporative losses and increased yields using new or improved agronomic and tillage practice recommendations under limited precipitation or irrigation.
- Soil health initiatives are based on better understanding of production outcomes due to quantification of and more realistic expectations of soil microbial community effects on soil water availability and crop water productivity.
- Enhanced water availability, yield, and CWP across landscapes using new or improved soil-, crop-, and climate-specific tillage and cropping strategies and recommendations under limited precipitation or irrigation.
- Improved decisions for water allocations to reduce risk and maximize yield and profitability.
- Improved nutrient use efficiency and precision conservation for soil and water quality.

Component 1-C Resources

Beltsville, Maryland
Bushland, Texas
Columbia, Missouri

Florence, South Carolina
Fort Collins, Colorado
Lubbock, Texas
Tifton, Georgia
Stoneville, Mississippi

Problem Statement 1-D: Develop Alternative Water Resources for Agriculture and Aquifer Management

Over the coming decades, U.S. agriculture will need to produce more while maintaining or reducing inputs. Currently, increasing water demand for non-agricultural uses and growing urban populations combined with aquifer depletion and climate change-induced droughts means that agriculture must look toward developing alternative water sources for irrigation and aquifer recharge. These sources include recycled municipal water, urban runoff, stormwater, agricultural drainage water, other industrial and agricultural waters, and lower quality natural water resources. Increased use of fertilizers and increased variability of precipitation in rainfed regions require new solutions for drainage water management, including water control and automation technologies for reclamation and storage for later irrigation during short-term drought. Developing strategies for safe and effective treatment and use of these alternative water resources for agricultural production and groundwater recharge requires:

- Developing indicators for emerging contaminants and pathogens;
- Assessing the migration and persistence of these agents in treated waste waters and the subsurface soil and water;
- Plant selection and breeding for tolerance to salinity and specific ions;
- Identifying optimal locations and approaches for managed aquifer recharge (MAR);
- Developing better estimates of irrigation storage capacity;
- Testing the viability of groundwater transfer to depleted aquifers using aquifer storage and recovery (ASR) technology; and
- Irrigation application and scheduling guidelines for effective, sustainable use of alternative water resources and the nutrients they contain.

Though this work is driven by water quantity objectives, the link to water quality is an integral component of successfully understanding the system, so this work is tied to other action plan components, particularly Component 2, Problem 2-C. This work is closely aligned with the EPA National Water Reuse Action Plan.

Anticipated Products

- Identification and treatment of emerging contaminants and pathogens in waste waters used as alternative water resources for irrigation and aquifer management, including contaminant and pathogen migration, persistence and/or accumulation in crops, movement in soils, and aquifers.
- Assessment of the persistence and effects of emerging contaminants and pathogens from alternative water sources in the environment.
- Plant identification, selection, and breeding for tolerance to salt, drought, and toxic ions.
- Water quality criteria for saline and reused water.

- Guidelines for irrigation management and scheduling, including salinity assessment, leaching requirements, and management of toxic elements.
- Identification of optimal locations, approaches, and utility of MAR and pilot testing of ASR for water storage and recovery.
- Effective removal and mitigation of emerging contaminants, nutrients and pathogens during MAR.
- Decision support tool that identifies and quantifies the proximity of alternative water sources to agriculture and their potential to mitigate drought, and improving irrigation schedules to optimize water supply and demand.
- Livestock wastewater more suitable for reuse in supplemental irrigation with a more balanced nitrogen to phosphorus ratio or for reuse in the barns with lower ammonia and pathogens.

Potential Benefits

- Increased production of crops that can phyto-manage toxic ions under saline and drought conditions and use brackish and poor-quality waters while removing toxic ions.
- Irrigation water requirements are reduced through revised leaching practice recommendations based on new knowledge and theory.
- More efficient use of nutrients in crop production via new/improved management guides/models for using nutrients in treated waste waters.
- New approaches to implement MAR and soil aquifer treatment increase aquifer recharge by overcoming challenges such as prolonged flooding and recharge time, seasonal time restrictions, crop damage, evaporation loss, clogging, non-point source pollution, nutrient leaching, and in-situ contaminant mobilization.
- Methods are available for the large-scale transfer of groundwater from rapidly recharged area of aquifer and injection of the water in depleted sections of the aquifer.
- Combinations of treatment technologies and approaches enable enhanced wastewater reuse in Concentrated Animal Feeding Operations (CAFOs).
- Increased water availability and crop production through use of alternative water resources resulting from new tools and recommendations for safely and effectively managing degraded and alternative water resources.
- Increased potential productivity of marginal lands and waters due to new and updated guidelines for: (1) irrigation BMPs related to irrigation water salinity, nutrient content, potential toxic ions, and impact of saline and recycled waters on soil physical properties; (2) the identification and selection of tolerant plant species suitable for use with saline and degraded waters, for water-limited (drought) conditions, for biofuel production and other products, and for phytomanagement of toxic ions; and (3) more effective manure management in livestock operations through innovative technologies that generate clean water for on-farm reuse.
- Innovative MAR and ASR techniques are used to: (1) capture episodic excess alternative water supplies, (2) store them in aquifers, and (3) recharge depleted aquifers in combination with large-scale groundwater transfer and injection methods for irrigated agriculture use, protecting groundwater quality, and mitigating aquifer depletion and land subsidence.

Component 1-D Resources

Davis, California
Florence, South Carolina
Jonesboro, Arkansas
Kimberly, Idaho
Maricopa, Arizona
Oxford, Mississippi
Parlier, California
Riverside, California
St. Paul, Minnesota
Tifton, Georgia

Problem Statement 1-E: Develop and Improve Simulation Modeling, Data, and Decision Support Tools for Water Management

Simulation models of agroecosystem processes have been developed over many decades, but further research is required to: 1) integrate simulation models with decision support tools for irrigation, drainage, surface storage, and aquifer recharge and recovery activities; 2) develop robust field data sets for model evaluation and improvement; 3) establish methodologies for use of models to guide field management and policy decisions; 4) develop new continuum-based, multi-scale watershed surface and subsurface hydrologic models useful for assessing basin scale water supplies; and 5) develop and apply related computational methods for model sensitivity analysis, model optimization, and integration of models with data. Strategies employed will include:

- Development of remote monitoring systems for reliable and meaningful data acquisition; Development of simulation models with decision support objectives in mind;
- Development and integration of models across the continuum of soil-plant-plot-field-watershed scales;
- Improvement of crop water requirement, ET, and irrigation scheduling subroutines of simulation models;
- Improved separation of evaporation and transpiration components of crop water use so that models will accurately assess outcomes of using different irrigation application methods;
- Improved snow melt and hydrologic subroutines for prediction of agricultural water supplies; and
- Development of artificial intelligence subsystems for arriving at decision support for complex systems.

Anticipated Products

- Improved models of ET and other agroecosystem processes that appropriately respond to water stress, tillage practices, nutrient stress, and other factors.
- Real-time or in-season irrigation decision support systems and BMPs that integrate data from remote sensing and soil water content sensors with process-based simulation models.
- Integrated remote sensing and modeling systems to inform basin-scale decisions, including snowpack, streamflow, and reservoir management.

- Knowledge of vine and orchard crop variability in atmospheric fluxes (water, energy, and carbon), ET, crop stress, irrigation requirements, and recharge in the field.
- Simulated outcomes of risk and uncertainty for alternative water management strategies using long-term datasets.
- Spatially and temporally variable tools that quantify aspects of water management, including water availability and need, wastewater, nutrient needs and losses, sediment, and hydrologic cycle interactions.
- Economic models that present optimization strategies under various water management scenarios (e.g. dryland, limited water, brackish or saline water).
- Publicly available, high-quality datasets at sub-daily time intervals of crop water use (ET) and weather, and at daily or larger time intervals for growth, agronomic practices, soil water content, yield and other pertinent environmental conditions and outcomes in machine readable form for model evaluation and improvement, and contributions to ensemble modeling activities using these high-quality datasets (e.g. AgMIP, OpenET).
- Development and utilization of innovative computational approaches, including machine learning and other AI approaches, sensitivity analysis, and optimization. In some cases, simulation modeling software will be made available in public source code repositories (e.g., GitHub) and linked to NAL Ag Data Commons.
- A tool to assess and refine the ability of empirical management models like Agricultural Policy/Environmental eXtender (APEX) and Soil and Water Assessment Tool (SWAT) to accurately capture water flow, deep percolation, and contaminant transport processes at large scales.
- Improved forecasts for water stream flow, vadose zone storage, and aquifer recharge under various climatic and management scenarios.
- Identification of optimal locations, designs, and management to maximize aquifer recharge and minimize impacts on groundwater quality.

Potential Benefits

- Improved irrigation decisions based on in-season measurements combined with and assimilated into modeling tools with the following results:
    - Crop managers and consultants adopt demonstrated methods for on-farm irrigation scheduling.
    - Decreased irrigation application, management time, and energy consumption while maintaining crop water productivity and quality.
    - Evaporative losses are reduced, resulting in increased crop water productivity.
    - Improved real-time water resource management operating procedures and emergency action plans.
- Increased farm profitability and sustainability through:
    - Use of decision support tools for variable rate irrigation systems allowing spatially and temporally variable irrigation scheduling and ET quantification.
    - Use of integrated crop models and irrigation scheduling methods to forecast yield and ET outcomes.
    - Increased sustainability and resilience of crops in arid and semi-arid environments with limited water supplies.
- Use of improved flood warning systems and erosion prediction models.

- Decision support tools identify and quantify alternative water resources and potential for drought mitigation.
- Optimized irrigation water allocation economics for multiple crops and multiple seasons.
- Improved agricultural resilience to water resource variability through management systems.
- Long-term sustainability of irrigated agriculture by mitigating groundwater depletion.
- Increased profitability and long-term sustainability of irrigated farming systems through assessment of long-term water management strategies using historical datasets, and readily available spatially variable analysis and prediction of water resources, feeding into whole-farm precision agriculture interfaces constrained by uncertain water availability and input costs.
- More capable decision support systems due to model inter-comparisons that lead to advancement of model algorithms.
- More effective water resource management from field to district and basin scales due to availability of more accurate agroecosystem models and daily ET data.
- Increased irrigation crop water productivity and sustainability due to delivery of intelligent systems that incorporate data from remote and proximal sensors that measure site-specific soil water content and plant stress conditions.
- Increased water availability and crop production through use of alternative water resources resulting from new computational tools and recommendations for managing alternative water resources.
- Reduced irrigation management time, reduced energy consumption, and improved irrigated water crop productivity.
- 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.
- Groundwater depletion is mitigated to ensure the long-term sustainability of irrigated agriculture.

Component 1-E Resources
Ames, Iowa
Beltsville, Maryland
Boise, Idaho
Bushland, Texas
Columbus, Ohio
Davis, California
El Reno, Oklahoma
Florence, South Carolina
Fort Collins, Colorado
Kimberly, Idaho
Lubbock, Texas
Maricopa, Arizona
Oxford, Mississippi
Stillwater, Oklahoma
Stoneville, Mississippi
Riverside, California

Temple, Texas
Tifton, Georgia

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 and terrestrial ecosystems. Interactions of land resource management practices and disturbances 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 and terrestrial ecosystems. Excess erosion destroys the ability of the soil to support the growth of crops that produce food and fiber and contribute to other ecosystem services. These issues need to be addressed at various scales, from local farm, hillslope, watershed, regional, to national scales.

Global climate change is increasing the magnitude, frequency, and duration of extreme weather events that can exacerbate water quality problems. Extreme temperatures, flooding, drought, severe local storms, and wildfires can all affect water quality. For example, intensification of severe local storms can exacerbate surface soil erosion and the increased suspended sediment and nutrient runoff that results. Increased flooding can inundate on-farm manure or chemical storage areas and transport pollutants into nearby watersheds. Disturbance-induced flooding and erosion on rangelands and forests pose hazards and increase risks to valuable natural resources, property, infrastructure, and human life. Drought-induced low water can also contribute to degraded water quality. Increases in global temperatures can contribute to worsening problems of hypoxia and harmful algal blooms. On arid and semi-arid landscapes, climate and land use-driven plant invasions, woody plant encroachment, and altered plant community dynamics amplify runoff and erosion rates that in turn perpetuate landscape-scale degradation over time through altered soil water use and long-term soil loss. Such bio-physical structural and functional feedbacks pose hazards to both on-site and off-site resources, habitat, and delivery of overall ecosystem goods and services.

Agricultural non-point source runoff transporting excess nutrients, sediment, and other associated contaminants are the leading source of water quality impairment in rivers and streams and the third leading cause of impairments for lakes, 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 can reduce reservoir capacity. Erosion of embankments and levees can cause severe flooding and loss of life, while many 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, harmful algal blooms, and hypoxia (i.e., oxygen depletion) at local, regional, and national scales. High nitrate levels in drinking water are a human health concern in many parts of the United States and the world. Due to the nutrient content of manure, the imbalance of phosphorus versus nitrogen in relation to plant needs, and manure's potential to harbor pathogens and other contaminants of emerging concern (e.g., pharmaceuticals and 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.

Agrichemicals (e.g., insecticides, herbicides, fungicides, plant regulators, and defoliants) and emerging contaminants such as the pharmaceuticals used in livestock production (e.g., antibiotics and hormones) can move from the point of application in production setting to surface and ground waters. This raises 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, in different combinations in the environment, and at different scales.

Research Focus

Field research is needed to address how climate change affects erosion processes, including its association with more frequent wildfire, plant community transitions, and increasing frequency of extreme rainfall events. Research is necessary to develop a better understanding of how field-scale processes of erosion and water yield may be influencing watershed-scale dynamics of gully and channel erosion. More information and measurements are needed to determine and model the connections between erosion processes, ecosystem disturbances, and fire-related impacts at all scales (hillslopes to watersheds) and the associated risks these dynamics pose to natural resources, infrastructure, and life. Foundational research is particularly needed on the interaction of wind- and water-driven erosion processes for croplands, rangelands, and forests to inform combined wind/water modelling. Field research and improved modeling on the effects of soil water repellency on runoff-driven erosion processes is critically needed for post-wildfire conditions, mitigation practices, and cost reduction. In addition to soil erosion, better information is needed on how soil organic matter and biology influence water transport and subsequent contaminant flux. Solving challenging salinity issues is an ongoing concern. Irrigation has the potential to impact both water quality and quantity. Research is needed to understand and quantify the impacts of different irrigation practices on surface water quality and groundwater availability. The links between surface water and groundwater need to be understood in greater detail to protect groundwater quality and preserve its availability for potential reuse.

An accurate understanding of the impacts of farm-scale management, hillslope, and watershed-scale processes is necessary to make informed management decisions and to establish realistic goals for water quality outcomes. There is a lack of information on how to value ecosystem services that are either (1) provided by agricultural land and rangelands, or (2) degraded by agricultural and other activities. If water quality can be accurately valued, then the establishment of trading markets and similar systems can be employed to improve water quality.

Producers seek more information about how to manage their crops/fields under adverse conditions. This includes ways to minimize environmental and economic impact of varying cropping scenarios as well as information about crop strains/varieties that are suitable for their region under scenarios of changing climate. Producers want better information about manure management to minimize environmental impacts and optimize production. Climate change effects need to be included when researching biophysical processes and accounting for social and economic concerns in decision support tools. In conjunction with overarching concerns about climate change and changes in water quality is the growing issue of mitigating harmful algal blooms and hypoxia in waterbodies that will require watershed-scale research and new tools.

Critical information necessary to address this issue include: edge-of-field to stream nutrient transport and relationship to overall water quality trends at local and regional scales; the impact of legacy nutrients (internal loading) on water quality; and improved understanding of underlying processes causing a lag between BMP implementation and change in water quality in streams.

There is great potential for technological improvements to enhance agricultural productivity while minimizing environmental impact. Research efforts will be focused to: (1) lower the cost and availability of current technology, (2) develop ways to increase accessibility to the farmer/rancher, and (3) ensure robust and uniform data handling. This includes investigating novel ways to treat drainage water via stacked conservation practices such as bioreactors and two-stage ditch design, as well as impacts of drainage applications on steep slopes. Long-term research approaches such as LTAR can be augmented for improved understanding across multiple scales. Improvements in quantifying sources and processes across multiple scales will help pinpoint priority areas and actions necessary for solving water quality problems (not all problems are necessarily agricultural and not all solutions need to occur in farm fields).

Decision support tools to guide producers and land managers need to include information about relative risk and/or uncertainty that accompanies decision guidance. Models can be employed to provide helpful information about multiple water quality/quantity processes across varying spatial and temporal scales. Research efforts should focus on improving models by linking them to real-world data sets and improve representation of watershed processes across varying scales. Research is needed to improve quantitative source attribution of sediment and contaminants affecting agricultural and urban water quality and on practices/tools that improve retention and reuse. Needed tools include real-time sensors and improved nutrient-contaminant-pathogen modeling which can be used in the economic valuation of resulting water quality outcomes and to support evidence-based programs and policies that protect/improve water quality. Research is also needed in the coupling of wind and water-driven erosion predictive technologies.

Problem Statement 2-A: Elucidate In-Field Processes Controlling Soil Erosion and Fate of Sediment and Contaminants

To effectively design and implement erosion and sedimentation control BMPs, basic research on soil erosion is needed, particularly with respect to process connectivity, impacts of disturbances and ecosystem degradation, effectiveness of conservation practices, and how soil properties such as soil erodibility are used in models. ARS will:

- Investigate effects of landscape attributes, surface-subsurface hydrology interactions, soil erodibility, and land transformations (i.e., row orientation) on soil erosion, deposition, and chemical transport processes for improved landscape management under different soil, geographic, and climatic conditions;
- Evaluate the effects of conventional and conservation management practices (i.e., biochar application, soil amendments, use of recycled water, vegetative buffers, alternative cropping systems, and urban agriculture) on the forms, fate, and transport of sediments, nutrients, contaminants, and agrochemicals in fields, along hillslopes, in waterways, and at the watershed scale;

- Investigate the role of landform types and precipitation type (rainfall vs snowfall) on soil erosion processes and drainage water quality and quantity;
- Examine the effects of different rain intensity on sediment loss in runoff from crops under different tillage methods, cover crops, and different edge-of-field buffer strips;
- Identify and quantify carbon, nutrients, sediments, contaminants, soil health and greenhouse gas emissions from agricultural production fields and grassland ecosystems during surface and subsurface flow at small scale, farm scale and watershed scale;
- Assess effectiveness of novel techniques (i.e., fallout radionuclides, tracers, and P isotherms) to quantify spatial erosion patterns, sediment sources, and nutrient dynamics;
- Quantify the effects of fire on vegetation, soils, surface hydrology, and erosion processes on rangeland, woodlands, and dry forests across hillslope to watershed scales;
- Quantify the impacts of plant invasions, woody plant encroachment, and associated conservation practices on hillslope surface hydrology and soil erosion processes;
- Measure aeolian sediment transport on rangelands through the National Wind Erosion Network and evaluate the interaction of wind- and water-driven soil erosion processes; and
- Evaluate the effects of plant community transitions and conservation practices on vegetation, soil properties, and hydrology and erosion processes.

Anticipated Products

- Improved assessments, identification, and quantification of surface water contaminants to guide investigation of sources and to develop management/mitigation practices to reduce sediment and contaminant transport.
- Guidelines and management practices for food production in urban/peri-urban communities based on water availability and the quality of the soil and water.
- Improved quantification of soil erosion from agricultural systems.
- Enhanced understanding of the mechanisms responsible for initial loss of soil and biological constituents from the terrestrial to the aquatic environment.
- Increased understanding of dissolved phosphorus loss mechanisms in the field under different circumstances, informing how to best prevent dissolved phosphorus losses.
- Improved understanding of drainage water during critical periods for nutrient loss, which is especially relevant as seasonal precipitation and temperature patterns shift due to climate change.
- Advanced understanding of fire effects on vegetation and soils and the resulting impacts on surface hydrology and soil erosion processes on rangelands, woodlands, and dry forests.
- Improved understanding of impacts of invasive species and effects of conservation practices on plant community dynamics, soils, surface hydrology, and soil erosion.
- Advanced understanding of combined aeolian and water sediment transport processes.
- Data sets for improved equations and parameterizations in developing and validating landscape-scale erosion, contaminant transport, and water quality models, relevant to:
    - Effectiveness of long-term biochar application on the mobility and degradation of agrochemicals;
    - Ecosystem controls of processes critical for nutrient and agrochemical leaching;

- Developing, enhancing, and evaluating models for predicting erosion impacts of climate change, invasive weeds, woody plant encroachment, fire, and management practices on rangeland, woodlands, and dry forests;
    - Modeling benefits of turf to ecosystems; and
    - Modeling nitrogen transport from cranberry bogs to coastal discharge areas.
- Improved techniques and sciences in generating spatial erosion data and sediment source information.

Potential Benefits

- Improved conservation/mitigation strategies to address disturbances, degradation, and climate change effects on croplands, rangelands, and forests.
- More efficient and precise placement and implementation of erosion control and water quality improvement practices in agriculture.
- Improved water quality, mitigation of soils with high nutrient content, and decreased soil loss on agricultural fields.
- Improved food quality and protection of water resources from anthropogenic contaminants associated with land use history, reuse waters, and/or surrounding land use/activities.
- Enhancement of food security in urban/peri-urban communities with production of healthy locally grown food.
- Controlled mobility and degradation of agrochemicals on agricultural fields due to new management strategies for use of biochar
- Reduced cost and increased effectiveness of post-fire management due to improved tools, assessment, and management practices for post-fire hydrologic and erosion risks.
- Improved management of ecologically important rangeland and woodland ecosystems through new and more effective BMPs.
- Improved erosion control due to BMPs based on conceptual/predictive models of sediment transport by interacting aeolian and water-driven erosion processes, and better placement of rangeland conservation practices resulting in improved soil health, and water quality, while saving costs by targeting conservation spending.
- More effective management of carbon and nutrient losses from fields and range due to improved BMPs based on better understanding of carbon and nutrient losses in the environment as influenced by management under different biophysical drivers (weather/climate, soil).

Component 2A Resources

Beltsville, Maryland
El Reno, Oklahoma
Jonesboro, Arkansas
Oxford, Mississippi
St. Paul, Minnesota
Stoneville, Mississippi
Tifton, Georgia
Tucson, Arizona
University Park, Pennsylvania
West Lafayette, Indiana

Problem Statement 2-B: Determine In-Stream Processes Affecting Contaminant Fate, Transport, and Biological Elements

Research is needed on stream networks, including drainage ditches, to quantify nitrogen, phosphorus, and carbon cycling, identify sinks/sources, and examine linkages with the soil. This is key to developing more effective management practices to reduce nutrient transport that results in harmful algal blooms and hypoxic events across the Nation. ARS will:

- Conduct multilocation research at regional and continental landscape scales to measure contaminants in groundwaters and surface waters;
- Identify biological elements, occurrence, sources, trends with land use/watershed characteristics, and effectiveness of mitigation/conservation practices to protect water quality;
- Conduct field experiments to examine the linkages among water quality, physical habitat, and aquatic population and community structure in agricultural watersheds;
- 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;
- Evaluate the influence of multiple environmental factors on ecosystem structure and function to better understand the ecological effects of conservation practices;
- Examine conditions affecting nutrient cycling and legacy nutrients in agricultural drainage networks; and
- Determine and measure the processes affecting in-stream transport and fate of sediment.

Anticipated Products

- Identification and quantification of surface water contaminants to guide investigation of sources and develop management or mitigation practices to reduce contaminant transport.
- High temporal resolution data set on stream water conductivity, Dissolved Oxygen (DO), turbidity, and Ortho Phosphate.
- Improved assessment of sediment and phosphorus losses.
- Improved understanding of the phosphorus budget at the watershed scale.
- Understanding microbial processes that affect contaminant fate and transport will allow development of management practices that reduce contaminants in surface waters.
- Information about empirical relationships between agricultural pollutants, physical habitat, and ecological responses in freshwater ecosystems.
- Enhanced understanding and data related to nutrient dynamics in drainage networks.
- Measurements and interpretation of changes to stream/riverbed topography and sediment transport caused by flow and/or surface soil erosion.
- Bottom topography from acoustic multi-beam measurements and particle size composition from physical samples for selected Mississippi Alluvial Plain rivers.

Potential Benefits

- Better control of erosion and unwanted nutrient losses based on improved understanding of the impact of land use on water quality and the effectiveness of management/conservation or mitigation strategies.

- Improved water quality in streams and water bodies due to management practices based on greater understanding of physical and biological processes controlling contaminant fate and transport within agricultural watersheds, including seasonal effects on sub-daily stream water quality processes. Enhanced methods for predicting water quality outcomes of different management strategies within agricultural landscapes.
- Initiation of restoration of water quality and other ecosystem services by reductions in amounts of agricultural contaminants resulting from alternative management options.
- Establishment of sustainable agroecosystems due to availability of restoration and management options to producers and resource managers.
- Improved management of sedimentation in waterways and reservoirs due to enhanced predictive capability for sediment transport in streams that do not typically maintain steady flow rates and better methods to measure sedimentation rates in lakes.
- Feasibility of groundwater recharge by rivers in the Mississippi Alluvial Plain and improved water resource management, including flood forecasting.

Component 2B Resources
Ames, Iowa
Beltsville, Maryland
Jonesboro, Arkansas
St. Paul, Minnesota
Columbia, Missouri
Tifton, Georgia
University Park, Pennsylvania
Columbus, Ohio
Oxford, Mississippi
West Lafayette, Indiana
Kimberly, Idaho
Tucson, Arizona

Problem Statement 2-C: Develop Practices to Control the Transport and Fate of Soil, Water, and Air Contaminants

To better design and refine best management practices that reduce risk and improve outcomes, 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 information on direct and indirect pathways of impact to terrestrial and aquatic ecosystems. ARS will:

- Evaluate the ecosystem services of turf and the effect of turf management on water quality, soil health, and greenhouse gases;
- Assess the persistence and transport of contaminants of concern in urban agriculture;
- Determine contributions of urban versus agricultural sources of nutrients and contaminants to surface waters;
- Determine the impact of single and stacked conservation practices on water, soil, and grain yield and quality;

- Test, demonstrate, and improve economic efficiency of media, structures, soil amendments and other technologies to reduce nutrients and agricultural contaminants in runoff;
- Assess the performance and effectiveness of erosion control practices such as earthen embankments and stream design; and
  Develop and test enhanced efficiency nitrogen fertilizers and methods for recovering nitrogen in manures.

Anticipated Products

- Datasets quantifying the soil/nutrient/agrochemical loss and agronomic effects of individual and stacked management practices.
- Improved predictive capability for understanding effects of management practices on nutrient and agrochemical losses.
- Analyses improving understanding of critical processes driving losses of soil, nutrients and agrochemical.
- Development of novel soil/nutrient/agrochemical loss mitigation practices and enhancement of existing practices.
- Development of enhanced efficiency fertilizer products and application techniques.
- Improvements to practice standards and management recommendations.

Potential Benefits

- Increased cost effectiveness of implementing management practices.
- Greater adoption of in-field and edge-of-field management practices, based on insights from extensive monitoring datasets, that will effectively maintain the quality of water resources and the sustainability of production practices.
- Improved water quality tied to increased productivity and sustainability of agricultural production systems through judicious use of management practices in the landscape.
- Improved water, soil, and air quality.
- Mitigation of soil, nutrient, and agrochemical losses.

Component 2C Resources

Beltsville, Maryland
Columbus, Ohio
El Reno, Oklahoma
Oxford, Mississippi
St. Paul, Minnesota
University Park, Pennsylvania
West Lafayette, Indiana

Problem Statement 2-D: Develop Tools to Improve Water Quality Management in the Landscape

Better scientific understanding of chemical and physical processes affecting water quality is crucial, but decision support tools are essential if producers and land managers are to effectively respond to challenging growing conditions and determine how/where to implement conservation/mitigation practices. ARS will:

- Expand the functionality of one or more of the predictive soil erosion models to include water quality components, databases, testing, and application recommendations. The model(s) will be applicable to multiple overland flow elements and small field watersheds with multiple hillslopes, channels, and impoundments;
- Improve watershed model predictions using a novel lag time estimation technique;
- Conduct physical modeling and/or monitoring of earthen embankments (zoned and/or homogenous) to assess performance of protected and/or unprotected surfaces under concentrated overtopping and/or internal flow;
- Develop forecasting tools to improve the timing of fertilizer applications;
- Improve fertilizer recommendations through development of a comprehensive database of soil fertility trials and a decision support tool modeled after the Australian Better Fertiliser Decisions for Cropping Systems;
- Develop small reservoir sediment management simulation technology;
- Scale water quality and ecosystem benefits derived from conservation practices from system level to the landscape scale; and
- Develop radiometry techniques and approaches for assessing water quality.

Anticipated Products

- Modeling tools that include hydrology, sediment generation, and pollutant transport science.
- Improved models to inform assessment of conservation/mitigation strategies and improve water quality.
- Enhanced Windows Dam Analysis Modules (WinDAM) and/or SITES model for predicting erosion processes and embankment breach and/or earthen spillway erosion.
- A decision-making tool (Fertilizer Forecaster) to assist managers in scheduling fertilizer or manure applications.
- A national fertilizer recommendation tool to support transparent fertilizer recommendations and to enable a reassessment of critical levels required for crop growth.
- Computer model components for reservoir sediment management.
- Tools or methods for connecting small-scale studies to landscape impacts.
- A protocol for using radiometry to reduce the number of samples required to assess the impact of conservation practices and land management on water quality.

Potential Benefits

- Improved water quality.
- Improved conservation planning by NRCS and Forest Service partners.
- Reduced failure potential of earthen dams.
- Better prioritization of dams for rehabilitation and/or decommissioning.
- Extension of the planned service life of dams for flood protection, irrigation water, rural and municipal water supplies, wildlife habitat, and recreational use.
- Improved fertilizer-use efficiency can reduce over-application of nutrients and reduce risk of nutrient losses.
- Improved sediment management of small reservoirs.

- Estimates of benefits of conservation practices at the landscape scale.

Component 2D Resources
Beltsville, Maryland
El Reno, Oklahoma
Fort Collins, Colorado
Oxford, Mississippi
Stillwater, Oklahoma
University Park, Pennsylvania
West Lafayette, Indiana

Component 3: Conservation Practices in Agricultural Watersheds

Challenges to water availability and quality in the 21st century include hypoxia in marine (e.g., Gulf of Mexico, Chesapeake Bay) and freshwater (e.g., Great Lakes) ecosystems, declining aquifers, climate uncertainty, increased eutrophication of water bodies, urban encroachment, and a human population expected to increase from 7.8 to 10 billion over the next 35 years. Conservation practices that protect natural resources and mitigate the impacts of agriculture play a critical role in achieving sustainable agriculture goals, as well as improving how agriculture interacts with surrounding natural landscapes and urban areas. Stakeholders are requesting more information on how conservation practices can meet the challenges to water availability and quality while still producing sufficient food and fiber for a growing population. Extremes of water availability pose critical problems. Crop 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 and in the same year, highlighting the need to develop conservation practices that are resilient to climatic changes. Practices could increase the capacity to store water on the landscape during times of excess for subsequent use during times of need. In addition, conservation practices will retain sediment and nutrients on the landscape and remove contaminants from agricultural water to minimize negative impacts on ecosystems. Water reuse will be critical to sustain agriculture as competition for water resources increases; however, research must address contaminant mitigation capacity of potentially reused water resources.

Understanding how implementing conservation practices affects soil and water processes and ecosystem services provided by riparian, wetland, stream, and lake ecosystems within agricultural and mixed-use watersheds is critical to developing new and evaluating existing conservation practices. Identifying connections among the physical, ecological, social, economic, and cultural components of conservation practices is also fundamental to their success. Remote sensing technology and geographic systems analysis can be used to study impacts of conservation practices at multiple spatial scales and to determine efficient placement of conservation practices within a watershed. More complete information is needed on how conservation practices affect sediment, water, and contaminant transport pathways and the processes involved in contaminant transformation and mitigation.

Additionally, understanding the ecological effects of conservation practices on terrestrial and aquatic flora and fauna is limited to selected practices, and there is a need to gain a holistic view of the impacts of conservation practices on terrestrial and aquatic ecosystems. Existing data and research findings also need to be synthesized to provide large-scale impacts of conservation practices, enable the refinement of existing models to better predict impacts of conservation practices, and develop novel models for predicting effects of changing climatic, land use, and socio-economic conditions on conservation practice effectiveness. The current paradigm is to evaluate single conservation practices for their efficiency in field settings. Therefore, there is a critical need for future research to evaluate the effects of using multiple conservation practices together (i.e., stacked practices).

The Conservation Effects Assessment Project (CEAP) is a multi-agency effort led by USDA's NRCS and ARS to quantify the environmental effects of conservation practices and programs. It includes the development of science-based approaches to manage agricultural landscapes for environmental quality. Research needs include prioritizing and combining the effects of soil conservation practices that reduce soil erosion associated with nutrient loss, reservoir sedimentation, and aquifer decline; determining how conservation practices affect soil health and water use; and synthesizing how conservation practices interact at landscape levels. The LTAR network is led by ARS. The network's mission is to develop national strategies for sustainable agricultural intensification. LTAR urgently needs multi-site research pertaining to the interaction of conservation practices with both business-as-usual and aspirational crop management, as well as information on how agricultural lands perform under changing climatic conditions. The multi-agency Mississippi River/Gulf of Mexico Hypoxia Task Force needs data on easy-to-use, field-scale conservation tools; legacy nutrients loading; edge-of-field to stream nutrient transport; and fertilizer use efficiency (e.g., 4Rs).

Research Focus

ARS will:

- Identify key contributors to soil erosion when conservation practices are used in critical areas, as opposed to whole field implementation, and identify how conservation practices impact water balance, including contaminant transport to groundwater, effects on soil properties, and soil water storage or reduced water usage by plants;
- Determine how practices can be used to reduce dependence on synthetic inputs such as pesticides and fertilizers, and how improved manure management can reduce nutrient discharge and microbial contamination; and
- Collect data needed to improve soil erosion models under conservation practices, nutrient management scenarios, and manured cropping systems, and evaluate how stacked conservation practices alter soil and water processes compared to single practices.

Problem Statement 3-A. Understanding Chemical, Physical, and Biological Processes That Affect Implementation of Conservation Practices

Conservation practices change soil and water processes in both agroecosystems and the surrounding agricultural landscapes to meet environmental and economic objectives. More information is requested by stakeholders regarding the processes involved with, and altered by, existing and novel conservation practices, including reduced tillage, residue management, grading/drainage, precision irrigation, soil amendment use, cover cropping, surface water storage, nutrient management, and intensified cropping systems. These soil and water processes include precipitation, irrigation, infiltration, available soil water storage, crop water productivity, surface and subsurface drainage, and evapotranspiration. Drivers of these processes may include, but are not exclusive to, surface vs subsurface/tile pathways, matric versus macropore/preferential flow, soil compaction or subsurface horizon properties, adsorption/precipitant versus chemical transformation, nutrient cycling and dissolution, biological processes (including carbon sequestration and denitrification), and biochemical transformation and transport of agrichemicals. Laboratory, plot, field, and watershed scale studies will be used to quantify and understand the processes that affect successful implementation of conservation practices.

Anticipated Products

- Characterization of the interactions between conservation practices and water budgets, crop water productivity, watershed hydrology, and wetlands.
- Data for modeling processes and characterizing business-as-usual and aspirational agricultural production systems.
- Characterization of soil/water processes affected by conservation practices implemented to improve water availability and/or quality, including soil erosion/redistribution, aggregate dynamics, compaction, crusting, and leaching.
- Guidelines for optimal nutrient management to reduce losses and improve water quality, e.g., precision application strategies for nitrogen and phosphorus.
- Improved tools and strategies that integrate soil health and water conservation, including placement of conservation practices for optimal effectiveness in watersheds.
- New or enhanced tools for effective mitigation of water contaminants.

Potential Benefits
- Improved soil and water quality, optimized nutrient management, reduced farm input costs, optimized greenhouse gas emissions, minimized erosion, and improved crop yields that are resilient to changing climate and periods of drought or excess water.
- Stakeholders at farm, community and regional scales benefit from enhanced water and nutrient availability and reduced adverse pollution due to improved predictions of conservation practice effects and interactions between conservation practices and agricultural production management under current and changing climate and resulting more effective management practices.

Component 3 Resources
Ames, Iowa
Beltsville, Maryland
Columbia, Missouri
Columbus, Ohio
El Reno, Oklahoma
Florence, South Carolina
Houma, Louisiana
Kimberly, Idaho
Lubbock, Texas
Oxford, Mississippi
Parlier, California
Tifton, Georgia
University Park, Pennsylvania
West Lafayette, Indiana

Problem Statement 3-B: Assess and Implement Conservation Practices in Agricultural Landscapes

Implementing conservation practices includes selecting the best practices as well as the best locations to apply the practices to achieve water resource goals. Research is needed to identify the conditions where practices are most effective and situations where practices may not be effective. The cumulative or interacting effects of multiple practices in agricultural landscapes need to be understood and quantified to obtain optimum results. A greater understanding is needed of the resilience and continued functioning of conservation under changing conditions and extreme weather events. There is also a need to understand the impacts of conservation practices on other resources such as farm productivity, air quality, and terrestrial and aquatic flora and fauna. This problem encompasses multiple scales, including plot, field, and watershed. Long-term climate, water, soil, and land management data from NP 211 will support CEAP goals to assess conservation practices and conduct hydrologic analyses. Strategies will include field to watershed scale research on gully erosion, effects of wetland restoration and riparian buffer management on ecosystem services and adjacent aquatic ecosystems, effects of changing conditions and weather extremes on conservation practice resilience, multi-scale efficacy of conservation practices and practice placement in the landscape affecting erosion and water quality, and the efficacy of precision agricultural practices to increase productivity and reduce adverse environment effects.

Anticipated Products

- Methods for mapping susceptible areas in the landscape for implementing conservation management practices.
- Long-term data on how conservation management affects water quality, including effectiveness during extreme events and conditions when practices are not effective.
- Cost effective stabilization practices for control of ephemeral gully erosion under a wide range of hydrogeologic conditions.
- Improved quantification of erosion at field-channel-watershed scales from all sources.
- Practices, knowledge, and models that improve management for attenuating all forms of sediment and nutrient pollution of surface and subsurface waters in landscapes under mixed land uses.
- Guidelines on how adopting precision agriculture technologies can be used to improve productivity, environmental outcomes, and profitability.

Potential Benefits

- Reduced loss of sediment, nutrients, and contaminants from agricultural landscapes.
- More resilient agricultural production.
- Better targeting of conservation practices for improved cost/benefit ratios.
- Improved ecosystem services.
- Wider acceptance and adoption of conservation practices.
- Enhanced conservation planning by linking soil and watershed datasets (e.g., linking NRCS Soil Surveys with long-term watershed data from CEAP and LTAR sites).
- Improved ability of drought-prone and flood plain areas to adapt to historic climatic variations and climate change.
- Increased adoption of policies for regional and state water planning based on information about how conservation practices affect water quantity and quality.

Component 3 Resources

Ames, Iowa
Beltsville, Maryland
Bushland, Texas
Columbus, Ohio

El Reno, Oklahoma
Florence, South Carolina
Jonesboro, Arkansas
Kimberly, Idaho
Lubbock, Texas
Oxford, Mississipi
Parlier, California
St. Paul, Minnesota
Stoneville, Mississippi
Temple, Texas
Tifton, Georgia
University Park, Pennsylvania
West Lafayette, Indiana

Problem Statement 3-C: Forecast the Impacts of Conservation Practices Within Changing Environments

Stakeholders identified a critical need to identify conservation practices capable of reducing the adverse impacts of agriculture in the context of current climatic, land use and socio-economic environments. The socioeconomic environment strongly affects the adoption of conservation practices and evidence of how practices improve cost/benefit ratios is therefore crucial. It is also anticipated that changes in agricultural practices will occur in response to changing climatic and socio-economic conditions, and conservation practices that are effective under current conditions may be ineffective in the future. Thus, potential system changes underscore the importance of modeling efforts that can forecast the impacts of conservation practices in the future. This problem area proposes a concerted research effort involving the synthesis of past research results, watershed modeling, and novel statistical modeling efforts to document the past, current, and future effects of conservation practices on agricultural and mixed-use watersheds at multiple spatiotemporal scales. Research strategies encompassed within this problem area include:

- Synthesis of past research results related to impacts of conservation practices with qualitative literature reviews, systematic literature reviews, and meta-analyses;
- Compilation of long-term monitoring databases and incorporating or linking relevant and available information from historical watershed databases with the current databases;
- Development of new watershed models and refining existing models, such as SWAT, Water Erosion Prediction Project (WEPP), Annualized Agricultural Non-point Source (AnnAGNPS), and Revised Universal Soil Loss Equation 2 (RUSLE2), to predict the impacts of conservation practices and anticipated future changes in climatic, land use and socio-economic environments; and
- Novel statistical modeling assessments of the impacts of conservation practices and changing environmental conditions (e.g., climatic, habitat, land use, socio-economic, socio-ecological, spatiotemporal scale, etc.) on ecological responses and ecosystem services in agricultural and mixed-use watersheds.

Synthesis and forecasting of the impacts of conservation practices will enhance our knowledge and understanding of the effectiveness of conservation practices in improving ecosystem services under changing environmental conditions. The primary products from this research effort are science-based tools stakeholders can use to manage soils, watersheds, cropland productivity and rotations, and irrigation water, and decision tools for local, state, regional, and national planning for conservation efforts.

Anticipated Products

- Addition of new data to existing databases that quantify long term responses of ecosystem services (biodiversity, water quality, water quantity, etc.) to conservation practices and long-term trends in water resource conditions relative to future changes in climate, land use, and socio-economic conditions.
- Improved and calibrated empirically based models and model predictions based on existing and novel models that predict 1) impacts of conservation practices; 2) assessments of runoff, profile water redistribution and water stress in dryland crop yields; 3) irrigation routines for SWAT; 4) nutrient effects on primary production and system metabolism; 5) national agroecosystem models; 6) simulation models, including conservation and climate scenarios at field, watershed and national scales; 7) forecasts of future runoff events and river water quality; and 8) ecosystem services related to water and soil resources, including costs and benefits of soil management and conservation practices.
- A collection of publicly available tools, decision support systems, outreach efforts, and publications that provide new information on the impact of conservation practices

Potential Benefits

- Improved decision support aids for managing agricultural watersheds to increase agricultural profitability, increase efficiency, benefit natural resources in agroecosystems, and identify practices that are resilient to changing climatic, land use, and socio-economic conditions.
- Improved ability to address natural resource issues related to agriculture (e.g., eutrophication, habitat degradation, species loss, etc.) by drawing from multiple improved conservation practices.
- Improved ecosystem services (e.g., biodiversity, water quality, water quantity, erosion control, etc.) within aquatic habitats impacted by agriculture.
- Ability to conduct cost-benefit analyses that can aid in justifying USDA conservation support incentives.
- Improved decision support systems for action agencies and producers based on a strong and growing database.

Component 3 Resources

Bushland, Texas
Beltsville, Maryland
Columbus, Ohio
El Reno, Oklahoma
Fort Collins, Colorado
Kimberly, Idaho
Lubbock, Texas
Oxford, Mississippi
St. Paul, Minnesota
Temple, Texas
Tifton, Georgia

West Lafayette, Indiana

Component 4: Watershed Management to Improve Agroecosystem Services

Water and agriculture are inextricably linked as 87 percent of the nation's drinking water flows over or through agricultural lands. Agricultural watersheds, including croplands, pastures, and rangelands, cover more than 70 percent of the continental United States. The water needs for food and fiber production are becoming more constrained across the food–water–energy nexus. Comprehensive 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. Achieving substantial levels of agricultural intensification will require holistic, integrated watershed management of our water resources. Water must be reserved to ensure that non-provisioning ecosystem services, such as wildlife habitat, greenhouse gas reduction, soil stabilization, and recreational opportunities, are maintained or improved. These challenges are in addition to ongoing climate change and wider variation of climate extremes. The primary research challenge remains the development and application of an integrated approach that is explicitly designed to elucidate the integrity, production capacity, and resilience of ecosystems. Within and surrounding agricultural landscapes, we must clearly describe the quantities and pathways of energy, matter, nutrients, and water exchange within and between ecosystems. Water is one of the main connectors transporting material in agricultural landscapes. Research is needed that improves our understanding of how and when water is channeled within and beyond agricultural ecosystems and how management can enhance the processes associated with ecosystem services.

By operating a national network of LTAR sites that includes the major long-term ARS experimental watersheds, many in operation for more than 60 years, the ARS is uniquely situated to address these questions. Long-term studies allow observation of changes that occur at different timescales, and helps differentiate between annual weather variations and persistent climatic change. When combined with results from the other three 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.

Watershed management to improve agroecosystem services requires designing sustainable agricultural systems that balance production, environmental, and rural prosperity goals under a changing agricultural landscape and climate. Whereas field studies have been carried out and modeling tools have been developed to address the three ecosystem services separately, studies are needed that use measured data and reliable modeling outputs to determine optimal production systems that consider all ecosystem services.

Therefore, research under this component will develop methods and tools that take into account the desired outcomes for various ecosystem services in order to determine optimal production systems that improve agroecosystem services.

Research Focus

Continued high-quality long-term measurements, coupled with fundamental process-oriented research and development of tools and methodologies, are required to address and resolve issues related to water supply and quality management and the provision of ecosystem services. The best way to document watershed responses and understand the dominant processes in our changing world is to make consistent, high-quality, long-term measurements. Critical measurements include precipitation, temperature, state and fluxes of water, soils, nutrients, and production. 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 relevant information for water management; to 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 other 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. Methods and tools must be developed to understand and provide guidance for producers and land managers when multiple objectives cannot all be accomplished so that trade-offs between different management decisions can be measured and assessed. Because the scale of this work is typically over large areas, these activities and investigations must be supported by new remote sensing tools and enhanced instrumentation. 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. These needs will be built on existing ARS expertise and infrastructure and offer an integrated research and development approach that enhances the beneficial utilization of land and water resources in agricultural landscapes and meets current needs for competitive and multi-objective management of land and water resources.

In this component of the NP 211 Action Plan, ARS LTAR sites and multiple ARS labs provide a foundation for multi-site research, analysis, and synthesis. 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 ARS labs advancing this component of the NP 211 Action Plan also contribute to National Program 212, Soil and Air, which contributes strongly to the LTAR network through its research focused on soil and air quality. These are inseparable in the physical world from water quality and dynamics in the soil, aquifers, streams and water bodies.

Problem Statement 4-A: Enable Data-Driven Agroecosystem Management Through Collection of Long-Term Observations, Data Interpretation, and Data Dissemination

Deep understanding of water-mediated agroecosystem behavior and performance can only grow through collection of basic and fundamental observations at high spatial and temporal resolutions both on the ground and through remote sensing approaches. Many ARS locations maintain long-term data collection efforts in experimental watersheds and in the LTAR common experiments which examine contrasting management practices characterized as Business-As-Usual (BAU) and Aspirational (ASP) treatments. Databases resulting from these efforts include hydro-climatic variables such as precipitation, runoff, evapotranspiration, soil moisture, and streamflow, as well as associated data on soil parameters, nutrients, plant condition, and production. This problem statement focuses on continuing that collection of data, including systematic, automated, and comprehensive QA/QC processes that lead to quantification of data uncertainties. New in the coming years is ARS focus on bringing in long-term datasets from locations outside the LTAR network. Rigorous interpretation of these data will seek to identify patterns, trends, causation, and consequences. In addition, these data will be utilized to verify simulation model and decision support system development, which is a focus of Problem Statement 4-C. Finally, the power of the data collected here is greatly multiplied through its careful and thorough cataloging and archiving, making it available for other scientists to interpret and to provide context over time.

Anticipated Products

- Diverse set of long-term datasets to analyze and compare environmental and production aspects of BAU and ASP practices in LTAR common experiments and at other ARS research stations.
- Syntheses of long-term hydrology and water quality observations to quantify impacts from climate, land-use, or management.
- Measurements for validation of remote sensing products and enhanced model development.
- New technology for measuring hydrological and water quality parameters through chemistry, sensors, and UAS imagery.

Potential Benefits

- Agroecosystem management will improve through use of new strategies for natural resource and agricultural management informed by increased data collection and synthesis.
- Critical agriculture related natural resource issues are mitigated in the face of changes in climate and socioeconomic drivers by using long-term datasets to improve:
    - Management of water availability for sustainable use by agriculture and urban users;
    - Management of agricultural systems for environmental and economic sustainability; and
    - Agricultural intensification while avoiding adverse system effects.

Component 4A resources:

Ames, Iowa
Beltsville, Maryland
Boise, Idaho
Bushland, Texas
Columbia, Missouri
Columbus, Ohio
Davis, California
El Reno, Oklahoma
Houma, Louisiana
Jonesboro, Arkansas

Kimberly, Idaho
Las Cruces, New Mexico
Lubbock, Texas
Mandan, North Dakota
Morris, Minnesota
Oxford, Mississippi
St. Paul, Minnesota
Stoneville, Mississippi
Temple, Texas
Tifton, Georgia
Tucson, Arizona
University Park, Pennsylvania
West Lafayette, Indiana

Problem Statement 4-B: Develop and Improve Tools for Watershed Management

ARS has significantly contributed to the development and evaluation of watershed models and modeling tools that inform on the effects of management on plant growth and crop yield, water use and availability, nutrient cycling, erosion, and overall transport of pollutants that originate on agricultural land. However, limitations in these modeling systems remain, including in rigorously capturing impacts of climate extremes and land-use change, in fully representing connections and feedbacks within the soil-plant-atmosphere-water and human system, and in comprehensive validation, in part due to lack of measured data. Furthermore, the upscaling power of remote sensing has not been fully integrated into existing modeling systems and management tools. The research proposed here will leverage data collected under Problem Statement 4-A and spatially comprehensive data to improve and validate representation of hydrologic, soil erosion and sediment transport, plant growth, nutrient, and carbon processes in integrated models and to identify and model linkages between climate variability, water availability, and primary productivity. Satellite methods for mapping water budget components and vegetation health will be advanced to higher spatial and temporal resolution. Mobilizing these modeling and monitoring assets, integrative tools will be developed to assess the long-term impacts of management practices on agroecosystem services.

Anticipated Products

- Improved representations of hydrologic, soil erosion and sediment transport, plant growth, nutrient, and carbon processes in integrated models using spatially comprehensive data.
- Improved estimates of water budget components at field to watershed scales and under current and changing conditions.
- Improved, accessible, water driven production models for cropland, rangelands, and pasturelands.
- Multi-scale tools for agricultural monitoring and management under current, extreme, and changing conditions.

Potential Benefits

- Water resources will be better managed and more available for multiple uses due to improved quantification of surface moisture and biophysical status over agricultural landscapes.
- Watershed managers will make more effective decisions using new, spatially based, and more realistic models and decision support tools.
- Agroecosystems will be more sustainably productive under climate and social change due to improved understanding of agroecosystem response to climate and management changes.

Component 4B Resources

Ames, Iowa
Beltsville, Maryland
Boise, Idaho
Bushland, Texas
Columbia, Missouri
Columbus, Ohio
Davis, California
El Reno, Oklahoma
Florence, South Carolina
Kimberly, Idaho
Oxford, Mississippi
St. Paul, Minnesota
Tifton, Georgia
Tucson, Arizona
West Lafayette, Indiana

Problem Statement 4-C: Quantify Agroecosystem Performance and Tradeoffs

A truism from the business world is that you can't manage what you don't measure. For agroecosystems to be managed efficiently, their performance across a range of metrics needs to be measured and accurately quantified. These metrics may include productivity, water availability, water quality, soil health, ecology, and quantities of allocated input resources. But new metrics must be developed and standardized in order to clearly understand tradeoffs between management alternatives. These metrics must be sensitive to one of the dimensions of the three-legged stool of LTAR (production, environment, and rural prosperity) and must be objectively measurable. The data collected by ARS scientists, especially data from LTAR efforts such as those collected in Problem Statement 4A, form the core information from which metrics are derived.

Sustainable intensification requires a solid understanding of the inherent tradeoffs that drive decisions. These tradeoffs may exist solely in the agricultural realm (e.g., production versus nutrient runoff) or tradeoffs may reflect competing agricultural and non-agricultural water uses (e.g., irrigation versus human water supply).

ARS will develop and collect objective measures derived from across NP 211 locations allowing for multi-location comparisons that will quantify agricultural decision-making outcomes.

System-level approaches such as lifecycle analyses, multi-objective optimization, and research that focuses simultaneously on each of the dimensions of the three-legged stool of LTAR (production, environment, rural prosperity) will inform complex decision-making at scales from the individual farm field to entire regions or specific agricultural industries.

ARS will assess the interdependencies that exist within the complex agroecosystems across major agricultural landscapes to provide an improved understanding of environmental and hydrological parameters. Additionally, 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.

Anticipated Products

- Metrics to evaluate sustainable intensification of agronomic systems.
- New and more sensitive measures of ecosystem change in agricultural watersheds.
- Improved understanding of tradeoffs between productivity, conservation, and rural prosperity.
- Decision-support tools for water management under sustainable intensification.

Potential Benefits

- National and state agencies (including NRCS and EPA), farmers, and citizens will have a more reliable basis for assessing tradeoffs between management schemes.
- Agroecosystem productivity will be increased while minimizing negative impacts to the environment using newly available management tools.
- Improved water resource management resulting from regional assessments of agroecosystem performance and tradeoffs that provide better information to stakeholders.
- Mitigation of eutrophication in rivers and lakes due to an improved understanding of production versus nutrient runoff tradeoffs.

Component 4C Resources

Beltsville, Maryland
Davis, California
El Reno, Oklahoma
Fort Collins, Colorado
Las Cruces, New Mexico
Oxford, Mississippi
Tifton, Georgia
Tucson, Arizona
West Lafayette, Indiana

Appendix A – Planning Process and Plan Development

This National Program is organized into four components:

1- Effective Water Management in Agriculture
2- Erosion, Sedimentation, and Water Quality Protection
3- Processes, Implementation, and Impacts of Conservation Practices in Agricultural Watersheds
4- Watershed Management to Improve Agroecosystem Services

These components were chosen after receiving input from the listening sessions designed to understand the problems and needs of our customers, stakeholders, and partners, and from other interactions with interested parties.

NP 211 listening sessions were held via Zoom (https://zoom.us) platform, for different regions across the country in late August 2020. More than 600 participants attended these listening sessions, 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 listening session 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.

Appendix B – Multi-Location Research Plans

Cooperative research among ARS units must occur to develop the products and achieve the outcomes identified in this action plan. Important Multi-Location Research Plans are identified here. 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.

Three multi-location research plans address specific high-priority areas of concern with highly coordinated research efforts that address the problems across a wide range of climate, soil and other environmental conditions required for successful problem solving. These efforts are similar to the LTAR approach except that they involve locations that are both formally involved in the LTAR network and locations not in that network, and they are more tightly focused on research and development to address specific problems, and on technology transfer to product users.

Multi-Location Research Plan 1-A: Dynamic Prescriptions for Site-specific/Variable-Rate Irrigation and Nutrient Decision Support

Research Locations: Bushland, Texas; Florence, South Carolina; Stoneville, Mississippi; Columbia, Missouri; Beltsville, Maryland; Maricopa, Arizona; and Fort Collins, Colorado

Research Problem: Differences in physical soil attributes (e.g., texture, slope, aspect, bulk electrical conductivity) within a field, and seasonal, spatial, and temporal changes in abiotic and biotic stresses imposed on crop plants can result in variable crop water and nutrient needs within a field. Site-specific irrigation and nutrient applications can reduce irrigation water use and improve crop production while reducing off-site movement of water and agro-chemicals. Center pivot and linear-move irrigation systems from all manufacturers have the capability for variable rate irrigation that can enable variable watering rates across a field. Variable rate microirrigation systems are also becoming available. However, to meet varying crop water and nutrient needs and improve crop water productivity at the field scale, it is necessary to build user-friendly dynamic prescriptions based on real-time or near real-time information from sensors and sensor network systems. Participating scientists will develop algorithms to use feedback from microclimatological, plant and/or soil water sensors (including in-situ, proximal, remote, stationary and mobile) from various platforms (ground-based, UAS or satellite) to generate dynamic prescription maps to inform and/or control water and nutrient management. The team will integrate these algorithms and the ancillary sensor and control systems into user-friendly decision support tools that will be field tested with partners.

National Program: NP211, Component 1 – Effective Water Management in Agriculture/

Objectives: As a team, meet quarterly to:

- Develop a general framework to address methods for delineating management zones to economically address variable crop water use;

- Develop robust algorithms for automatic site-specific irrigation scheduling and nutrient application of crops in arid/semi-arid and humid regions (including AI methods where appropriate) to improve crop water productivity;
- Move centralized data acquisition to the cloud where possible;
- Modify the ARSmartPivot client-server software to include canopy spectral reflectance indices and soil-plant-atmosphere energy balance models for irrigation and nutrient management, and to include data stored on a cloud server, including remotely sensed ET data;
- Combine static sensors and mobile proximal sensing to generate soil water and nutrient profile maps and prescription maps for variable-rate irrigation and fertigation;
- Integrate proximal sensing data with crop growth models for computing site-specific irrigation and fertigation management recommendations; and
- Work with irrigation system companies to transfer technology and best management practices for site-specific irrigation and nutrient application management.

Multi-Location Research Plan 1-B: Increasing water resources through managed aquifer recharge using alternative water sources

Research Locations: Maricopa, Arizona; Davis, California.; Jonesboro, Arkansas; and Oxford, Mississippi

Research Problem: Irrigated agriculture in the U.S. is among the most productive in the world. However, competition for traditional water supplies is increasing, especially during times of drought, and this may result in reduced agricultural productivity. Future development of large-scale surface water storage and distribution systems is unlikely due to their adverse impacts on aquatic ecosystems. Alternatively, storage within existing aquifers offers a low-cost option to mitigate groundwater depletion, land subsidence, and a means to store water for future irrigation needs. The efficient storage and recovery of water in aquifers is often referred to as managed aquifer recharge (MAR). Optimization of MAR requires maximizing infiltration, vadose zone transmission, and groundwater recharge rates, while ensuring the overall quality of stored and recovered water. Specific strategies under investigation include, but are not limited to, Ag-MAR, drywells, filtration basins, infiltration galleries, and stream bank extraction projects. In water stressed environments, most water is already allocated, with little excess water available for MAR. Alternative water sources, such as treated municipal wastewater, storm water runoff, excess precipitation, drainage water and irrigation tailwater, are all potential sources of water that can be used for MAR. In more humid environments with declining aquifers, opportunities exist to store excess runoff during the non-growing season for later use using MAR. Groundwater withdrawal from rapidly recharged sands near a river is a possible strategy for providing large volumes of clean water that can be reinjected into the aquifer in areas where water levels are depressed. Due to the sensitive nature of groundwater and its multiple uses, it is essential that water quality be protected during MAR. Most alternative water sources pose water quality challenges that require careful implementation of management and/or treatment practices to ensure successful MAR operations. Soil aquifer treatment (SAT) is the process thorough which water is naturally attenuated and cleaned during MAR. SAT has been shown to provide treatment and removal of nutrients, heavy metals, solids, organics and pathogens found in waters used for MAR. In addition to SAT, protection of groundwater quality may require appropriate pretreatment of alternative waters prior to MAR application. Aquifer storage and recovery, where water is pumped into an aquifer for distribution and use at a later time, is another viable method for reversing declining trends in groundwater level in stressed aquifers.

National Program: NP211, Component 1 – Effective Water Management in Agriculture.

Objectives: As a team, meet quarterly to:
- Identify optimal locations and designs for MAR under various hydrologic, source water, and climatic conditions;
- Develop management practices to maximize and maintain water infiltration, vadose zone transmission, and aquifer recharge rates during MAR;
- Mitigate the adverse effects of on-farm MAR on crop health and production;
- Determine the capacity and efficacy of SAT for removal of contaminants found in alternative waters used for MAR;
- Develop appropriate pretreatment options for alternative waters used in MAR;
- Improve characterization of subsurface heterogeneity and MAR efficacy at sites; and
- Evaluate management plans on water quantity and quality at several MAR sites.

Multi-Location Research Plan 1-C: Providing High Quality Vegetation and Water Balance Data for Model Improvement and Intercomparison

Research Locations: Bushland, Texas; Boise, Idaho; and Kimberly, Idaho.

Research Problem: Agricultural simulation models are improving to the point that there is the possibility of building these models into decision support tools to aid producers, managers, and action agencies to make better decisions at scales from fields to watersheds to regions of the nation. However, simulation models must meet more strict criteria for accuracy if they are to be used in decision support. There is a critical need for high quality water balance and cropping data for model improvement, testing and intercomparison. Weighing lysimeters are known as the most accurate means of determining the water balance and vegetation water use (evapotranspiration, ET) but existing data sets are complex, difficult to convert to machine readable form needed to support simulation modeling, and require further quality control before public release. Recent model Intercomparison results from the Agricultural Model Intercomparison and Improvement Project (AgMIP) show that a wide range of evaporative demand is key to finding and fixing model limitations in ET estimation. Participating locations are in a wide climatic range. Participating scientists will prepare research grade weighing lysimeter and associated management and vegetation data in machine readable form as described by the USDA NAL Ag Data Commons and AgCROS platforms for data sharing. Scientists will share methods of data quality control and work towards a common format for data presentation to the extent possible. Anticipated users are crop and environmental simulation modelers in ARS and university locations across the nation as well as the AgMIP, and the OpenET project that is building a nation-wide daily ET map at 30-m resolution based on simulation modeling and satellite and weather data.

National Program: NP211, Component 1 – Effective Water Management in Agriculture, Component 4 – Watershed management to improve agroecosystem services.

Objectives: As a team, meet quarterly to:

- Share and improve quality control methods for lysimeter, soil water content, vegetation, and ancillary data.
- Share and improve methods for translating data into machine readable form compatible with simulation models, and with the NAL Ag Data Commons and AgCROS data sharing platforms.
- Place quality controlled, properly formatted, machine readable data on the USDA ARS NAL Ag Data Commons and AgCROS platforms for public accessibility.
- Cooperate with ensemble modeling activities using these high-quality datasets (e.g. AgMIP, OpenET).

Ten specific multi-location research plans are proposed for Component 4. These efforts address specific high-priority areas of concern with coordinated research efforts that address the problems across a range of climate, soil and other environmental conditions required for successful problem solving. Plan problem statement titles and collaborating locations are identified in the list that follows.

Multi-Location Research Plan 4-1 (4A): Contribute to analysis of hydrology, phenology, WUE, soil carbon, carbon fluxes, water chemistry, etc. across the LTAR network.

> **Research Locations:** Boise, ID; Las Cruces, NM; Mandan, ND; Beltsville, MD: St. Paul, MN; Tifton, GA; University Park, PA; Morris, MN; Tucson, AZ; El Reno, OK; and Oxford, MS

Multi-Location Research Plan 4-2 (4A): Determination of the surface energy/water balance in semiarid lands

> **Research Locations:** Tucson, AZ; Boise, ID; and Bushland, TX

Multi-Location Research Plan 4-3 (4A): Develop long-term remote sensing data products over LTAR sites describing evolution in ET, soil moisture and vegetation conditions over surrounding landscape

> **Research Locations:** Beltsville, MD; Tucson, AZ; and Boise, ID

Multi-Location Research Plan 4-4 (4A): Evaluation of water sources and flow pathways across drained regions (IN, OH, MN, IA) through LTAR drainage group collaboration.

> **Research Locations:** West Lafayette, IN; Ames, IA, St. Paul, MN; and Columbus, OH

Multi-Location Research Plan 4-5 (4A): Remote sensing of rangeland vegetation using a variety of sensors.

Research Locations: Tucson, AZ; Boise, ID; and Las Cruces, NM

Multi-Location Research Plan 4-6 (4A): Quality assurance and control of 30 years of large weighing lysimeter, cropping, irrigation, ET, and weather data. Joint with Component 1.

Research Locations: Bushland, TX and Kimberly, ID

Multi-Location Research Plan 4-7 (4A and 4B): Measurement and modeling of snowpack response to precision vegetation management in seasonally dry forests.

Research Locations: Tucson, AZ; Boise, ID; and Fort Collins, CO

Multi-Location Research Plan 4-8 (4A and 4B): Improve irrigation simulations in watershed hydrology modeling to inform adaptation planning.

Research Locations: El Reno, OK and Kimberly, ID

Multi-Location Research Plan 4-9 (4B): Develop or apply models that describe watershed processes. In collaboration with the LTAR Drainage working group, evaluate and test the SWAT model and its subsurface drainage component at the field and watershed scale.

Research Locations: Ames, IA; St. Paul, MN; Columbus, OH; and West Lafayette, IN

Multi-Location Research Plan 4-10 (4C): Understanding of ecosystem ET, net and gross productivity and soil moisture in semiarid and other water-limited regions.

Research Locations: Tucson, AZ; Boise, ID; and Fort Collins, CO

Multi-Location Research Plan 4-11 (4A and 4C): Measuring aquatic agroecosystem metabolic regimes as an integrative long-term indicator of change in LTAR watersheds.

Research Locations: Oxford, MS; Columbus, OH; and Tifton, GA

Multi-Location Research Plan 4-12 (4C): Assess algal nutrient limitation and thresholds for eutrophication across several agroecosystem management systems.

Research Locations: Oxford, MS; Ames, IA; Columbus, OH; West Lafayette, IN; University Park, PA; Beltsville, MD; Columbia, MO; and Tifton, GA

Appendix C – Data Management

Because all ARS National Program 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 (i.e., 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 a 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 publicly 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.