Water Quality and Management National Program (NP 201) Accomplishment Report 2001-2004




National Program Assessment Panel Meeting
May 24-25, 2005
Beltsville, Maryland

Water Quality and Management Customer Workshop
June 7-10, 2005
Denver, Colorado

Table of Contents

Water Quality and Management National Program (NP 201)
Accomplishment Report

Introduction

The Agricultural Research Service (ARS) is the principal in-house research agency of the U.S. Department of Agriculture (USDA). The mission of ARS is to conduct research to develop and transfer solutions to agricultural problems of high national priority and to provide information access and dissemination in order to:

- Ensure high-quality, safe food, and other agricultural products
- Assess the nutritional needs of Americans
- Sustain a competitive agricultural economy
- Enhance the natural resource base and environment, and
- Provide economic opportunities for rural citizens, communities, and society as a whole.

To facilitate achieving its mission ARS has arranged its research portfolio into 22 National Programs. These National Programs are organized within four broad areas: Animal Production and Protection (APP); Natural Resources and Sustainable Agricultural Systems (NRSAS); Crop Production and Protection (CPP); and Nutrition, Food Safety/Quality (NFSQ). The Water Quality and Management National Program (NP 201) is part of NRSAS, but interaction also occurs with researchers in APP, CPP, and NFSQ. The National Program structure allows ARS to link scientists in laboratories around the country to address research problems of local, regional, national, and international interest.

The research in NP 201 is conducted through 57 projects at 38 primary laboratories (Table 1). The annual budget for NP 201 is approximately $55.8 million net dollars that are allocated to the various locations. Congress sets the annual funding level and often the specific research thrust at a location. With this annual appropriation the locations must cover staff salaries and all direct and indirect costs to operate, repair, and maintain its research location. The budget is roughly proportioned as $25 million for the Agricultural Watershed Management component, $17.8 million in the Irrigation and Drainage Management component, and $23 million in the Water Quality Protection and Management component. The entire national program has approximately 157 SYs (scientific-person years; includes summation partial time that some scientists contributes to this national program) engaged in research. The actual number of ARS scientists that are involved is estimated at 225.

The current ARS Strategic Plan envisions multidisciplinary teams of scientists working to develop the tools and techniques required to maintain, restore, and enhance the physical, chemical, and biological integrity of the Nation’s watersheds and its surface and ground water resources (ARS Strategic Plan Goal 5.1.1). The vision for NP 201 is "A Safe, More Water Efficient Society." The primary mission of this national program is twofold: to develop innovative concepts for quantifying the movement of water and its associated constituents in agricultural landscapes and watersheds, and to develop new and improved practices, technologies, and strategies, for managing the Nation’s agricultural water resources. These advances will provide farmers/ranchers, local communities, and natural resource management agencies with the tools they need to improve water conservation and water use efficiency in irrigated and rainfed agriculture, enhance water quality, protect rural communities from the ravages of floods and droughts, and prevent the degradation of riparian areas, wetlands, and stream corridors.

Table 1. ARS Research Locations Contributing to the Water Quality and Management National Program Component Areas*

		Program Components		
State	**Locations**	**Agricultural Watershed Management**	**Irrigation and Drainage Management**	**Water Quality Protection and Management**
AZ	Phoenix		X	X
AZ	Tucson	X		X
CA	Parlier		X	X
CA	Albany			X
CA	Riverside		X	X
CO	Ft. Collins		X	
FL	Canal Point		X	
FL	Ft. Lauderdale		X	
FL	Ft. Pierce			X
FL	Miami			X
GA	Dawson		X	
GA	Tifton	X		X
GA	Watkinsville	X		X
IA	Ames	X	X	X
ID	Boise	X		X
ID	Kimberly		X	X
IN	West Lafayette	X		X
LA	Baton Rouge		X	X
MD	Beltsville	X		X
MN	St. Paul			X

Program Components				
State	Locations	Agricultural Watershed Management	Irrigation and Drainage Management	Water Quality Protection and Management
MO	Columbia		X	X
MS	Oxford	X		X
MS	Stoneville		X	X
MT	Sidney		X	
NE	Lincoln		X	X
OH	Columbus		X	X
OH	Coshocton	X		
OK	El Reno	X		
OK	Stillwater	X		
OR	Pendleton			X
PA	University Park	X		X
SC	Florence		X	X
TX	Bushland		X	
TX	Lubbock		X	
TX	Temple	X		X
TX	Weslaco	X		
WA	Pullman			X
WV	Beaver			X

* Starting in 2004 a number of the ARS locations have become more involved in the agricultural watershed management component and water quality protection and management component based on their involvement in the USDA Conservation Effects Assessment Project.

NP 201 scientists cooperatewith the Cooperative State Research, Education, and Extension Service (CSREES); Economic Research Service (ERS); and National Agriculture Statistics Service (NASS) to provide research, decision support systems, technology transfer, education, extension, and economic assessments for the Natural Resources Conservation Service (NRCS), Farm Service Administration (FSA), U.S Forest Service (USFS), and other action and regulatory agencies within USDA. Research activities are also carried out in partnership with the Nuclear Regulatory Commission (NRC); U.S. Environmental Protection Agency (USEPA); U. S. Department of the Interior, including the U.S. Geological Survey (USGS), U.S. Bureau of Land Management (USBLM), and U.S. Bureau of Reclamation (USBR); the U.S. Department of Defense (DOD); the U.S. Department of State (USDOS); the U.S. Army Corps of Engineers (USACE); and the U.S. Department of Commerce, including National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautical Space Agency (NASA). ARS also works closely with State and Land-Grant Universities, private consultants, and international collaborators, where appropriate, to develop cost-effective technology and improved understanding of the hydrological cycle and its impact on agriculture and the environment.

Based on input received by ARS from many sources, research in NP 201 was organized into three component areas: agricultural watershed management, irrigation and drainage management, and water quality protection and management. A brief overview of the component areas is given below. The current Action Plan and Executive Summary is available on the following website: http://www.ars.usda.gov/research/programs/programs.htm?NP_CODE=201. The Action Plan includes a complete description of the components, problem areas, and goals, and the Executive Summary describes the 12 outcomes that were initially proposed. A more comprehensive discussion of the accomplishments for each of the problem areas for each of the components is provided in the appendices: Appendix A addresses Agricultural Watershed Management; Appendix B addresses Irrigation and Drainage Management; and Appendix C addresses Water Quality Protection and Management.

Agricultural Watershed Management. This component fosters research on weather and climate characterization, hydrologic processes and watershed characteristics, and watershed management. The research focused on the interaction between water availability and use and the environment and agricultural production on irrigated croplands, rainfed croplands, and grazinglands at field, farm, and watershed scales. Research on watershed management will promote more effective use of precipitation, optimal allocation and improved assessment of available water resources, and hydraulic advances in integrated ecosystem management. Research also focused on improving the hydrologic efficiency and safety of structures used to store and regulate water flows. Databases are being developed from information collected on the long-term agricultural watersheds. Models and decision support systems are developed from these databases to optimize the allocation and use of available water resources, resolve conflicts among competing demands, and provide water resource managers with science-based technologies to establish sound programs and policies.

Irrigation and Drainage Management. Existing and future water resources for irrigation are projected to decline even more than in the last 5 years. Therefore, improved irrigation and drainage practices become increasingly important to enhance water quality, conserve water, and sustain American food, feed, and fiber production for strategic national economic and societal benefits. Innovative irrigation and drainage techniques and management are required that increase cost-effectiveness of crop production, protect water quality, limit soil erosion, reuse waste water, and reduce energy requirements while enhancing and sustaining crop production and water use efficiency. Advanced technologies, such as precision irrigation, site-specific management, remote sensing, and decision support systems, are needed to address the water quantity and quality problems in irrigated agriculture. Sustainable irrigation and drainage systems are needed in arid and humid areas to minimize environmental impacts on agricultural, urban, and ecological sectors. Databases will be developed to improve irrigation and drainage practices and management systems.

Water Quality Protection and Management. New and improved strategies are needed to reduce water contamination from agricultural lands. Improved technologies are required to manage agricultural chemicals (fertilizers and pesticides) and waste waters (agricultural, municipal, and industrial effluent waters) and to transfer specific farming management systems from one geographical area to another. Field practices will be developed to reduce impacts of nutrients, pesticides and other synthetic chemicals, pathogens and other bacterial contaminants, sediments, salts, trace elements, and water temperature in surface waters and groundwaters. Monitoring and research efforts will be increased to protect coastal ecosystems and implement TMDL guidelines for nonpoint source water quality improvements. New management practices and management systems should be developed that expand upon the Management Systems Evaluation Areas and Agricultural Systems for Environmental Quality sites. Models and decision support systems will be developed that optimize strategies to manage water resources; to resolve conflict among competing water demands when the supplies are limited; and to determine the socioeconomic and environmental impacts of proposed water, nutrient, and pesticide management programs and policies. Databases should be developed to demonstrate on-farm and off-site opportunities to improve water quality.

Previous Customer Workshops and Research Priorities

Each of the three components in NP 201 held workshops in 1998 and 1999 to focus the research program and to learn problems and needs of customers, stakeholders, and partners. These workshops helped ensure that our research components and projects were relevant to the concerns of our constituents. Approximately 200 participants attended these planning workshops, including producers, commodity group representatives, industry representatives, public interest group representatives, scientists from universities, and scientists and administrators from ARS and other Federal and State agencies. The workshop participants recommended that protecting, preserving, and enhancing the water resource should be a key focus and target of this national program. They provided many suggestions on how this program could be improved. They also recommended that an overall fundamental understanding of water quality and quantity properties and processes would allow development of water quality and management practices to ensure sustainable food, feed, and fiber production while protecting and enhancing the environment.

NP 201 addresses 9 of the 14 high priority issues related to the USDA NRCS science and technology needs as indicated in bold in Table 2 and 19 of the 27 high priority research issues, listed in Table 3, related to water availability and water use listed in two recent reports by the Water Science and Technology Board of the National Research Council (NRC 2001, 2004). The ARS does not perform research on water institutions and water law that were also listed in the NRC reports.

Table 2: NRCS High Priority Needs Identified in 2002

1	**Effects of conservation practices related to nutrients and pathogens from land applications and farm runoff ****
2	The role and effectiveness of conservation practices for particulate matter and/or odor control related to animal feeding operations
3	**Environmental or public benefits related to conservation practices**
4	Nutrient removal/harvesting from animal waste
5	**Groundwater contamination from animal waste and seepage measurement associated with wastewater holding facilities**
6	**Efficiency of vegetated filter areas in removing nutrients, pathogens, and suspended solid**
7	**Acceptable and scientific basis for tests in determining thresholds for nitrogen and phosphorus**
8	Identify new forage, crop varieties, and other vegetative means that remove large amounts of phosphorus from the soil
9	Causes and effects (including health impacts) of gaseous emissions and/or greenhouse gases
10	**Rehabilitation of aging flood control dams**
11	**Relationship and restoration of upland riparian and floodplain processes that contribute to improve aquatic habitats**
12	**Stream corridor restoration design**
13	**Impacts of subsurface tile drainage on water quality**
14	Opportunities for specialty crops from the forest and agroforestry lands

*** Bold items represent priorities addressed by ARS.**

Table 3. Water Science and Technology Board of the National Research Council (NRC 2001, 2004) High Priority Research Needs.

I. WATER AVAILABILITY

1	**Develop new and innovative supply enhancing technologies ****
2	Improve existing supply enhancing technologies such as wastewater treatment, desalting, and groundwater banking
3	Increase safety of wastewater treated for reuse as drinking water
4	**Develop innovative techniques for preventing pollution**
5	**Understand physical, chemical, and microbial contaminant fate and transport**
6	**Control nonpoint source pollutants**
7	**Understand impact of land use changes and best management practices on pollutant loading to waters**
8	**Understand impact of contaminants on ecosystem services, biotic indices, and higher organisms**
9	Understand assimilation capacity of the environment and time course of recovery following contamination

10	Improve integrity of drinking water distribution systems
11	**Improve scientific bases for risk assessment and risk management with regard to water quality**
12	**Understand national hydrologic measurement needs and develop a program that will provide these measurements**
13	**Develop new techniques for measuring water flows and water quality, including remote sensing and in situ**
14	**Develop data collection and distribution in near real time for improved forecasting and water resources operations**
15	**Improve forecasting the hydrological water cycle over a range of time scales and on a regional basis**
16	**Understand and predict the frequency and cause of severe weather (floods and droughts)**
17	Understand recent increases in damages from floods and droughts
18	**Understand global change and its hydrologic impacts**

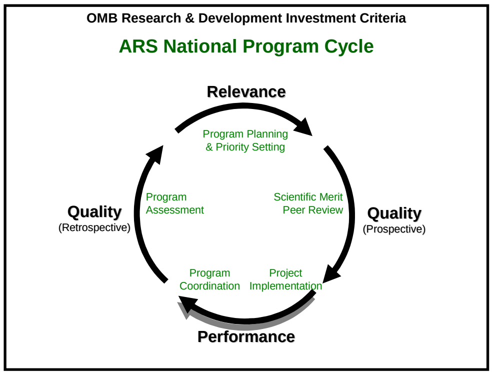
**** Bold items represent priorities addressed by ARS.**

II. **WATER USE**

1	**Understand determinants of water use in the agricultural, domestic, commercial, public, and industrial sectors**
2	**Understand relationships between agricultural water use and climate, crop type, and water application rates ****
3	**In all sectors, develop more efficient water use and optimize the economic return for the water used**
4	Develop improved crop varieties for use in dryland (rainfed) agriculture
5	**Understand water-related aspects of the sustainability of irrigated agriculture**
6	Understand behavior of aquatic ecosystems in a broad, systematic context, including their water requirements
7	Enhance and restore of species diversity in aquatic ecosystems
8	**Improve manipulation water quality and quantity parameters to maintain and enhance aquatic habitats**
9	**Understand interrelationship between aquatic and terrestrial ecosystems to support watershed management**

****Bold items represent priorities addressed by ARS.**

NP 201 Program Planning Cycle

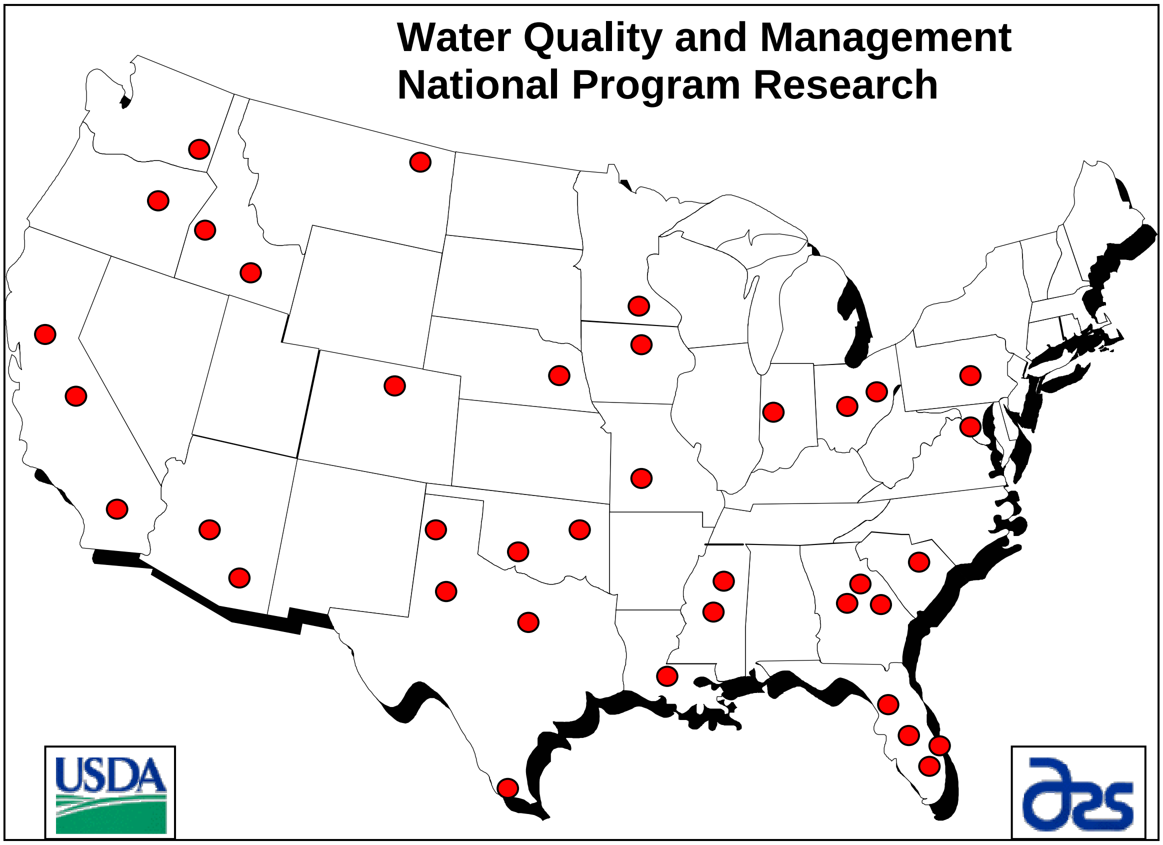


Teams of ARS scientists worked with members of the National Program Staff to develop an Action Plan that provided the framework for ARS research for the first five-year period (2000 through 2005). Each of the three components contained numerous problem areas. Groups of ARS scientists at each of the locations wrote project plans that described the research they would conduct, the anticipated products or information to be generated by the research, roles and responsibilities of ARS scientists and their cooperators, and timelines and milestones to measure progress toward achieving the goals of the research. All the project plans were reviewed for scientific quality in a process managed by the ARS Office of Scientific Quality Review in 2000 and early 2001 by three panels of non-ARS experts in the field. ARS scientists used input from this panel to revise and improve their planned research. The ARS locations working in the different component areas under the current Action Plan are listed in Table 1. Also, a map of the 38 locations is shown in Figure 1.

As depicted in the diagram on this page, NP 201 is now nearing completion of its first 5-year cycle. The ARS NP 201 team has the responsibility for outside review to assess the research program and assure other State and Federal agencies that our research impact is of the highest quality. To accomplish this task, an external panel has been asked to assess this national program from a retrospective point of view. The panel is composed of a chair and members drawn from users of ARS research, including industry, action agencies, universities, farmers/ranchers/ and NGOs.

The National Program Staff, based on recommendations of the scientists working in NP 201, contracted with a panel chair to manage the assessment of impact of this national program. The panel chair is responsible for selecting and assembling an expert panel of scientists, action agency personnel, and producers to evaluate the impact of ARS research accomplishments based on the summarization of accomplishments provided by ARS scientists. The main accomplishment report was designed around the 12 key outcomes that ARS had committed to working on when the NP 201 Action Plan was first initiated in 2001. Here selected accomplishments, drawn from the collective work of ARS scientists, are summarized and highlighted. More detailed documentation of the accomplishments is provided in 3 attached appendixes. Again, teams of scientists worked to develop these exhibits. For all three components, accomplishments, impacts, and example references are provided according to the 19 problem areas being addressed in this national program. In addition, the references cited in the appendixes are available for the panel to review if desired during the panel meeting. Input from the NP 201 assessment panel, partners and customers, and directives from the Department of Agriculture will be discussed at the upcoming NP 201 Assessment and Customer Workshop to be held June 7-10, 2005, in Denver, Colorado.

Figure 1. Location of ARS Water Quality and Management National Program Research Locations



Current NP 201 Assessment Process

The NP 201 assessment panel is asked to review and evaluate the impact of ARS accomplishments in response to the 12 outcomes that were initially proposed in the Action Plan and to offer suggestions for future ARS research direction and emphasis. The following questions are being asked to determine the impact or anticipated benefits of the research to end-users, scientific communities, and/or the broader society:

- Were major water quality or water availability problems ameliorated, mitigated, or solved?
- Were new conservation, restoration or water management practices developed or validated?
- Has the research demonstrated improvements in water use, water availability, water quality, or related environmental quality indicators?
- Were new decision support systems developed and adopted by users?
- Has the research resulted in or is likely to yield economic or environmental advantages for producers?
- Did the research contribute to the development and/or implementation of regulations or environmental criteria used by Federal and State agencies or others?

- Has the research resulted in technology that has been patented or licensed, and if so, has it led to commercialization?
- Did the research fill a critical gap in knowledge/theory and did it influence or impact other scientists conducting research in the same or some related scientific fields?
- Have new or improved scientific methods or technologies been developed by ARS and adopted by others (e.g., producers, commercial vendors, action agencies, and/or other scientists)?

It is anticipated that the expert panel's assessment will help ARS to answer the following questions:

- Are there significant, agriculturally related, water quality and quantity problems that are not being addressed?
- Are research efforts devoted to questions that would be (or are being) better addressed by other institutions?
- Are the links with other, water-related, research institutions adequate to reduce redundancy and ensure sound science?
- Are the links with stakeholders and end users adequate to ensure that the research is focused on high priority problems and that results are actually used to improve water quality or quantity?
- Is there a good balance between short-term and long-term research?
- Is there a good balance between fundamental and applied research?
- Is the quantity of research accomplishments in line with the research investment?

To assist the NP 201 assessment panel, the following two questions will be asked at the customer workshop to be held in Denver, Colorado, in June 2005:

- Was a critical gap in knowledge/theory or a specific technology, method, tool, or management practice developed by ARS that has provided significant benefit to producers, action agencies, and/or other scientists?
- How can ARS enhance the impact or performance of a specific technology, method, tool, or management practice in the next 5 years?

The entire assessment process will provide the necessary information for ARS to design its research effort for the next five years to ensure it is focused and effective at addressing the problems of today and those that will emerge over the next 5 to 10 years.

Output Summary for NP201 from 2001-2004

Table 4 provides documentation of overall activity by component area. This table documents the total number of peer-reviewed manuscripts, technical reports, and technology transfer documents that ARS scientists have written over the last 4 years. In addition, the number of invited keynote presentations at technical conferences and symposiums by ARS scientists is documented. The panel is also presented with the number of patents filed and Cooperative Research and Development Agreements (CRADAs) that ARS has initiated with private industry to commercialize inventions or technology concepts developed by ARS scientists.

Table 4. Water Quality and Management National Program Component Outputs for 2001 through 2004

	Peer-Reviewed Publications	Technical Reports[1]	Technology Transfer Documents[2]	Invited Presentations[3]	CRADAs[4]	Patents	Graduate Students Mentored	Postdoctoral Associates Mentored	Extramural Grants Funded[5]
Watershed	484	22	69	167	1	0	65	26	92
Irrigation and Drainage	557	86	201	340	8	4	91	33	96
Water Quality	547	76	145	294	8	2	91	39	70
Totals	**1,588**	**184**	**415**	**801**	**17**	**6**	**247**	**98**	**258**

[1] Reports developed by ARS in response to extramural funding or published by ARS in terms of model user or scientific documentation of models.
[2] Documents prepared as an ARS bulletin, fact sheet, a popular journal article, an ARS magazine article, etc.
[3] Papers (not abstracts) prepared for conferences or symposiums, e.g. papers that were distributed as handouts or on CD's as proceedings at conferences or symposiums.
[4] Cooperative Research and Development Act (CRADA) agreements relate to the Federal act that facilitates transfer of research to the private sector. CRADAs are often a step in transferring patentable results or technologies to the private sector, but not all CRADAs involve patents.
[5] This column represents the number of cooperative and other agreements where the scientists received extramural funding. Some of this extramural funding may have existed for only a single year.

Over the last 4 years, ARS scientists have published 1588 peer-reviewed papers, 184 technical reports, and 415 technology transfer documents. They have also given 901 invited presentations, developed 17 new CRADAs, obtained 6 patents, and mentored over 247 master and doctorate level graduate students. In addition, there were 98 Research Associates (Post-Doctoral candidates) that were funded, and 258 competitive grants awarded to ARS scientists involved in this national program. These extramural grants were used to accelerate the development and delivery of tools, techniques, and decision support systems to improve and enhance ecological sustainability of the Nation's watersheds and the quality and quantity of water emanating from agricultural lands.

Key Accomplishments/Impacts of the Water Quality and Management Program from 2001-2004

Agricultural Watershed Management Component

Outcome #1: Reliable characterizations of agricultural watersheds that determine the temporal and spatial characteristics of important hydrologic variables.

ARS scientists over the last 4 years have made great progress in utilizing a variety of remote sensing technologies to improve our scientific understanding of the hydrologic cycle and in developing tactical tools for applying this new information to meet a wide array of customer needs. Listed below are selected examples of recent accomplishments that demonstrate the breath and depth of ARS research that is focused on improving our knowledge before important hydrologic variables in agricultural watersheds. A more comprehensive listing of accomplishments is provided in Appendix A.

<u>Precipitation variations quantified for regions of the Great Plains.</u> Over the last decade over one-half of the U.S. has been in persistent drought at least once during the decade. USDA drought relief programs have allocated billions of dollars to help cope with this natural disaster. ARS scientists are looking for ways in which those affected may mitigate or better cope with the erratic nature of precipitation. Analysis of the rainfall records over the Great Plains by ARS scientists has revealed decade-long oscillations in annual precipitation. The characteristics of these variations were characterized for nine broad regions in the Great Plains. Results show that in the final decades of the 20th century, the majority of the Great Plains experienced the largest and longest (up to 20 years) increase in precipitation over the past 105 years. These findings have important implications for agriculture and rural communities because of their potential impact on the future productivity of agriculture in these regions and the potential for meeting the water requirements of these rural communities. Research was also done to determine the variations in monthly, seasonal, and annual precipitation where the variation between locations was found to be significant. This research showed that the ability to predict precipitation values at some specific location remains quite limited and cannot be improved without additional research.

<u>Monitoring soil moisture throughout the world.</u> Scientists from NASA, NOAA, NRCS, and universities have joined ARS scientists in designing and testing satellite systems that will one

day be able to monitor and map global soil moisture and evapotranspiration. The sensors require an antenna that looks like an umbrella or a satellite dish. The equipment functions like a mirror, constantly reflecting radiation emitted from Earth onto sensors that measure the strength of the radiation using microwave signals emitted from soil. The ARS scientists have developed and tested the equipment and methods to be used for new satellite systems called the Hydrosphere State Mission (HYDROS) and the Advanced Earth Observation Satellite (ADEOS) that NASA plans to launch by the end of the decade. Based on the success of the current research thrusts by ARS scientists, NASA has decided to continue to develop the Hydrus satellite. In addition, NASA has provided funds to ARS for a multiyear project to operationally map soil moisture in the southern region of the United States.

U.S. Army using remote sensing to estimate real-time soil moisture. To meet the needs of the U.S. Army for an accurate method to determine real-time estimates of surface soil moisture to help it plan and execute its missions in arid and semi-arid regions of the world, ARS scientists developed a method for rapidly and accurately estimating soil moisture. The ARS scientists developed a new and simple remote sensing technique of image differencing in part by using data from the long-term highly instrumented ARS Walnut Gulch watershed. This new procedure was found to be superior to the more complex and expensive model currently used by the U.S. Army because it can more accurately account for the rock content commonly found in desert soils.

Water use can be estimated using remote sensing technologies. ARS scientists and partners have also developed satellite-based technologies for measuring and mapping of evapotranspiration, a critical element of hydrologic and atmospheric processes. Using the soil moisture, evapotranspiration, snow pack, and land surface roughness measurements obtained from microwave, thermal, LIDAR and optical remote sensing instruments, ARS scientists have documented how a limited number of ground based point measurements can be successfully scaled up to provide accurate estimates of regional evapotranspiration, which is a critical biophysical process that USDA must be able to monitor and predict to successfully fulfill its mission of drought preparedness, mitigation, and relief that is needed by NRCS, USBR, and private consultants.

Outcome #2: Safer and more cost-effective measures for protecting farms, ranches, and rural communities from ravages of floods and droughts, and from rising demands on the nation's limited water resources.

ARS scientists are working with a variety of partners to enhance our understanding in predicting seasonal precipitation amounts and spatial and temporal distribution during a rainfall event to provide early warning of floods and droughts and to provide timely tactical information to the agricultural community for use in determining what crops to plant based on the probability of seasonal precipitation amounts. Listed below are selected examples of recent accomplishments that demonstrate the breath and depth of ARS research that is focused on improving our communities from the ravages of floods and droughts in agricultural watersheds. A more comprehensive listing of accomplishments are provided in Appendix A.

Doppler radar system improved for use in the Northwest. The National Weather Service operates the NEXRAD Doppler radar system at more than 150 sites across the nation. The National Weather Service uses a computer model to convert radar reflectivity to precipitation estimates for use in river forecast models and weather hazard assessment. ARS scientists found that the original methods used by the National Weather Service under-estimated rainfall by 25 to 60 percent compared to measured precipitation data from six of the ARS highly instrumented experimental agricultural watersheds. ARS scientists developed a new method to predict precipitation from the available radar data that significantly improved the spatial estimate of precipitation. Based on the research findings from the ARS watershed program, the National Weather Service reprogrammed the radar system in 2004 and determined that the ARS derived technique has greatly improved the accuracy and precision of rainfall estimation. The new and improved model will enable the National Weather Service to make better radar-precipitation estimates from its NEXRAD radar locations.

New techniques developed for seasonal precipitation forecasts developed for NOAA's Climate Prediction Center. Any reliable signal in precipitation forecasts will potentially reduce uncertainty and associated management risks in agricultural and water resource management, and identify windows of opportunity for favorable conditions. In the past, seasonal forecasts by NOAA's Climate Prediction Center have varied significantly by location, season, and state of the El Niño – Southern Oscillation (ENSO). ARS scientists developed practical assessment methods for scaling of the forecasts to specific applications (e.g., streamflow, erosion potential, crop production). The new technique will allow NOAA to disaggregate 3-month overlapping forecasts into monthly values. A number of demonstration projects are now underway within various divisions and offices of NOAA, including the Climate Services Division and National Weather Service Forecast Office.

Predicting climate conditions depends on identifying and understanding slowly developing and persistent climate variation. To detect such variation over the continental U.S. and important U.S. growing regions, a unique statistical analysis method was developed to identify intra-to multi- decadal (IMD) variation in rainfall, streamflow, and temperature in the historical record. This method and a parallel study of past climate conditions over the Pacific Ocean showed the influence of the El Niño–Southern Oscillation and Pacific Decadal Oscillation in both sustaining the 1950's drought and ending the droughts of the 1930's and 1950's. It also showed evidence of significant U.S. climate change at the end of the 20th century. The incidence of nationally wet and warm years in recent decades is highly inconsistent with typical climate variation, but is consistent with the increased surface warming and stronger hydrological cycle expected to accompany greenhouse warming. As a result, this research supports the idea that the first effects of that warming may be already apparent over the continental U. S. These results have been published in the scientific literature and reported to various subcommittees within the Executive Office of the President, Office of Science and Technology Policy.

Variability of dry periods between storms mapped for part of the Great Plains. ARS scientists have developed a storm generation model (StormGen) that simulates storm occurrence, duration, and precipitation intensities within the rainfall event. StormGen can be used with other watershed models to show how various agricultural practices might impact surface and subsurface water movement in areas where no precipitation records exist. A "critical duration"

(CD) parameter for characterizing minimum dry times between storms was mapped over a 225,000 square kilometer 87,000 square miles (55.6 million acres) area east of the Rocky Mountains covering parts of Wyoming, Colorado, Nebraska, and Kansas. The monthly mapped CD values provided the most accurate estimates of CD, which is highly variable from month to month and from location to location. The results of this study have led to further successful studies, which have more completely quantified the time between storms. StormGen should improve groundwater and runoff modeling, better estimates of peak flood flows, improved characterization of droughts, and better erosion-control designs by Federal and State agencies, university scientists, and private consultants.

Outcome #3: Improved technologies to better manage riparian areas, wetlands, aquatic ecosystems, and stream corridors for the protection of agricultural watershed health and prevention of water quality degradation.

ARS scientists over the last 4 years have concluded many seminal studies on the environmental benefits of developing and managing buffers for improving and protecting the quality of the nation's aquatic ecosystems that originate on agricultural watersheds. Also, listed below are selected examples of recent accomplishments that demonstrate the breath and depth of ARS research that is focused on improving our knowledge on managing and protecting our nation's riparian corridors. A more comprehensive listing of accomplishments is provided in Appendix A.

<u>Grass buffers reduce sediment transport and leaching of herbicides to groundwater.</u> Previous studies by ARS have documented the effectiveness of stiff grass hedges and grass buffers in reducing sediment transport from farm fields to streams and lakes. The results of this research are that both stiff grass hedges and grass buffers are now approved best management practices. Information on the practices is available in the NRCS field office technical guide. These practices qualify for cost sharing through various USDA, USEPA, State, and non-profit conservation programs. New research by ARS has documented that grass buffers can also reduce the amount of an herbicide (such as atrazine) being carried to the stream, but little information was available on the leaching or degradation of the herbicide after it enters the buffer. Investigations on the fate of the more common herbicides in these grass buffers were conducted in Iowa. Switchgrass buffers tended to decrease the leaching of atrazine to the groundwater more effectively than big bluestem and eastern gamagrass. The switchgrass buffers tended to decrease leaching of atrazine to the groundwater by about 50 percent compared with the adjacent cropland. Although some leaching of the herbicide occurred in all grass buffers, more atrazine was retained or degraded in all grass buffers than in the nearby field being cropped with no conservation practices. A possible reason for the increased effectiveness of the grass buffers is that the decomposing root system increases the soil's ability to bind atrazine. ARS is conducting additional research across the Nation by using its watershed network to verify this work under various climate and soil conditions. When completed, this work will be incorporated into the agency's Riparian Ecosystem Management Model that has previously been delivered to NRCS, USEPA, and private consultants for use in designing and maintaining natural and man-made buffer systems.

Designing the best possible conservation buffer. Vegetative, or conservation, buffers that include trees or forests can serve many different purposes all aimed at the same goal – cleaner water. ARS scientists in partnership with university scientists in the Southeast have recently completed a 9-year study to determine whether restored conservation buffer zones in wetlands next to agricultural fields can reduce the amounts of phosphorus and nitrogen that reach streams. These studies showed that the restored riparian wetland buffer retained or removed at least 60 percent of the nitrogen and 65 percent of the phosphorus that entered from the adjacent manure application site. Additional studies have found the buffers can be an effective way to prevent harmful bacteria from manure applications, like *Escherichia coli* 0157:H7 and *Salmonella*, from reaching streams and contaminating drinking water supplies. ARS scientists in the mid-Atlantic region have led additional studies on how such pathogenic organisms can spread into the environment and whether grass buffer strips will filter them out. To date, grass buffer strips were far more effective at filtering out manure-borne pathogens then expected. The buffers stopped at least 90 percent of all the water runoff and almost no bacteria left the highly-instrumented field and entered surface water systems. However, macropores, which are created by animals burrowing through the soil or by cracks in the soil that occur in drier years, can pose a problem. These large holes, or macropores, alongside the streams can act as a bypass, such that contaminants can travel beneath the buffer and directly into the streams through seeps and springs. Additional work is now being conducted to provide risk assessment tools to predict when these bypass conditions may occur and mitigation technology to address the problem when it has been identified.

Managing buffer systems for multiple uses. Although conservation buffers are not a magic bullet, it has become clear that trees or forests must be part of the conservation buffer system if nitrogen and phosphorus and other pollutants are going to be effectively removed. Novel research being conducted by ARS scientists in the southeastern U.S. has demonstrated that forested areas can be managed with long-term strategies to provide wood products or biofuels while maintaining water quality. TMDL assessments in the Suwannee River Basin of Georgia and Florida have indicated a need for nitrogen nonpoint source pollution reduction from agriculture. Forested lands adjacent to agricultural fields have been shown to reduce nitrogen concentration of water moving from the fields to adjacent streams and waterways. ARS researchers determined that forested zones bordering agricultural fields could be harvested for lumber, fuelwood or pulpwood and still function as filters for groundwater nitrate reduction. An additional benefit of trapping nutrients in buffers is that this unintentional fertilization has been documented to increase growth rates of forested riparian buffers in the mid-Atlantic region. This accelerated growth process also increases the rate of storage and sequestration of carbon, which may provide for additional economic benefits to producers when carbon credits and carbon trading programs are fully implemented and operational.

Stiff-grass hedges can halt soil erosion caused by flowing water. Narrow, parallel rows of stiff-stemmed grass should be planted along the steep hills. Although this can be a valuable conservation tool, little data on their hydraulic behavior are available to address under what hydrologic conditions they might fail. ARS scientists determined when grass hedges are likely to fail during a flood event and what is the survivability of these systems after flooding has occurred. In addition, ARS scientists compared two types of stiff-grass hedges: switchgrass and eastern gamagrass. Switchgrass proved better adapted to flooding than gamagrass. Switchgrass held back sediment and water until the water ponded upstream to a depth of 0.4 to 0.6 meters (1.4 to 1.6 foot). Switchgrass also recovered better than gamagrass from the previous years flooding. NRCS, FSA, USEPA, Federal and State agencies, university scientists, and private consultants are currently addressing multiple resource concerns or issues by using conservation buffers.

Tiny crustaceans help to measure water quality. The thought of tiny crustaceans in your water may seem disgusting. However, ARS researchers have found a whole lot of healthy critters in surface waters - especially if they're *Hyalella azteca*. ARS scientists have been leading the way in developing a simple and inexpensive biological indicator of good quality water using crustacean counts. The 0.3 to 0.6 centimeters (1/8-to-1/4 in) long crustaceans are commonly found in lakes, ponds, and streams throughout North America. Monitoring water quality through chemical and physical measures reveals the effects of improved conservation farming practices. However, the use of hyalella as a biological indicator will confirm whether these practices have actually improved the overall health of the ecosystem for fishing or swimming at a fraction of the cost of traditional biophysical monitoring approaches. USEPA, Federal and State agencies, university scientists, and private consultants are currently using this technology as an indicator of water quality health.

Outcome #4: Improved structures and channels for storing and regulating water supplies for flood control, water conservation, and reducing erosion and sedimentation.

ARS has the principal responsibility to develop technology and tools for use by the Natural Resources Conservation Service in designing and implementing flood-control structures that USDA sponsors. Listed below are selected examples of recent accomplishments ARS scientists and engineers over the last four years in providing tools to cost-efficiently rehabilitate aging flood-control structures and novel approaches for reducing channel degradation. A more comprehensive listing of accomplishments provided in Appendix A.

Techniques for rehabilitating aging hydraulic structures. In 2001 ARS released the SITES 2000 Water Resource Site Analysis Program to NRCS for use in designing and evaluating earthen flood-control structures. Over the past half century, the USDA has assisted in the construction of approximately 11,000 flood control dams that presently provide $1.7 billion dollars of benefits annually. These structures were constructed with help from USDA under PL-534, PL-566, and Resource Conservation and Development groups. An example of the scope of the national problem is typified by the State of Oklahoma where approximately 460 of the 2,100 flood control structures will reach the end of their planned service life by 2010. Structures that were originally designed to protect agricultural land now protect lives, homes, and businesses as a result of urban development in the flood protected areas. Because of these changes, many of these aging structures do not meet current standards and some form of rehabilitation or modification of the structure is urgently required. The SITES 2000 model was developed to assist NRCS in evaluating the safety of aging earthen flood-control structures mandated by Congress through the enactment of the Small Watershed Amendments of 2000 (PL-106-472, Section 313). The USACE and State dam safety engineers also utilize the SITES 2000 model to complete their missions in designing, regulating, and inspecting earthen dams. The model is available to the public through a web site maintained by NRCS and is supported by ARS scientists.

New technologies developed to characterize sediment found in flood-control structures. New legislation directed toward the rehabilitation of aging dams and other hydraulic structures has forced the examination of problems associated with decommissioning aging hydraulic structures. Many of the nation's 11,000 flood-control structures built by NRCS are being adversely affected by sediment buildup, which reduces a reservoir's ability to hold back floodwaters. ARS has developed acoustic and geophysical technologies and procedures for characterizing the quality and quantity of the sediment impounded in such structures, based on tests conducted on flood-control structures that are typical of western conditions. NRCS is now using these technologies for assessing, rehabilitating, and decommissioning aging hydraulic structures without adversely affecting the environment and downstream aquatic ecosystems.

The nation's number one pollutant is sediment. ARS scientists have developed a low-cost means of reducing gully and stream bank erosion, one of the major causes of soil loss and sedimentation within our nation's streams. Traditional measures for controlling this type of erosion require costly stone or concrete structures. The large woody debris structures, being studied by ARS scientists, provide shelter for fish and insects, restore riparian habitats, and cost less than traditional methods. The structures consist of uprooted trees stacked in crossing layers, and are anchored with steel cables to the streambed. The structures reduce sediment transport, triggering natural deposition to heal channels enlarged by years of erosion. The structures cost about $82 per meter ($25 per foot) of treated bank, or 20 to 50 percent of the cost of recent stone bank-stabilization projects in the region. This technology has been transferred to the Corps of Engineers and is being implemented in several badly eroded watersheds in the Southeastern U.S.

Measuring streambed erodibility. There has been no established or accepted procedure for measuring streambed erodibility. A jet test device suitable for measuring streambed erodibility in the field or laboratory was developed and patented by ARS scientists. Procedures for use and interpretation of results were also developed. This device is now being used to evaluate stream channel stability for optimum cost-effective placement of stream stabilization measures in the Southeastern region of the United States. This technology is being used by primarily NRCS and USACE to help determine when large woody structures can be safety implemented or when the more traditional and costly concrete and rock structures are required.

Outcome #5: Improved strategies that enhance and safeguard the amount and quality of water supplies used for rainfed crop production and livestock production on rangelands and pasturelands.

ARS has been the principal agency responsible for developing strategies and tools to predict soil loss on rangelands and croplands for the last 50 years. ARS scientists have recently released a series of new enhancements to improve our ability to accurately predict soil loss and prevent the degradation of riparian corridors by grazing livestock. List below are selected accomplishments that document how we are continuing to improve water resources on rainfed crop production and livestock production, including more dependable drinking water for grazing livestock. A more comprehensive listing of accomplishments are provided in Appendix A.

New tool reduces risk of soil erosion on forestlands. ARS scientists have worked together to develop new technology to assist the U.S. Forest Service (USFS) in predicting surface runoff and soil erosion rates that result from both wild and prescribed fires in western ecosystems. This research is now helping the USFS Burn Areas Emergency Rehabilitation teams decide where and when emergency funding is needed to reestablish vegetation or install physical structures for protecting the environment, streams, human life, property, or infrastructure from the ravages that are caused from flooding or soil erosion on public and private lands. The enhanced Water Erosion Prediction Project (WEPP) tool is available to USFS and other land managers via an interactive internet-based decision support system maintained by the USFS in Moscow, Idaho.

Grazing cattle on lands where groundwater was once polluted. ARS scientists recently concluded that cattle can be grazed on pastures that overlie shallow contaminated aquifers without fear of additional contamination from the nitrogen in cattle waste. The secret is to minimize or eliminate nitrogen fertilization on the pastures for at least 2 years before resuming cattle grazing to allow the system to come back into equilibrium. Using this management practice, ARS scientists found that the nitrate-nitrogen in groundwater was brought down from a high of 26 mg/L (26 ppm) to 2-4 mg/L without any impact on livestock health or performance. When livestock grazing was resumed, the nitrogen concentrations in the water were maintained below 10 mg/L, the USEPA guidelines for human drinking water. The key is to the timing and amount of fertilizer being applied to the pasture. NRCS, USEPA, and USBLM are the primary users of this information.

Erosion tool used to evaluate the effect of tillage. Upland soil erosion and sediment in the nation's rivers and lakes is the single greatest pollutant/impairment that requires a stream reach to be listed as not meeting TMDLs set by USEPA. To help control soil erosion ARS scientists developed the Revised Universal Soil Loss Equation (RUSLE) model. The RUSLE model is the most universally utilized soil erosion prediction tool in the world. The ARS scientists in Pullman, Washington, conducted research to modify and enhance the RUSLE model to account for interactions of crop management with soil freezing and thawing conditions. They found that low growing crops with a horizontally displayed canopy near the soil surface had a greater reduction of soil erosion than did a vertical standing crop canopy. Based on these results, new methods of calculating erosion reduction and water quality benefits from different crop types were included into the RUSLE model improving its effectiveness in evaluating alternative cropping systems for the Pacific Northwest region. NRCS and USEPA have provided this information to their technical specialists and consultants.

Model tested for use in estimating TMDLs. All States are now required by the USEPA to set TMDL limits for the major water quality contaminants degrading streams and rivers. Mathematical models are being developed and tested for performance and reliability as prediction tools to assist with these activities. A hydrology/water-quality model developed by USEPA [Hydrologic Simulation Program Fortran (HSPF) model] was calibrated and validated for claypan soil conditions by ARS scientists in, Missouri. The results of this research have been transferred to the Missouri Department of Natural Resources and are being used by them as they develop TMDLs for Missouri. Although these calibration factors will need to be verified for other soil conditions, other states now have the opportunity to follow a well-established scientifically defensible method of calibrating the HSPF model. This should reduce the time and expense of developing TMDLs in other regions of the country, directly benefits NRCS, USEPA, and private consultants throughout the Midwest.

A low-cost solar pumping system developed for livestock watering. Farmers and ranchers need a reliable, low-cost means of pumping water for cattle or other livestock on remote rangelands. Commonly used solar panels degrade at about 15 percent per year. Data collected by ARS scientists in the Southwest found that amorphous-silicon panels, pumps, and controls did not degrade over a 5-year period. At the same time, the amorphous-silicon panels cost about two-thirds what the thin-panels cost. This is an extremely cost-effective method to develop alternative water supplies that do not require access to riparian areas, which is a major concern of land managers across the Nation. By providing alternative water sources to livestock away from riparian areas, this water pumping system will reduce the environmental impact in riparian systems and improve water quality within streams and lakes. Several pumping companies are currently manufacturing and distributing technologies based on this work.

Irrigation and Drainage Component

Outcome #6: More water-efficient methods and farming systems for producing high-value crops that reduce impacts from increased salinity and groundwater depletion while ensuring the long-term sustainability of irrigated agriculture.

ARS scientists and engineers have developed a wide range of approaches and tools for efficiently utilizing scarce water resources to improve the efficiency of agricultural production systems. These novel approaches range from developing techniques that have plants remove pollutants from irrigation return flow to systems that were installed for drainage to be used for irrigating the crop during the dry season. Selected examples of techniques and approaches developed by ARS scientists are listed below as examples of how precision agriculture can be effectively implemented. A more comprehensive listing is provided in Appendix B.

Precision irrigation and fertilizer application needs vary with soil type. Despite the promise of variable-rate water and fertilizer applications through irrigation systems, it has been difficult to recommend precision irrigation or site-specific management technologies because of limitations in our understanding of responses on variable soil types. A center-pivot irrigation system at Florence, South Carolina, was used to test corn's response on a typical Coastal Plain field. Corn production rose with irrigation water (as expected) and increased nitrogen (N) fertilizer (but slightly less than expected). But most important, the responses to both inputs were markedly different for different soil types. The findings show that site-specific fertilizer recommendations should be based on direct measurements of soil response, rather than on estimates of soil variability. This approach can both improve on-farm economics and protect water quality. Users of these findings include farmers, irrigation company representatives, and private consultants.

New sensors tested for precision application of water and fertilizer. Yield-reducing crop stresses are routinely identified using remotely sensed data. Detection accuracies need to be improved early in the season when management options can be more effective. Researchers in Arizona designed and built a prototype sensor for a linear-move sprinkler irrigation system. The sensor's data were used to develop a new canopy chlorophyll content index and refine an existing crop water stress index, which together enabled the separate detection of water and nitrogen deficiencies. The two indices were successfully tested in multiple years for improved fertilizer and water application in cotton production. Similar research was conducted in Nebraska, to evaluate the performance of the updated chlorophyll index for its ability to operate under a variety of lighting conditions while monitoring crop stresses. Sensors were evaluated in Brazil and the United States on corn at various growth stages and different levels of nitrogen fertilization. These sensors were modified and found to compensate for changing light intensity and to monitor crop greenness, which is highly correlated to crop nitrogen and grain yield in most cases. The ability to convert remotely sensed data into treatment maps for fertilizer applications on irrigated and dryland conditions, and for irrigation water applications, provides agricultural producers with a powerful and cost-effective crop management tool. Farmers, irrigation company representatives, and private consultants are beginning to use remotely sensed data for improving water quality.

A remotely sensed nitrogen index can reduce nitrogen applications. Irrigators want to reduce nitrate contamination of ground and surface water supplies and, at the same time, need techniques that increase the efficiency of nitrogen (N) fertilizer use beyond current best management practices. A remotely sensed index (Nitrogen Reflectance Index calculated from crop reflectance in the green and near-infrared light spectrum) was evaluated to detect plant N deficiencies and recommend in-season N applications for a sprinkler-irrigated cornfield in eastern Colorado. The N applied by fertigation during the growing season totaled 105 kilograms per hectare (94 pounds per acre) from four applications on the remotely sensed portion of the field; the farmer applied a total of 144 kilograms per hectare (129 pounds per acre) in six applications on the remainder of the field. Average grain yields for the remotely sensed area and the remainder of the field 4,400 and 13,800 kilograms per hectare (214 and 205 bushels per acre), respectively. The new nitrogen management technique reduced applied N by 16 kilograms (35 pounds) and input costs by more than $14.80 per hectare ($6 per acre). Farmers, irrigation company representatives, and private consultants are beginning to use remotely sensed data for improved nitrogen fertilizer management for irrigated agriculture.

Crop production functions lead to improved irrigation management for humid areas. Crops of the southeastern U.S. Coastal Plain frequently suffer from drought, and uniform applied irrigation water amounts can result in or insufficient soil water conditions. ARS scientists in South Carolina, developed soil-specific irrigation production functions for corn on 12 different soils using a site-specific center pivot irrigation facility that imposed contrasting degrees of water stress. Inexpensive infrared thermometers mounted on the center pivot irrigation system were used to sense crop water stress, proving that water stress can be detected in humid environments. The production functions will be used to develop models for determining water needs for each soil type at the level of water stress measured by the infrared thermometers. This will enable real-time control of site-specific irrigation, which could be regulated by a Variable-Rate, Digitally-Controlled Fluid Metering Device, recently patented by ARS. These technologies are expected to provide the basis for more efficient irrigation management for humid areas, and several irrigation consultants are beginning to look at precision irrigation systems as a tool for increased production and environmental protection in the southeastern U.S.

Mapping of crop response results in improved water and nutrient management. Mitigating the risks of low crop yield by uniformly applying irrigation water and nutrients is often foiled by significant variability of factors affecting yield and crop response. Measurements and simulations were used to map the temporal and spatial distribution of water and nitrogen applied through irrigation water for several fields in the Great Plains by the ARS researchers. Locations of excess water application and the potential impact of these locations on chemical leaching were determined. Maps of the field, with these sensitive locations highlighted, were used to reduce irrigation water and nutrient applications for these areas, thus avoiding saturation and reducing nitrogen losses from the field. Using the above procedures, the irrigation farmer is able to increase the efficiency of water and fertilization applications on highly variable soils. Irrigation farmers, NRCS technical specialists, and private consultants are able to increase the efficiency of water and fertilizer applications on highly variable soils.

Salinity assessment technology is widely adopted. Soil salinization is a major problem, causing decreased crop production and water quality problems in irrigated lands of arid and semiarid regions of the world including the southwestern. Over the past 15 years, ARS researchers have developed technology for using electrical resistivity and electromagnetic induction sensors to measure soil salinity. Within the past 4 years, this technology was combined into a mobile platform (typically a modified spray tractor) with global positioning systems (GPS) and a computer to rapidly and remotely collect soil conductivity data with depth and spatially across a field. The information is linked to a Geographic Information System (GIS) and utilizes spatial statistics to model and map salt accumulation in soil and drainage water systems. This technology can be used to measure and map the effects of salinity on soil and water resources for areas as small as farm fields to as large as major watersheds. The work is being conducted in cooperation with the USBR, Bureau of Indian Affairs, Coachella Valley Resource Conservation District, Imperial Irrigation District, and the University of Arizona Experiment Station where a salinity assessment network has been recently deployed throughout the Lower Colorado Region. The primary end-users of this technology include technical specialists from the USBR and the Natural Resource Conservation Service along with water district personnel throughout the western. Various university extension specialists and research scientists in saline regions throughout the world, including Canada, Mexico, South America, Australia and the Middle East have adopted this technology to assist them in managing crop production systems under saline conditions.

New plants shrug off salinity. Two new lines of salt-tolerant plants from ARS scientists are proving to be a boom not only for wheat growers but also salt-laden wildland ecosystems. Salt tolerance is a prized trait in the irrigated wheat-producing regions of the American West, where irrigation can accelerate buildup of salts. The scientists are working to understand the complicated genetics of these plants including some that are relatives of wheat. These studies are key to making hardier and more nutritious feed grains and forages for livestock and wildlife such as deer, elk, and moose, as well as improved plants that could be used to revegetate rangelands, roadsides, burned sites, or erosion-prone slopes. The work has already attracted the attention of researchers and plant breeders throughout the United States, Pakistan, and many other nations with arid and semi-arid climatic conditions.

A wetland/reservoir/subirrigation system reduces sediment and nutrient loadings to streams and rivers. Researchers at Columbus, Ohio, have demonstrated that a new water management technology, called a wetland/reservoir/subirrigation system (WRSIS), can reduce off-site losses of runoff water, sediments, and nutrients to lakes and streams by as much as 80 percent. The WRSIS technology collects runoff and drainage water from subsurface pipes into a constructed wetland where it is treated and then stored in a reservoir. The water is then used in dry periods to subirrigate crops by putting it back into the same pipes used for drainage. A cost/benefit analysis of the new water management technology, based on current economic values, was used to compare operation and investment costs with benefits, including improved crop production, improved water quality, increased residual land value, decreased tax liability, and wetland mitigation payments. The results suggest that many farmers will be unable to adopt this system unless they receive a mitigation payment or subsidy for the environmental benefits. This finding has been published in a number of farmer magazines, and NRCS, USEPA, private consultants, university extension specialists are beginning to use this technology within the Midwest.

Outcome #7: Improved strategies and decision support systems that will allow irrigated agriculture to conserve water and efficiently deliver water without comprising crop production, food safety, and water quality impacts.

ARS scientists have developed a variety of tools and techniques to save water and efficiently deliver water where and when it is required. In addition, ARS engineers have developed techniques to reduce erosion and the transport of pollutions that have historically been a major concern when irrigating row crops. A few of the novel innovations and techniques ARS scientists and engineers have developed over the last 4 years are listed below. A more detailed presentation of accomplishments is listed in Appendix B.

New standards developed for estimating crop water use. Water availability and scarcity has resulted in several major disputes over water rights, both within and between States. Irrigation consumes up to 90% of water resources in some western States. Issues of appropriate use (how much irrigation water is required to grow crops in a specific region) and of water marketing require good information based on the science of crop water use. The predominant paradigm for crop water use estimates makes calculations based on a location-specific reference evapotranspiration (ET) multiplied by a region-specific crop coefficient, which changes as the crop grows. ARS scientists and engineers from California, Idaho, and Texas worked together with university researchers from several States (Arizona, California, Idaho, Nebraska, Oklahoma, and Oregon), State water agencies, irrigation districts, and private engineering consultants to develop a new standardized method for computation of the reference ET that would be based on data from many locations and on new knowledge of environmental biophysics. Also, ARS researchers determined crop coefficients for major irrigated crops in the Pacific Northwest and Southwest and related these to growing-degree days (GDDs) rather than the days since planting basis previously used. Crop coefficients adjusted by GDDs better-matched crop growth stage in both regions, which should improve transferability of crop coefficient data across locations and years. Key enhancements in both the daily and hourly reference ET methods were developed for both “tall” (like alfalfa) and “short” (like grass) reference crops. Users include water resources agencies in many States, the Irrigation Association, the Bureau of Reclamation, NRCS, private consultants, the California Irrigation

Management Information System (CIMIS), and the AgriMET network in Idaho, Oregon and Washington. The biggest success stories in the last 2 years have been the improvements made to aid farmers to wisely schedule irrigations on millions of acres in the North and South Plains ET Network in Texas and the program that is fully operational for the entire California Central Valley.

Irrigation uniformity standard developed for NRCS. Sprinkler irrigation systems are used to irrigate approximately 51 percent of the total land irrigated in 2003 in the U.S. In the 2002 farm bill, NRCS was requested to cost share on both the installation of new systems and the upgrading of existing systems under the Environmental Quality Improvement Program (EQIP). ARS and NRCS developed a new sprinkler conservation practice standard (442-1) to evaluate the performance of center pivot irrigation systems. The CPEDlite computer program was written to meet NRCS and industry requirements and specifications. Several training sessions were presented to NRCS technicians. NRCS technical service providers and industry designers have developed a program that translates the output from their design programs into the input format to CPEDlite. The adoption of CPEDlite saves a significant amount of time for the NRCS and their technical service providers in evaluating and approving proposed designs. Water conservation in NRCS targeted areas has been greatly enhanced by ensuring quality designs of sprinkler systems that are cost shared with producers to save water and reduce water pollution.

Soil moisture system that is accurate and reliable. Validation of computer models of the soil-plant-atmosphere continuum, applied to problems of irrigation efficiency and crop water use, requires detailed data on water content in the root zone. These data were not available until the advent of time domain reflectometry (TDR) methods. ARS scientists integrated a combination of hardware and software into a new TDR system that was commercialized through a CRADA (Dynamax, Inc., Houston, TX). The scientists created a supervisory control and data acquisition (SCADA) computer program to control the system and acquire data on water content and soil salinity. Soil probes and a coaxial multiplexer for switching between probes were designed, proven and commercialized. The computer program was re-designed in 2004 to allow its use in a distributed system of data acquisition computers linked through an Ethernet network. A 112-page manual was published detailing the system components, interconnections, software use, and operation in remote solar powered situations. The commercial system is in use at more than 100 university and federal research locations, including ARS, FS, and USGS. Several workshops to train researchers and technicians in the use of the system have been held by ARS. The user manual and system software are available on the Internet (http://www.cprl.ars.usda.gov/programs/).

PAM protects against pollutants and pathogens. An environmentally friendly compound nabs nutrients and troublesome microbes before they can escape from farmers' fields and make their way to ponds, lakes, streams, or rivers. Known as polyacrylamide, or PAM, this powder can keep nutrients, such as the phosphorous in manure or fertilizers, from traveling beyond the farm in irrigation runoff. Similarly, PAM helps keep diseasing-causing microbes or pathogens, like those in cow, pig, or fish manure, from being swept beyond the confines of farmyards or feedlots. Previously, PAM was shown to reduce soil losses from irrigated fields by more than 95 percent. PAM is currently being used on about 1.6 million hectares (4 million acres) of irrigated lands with technical assistance being provided by NRCS, university extension persons, private consultants, and several manufacturers and commercial companies.

Irrigation scheduling automated using plant temperatures. Traditional soil water-based irrigation scheduling methods often fail to avoid plant stress and yield reductions in the hot and windy southwestern States. ARS attacked this problem through cooperative research efforts at two laboratories in Texas and one in Arizona. Research conducted by ARS scientists in Texas determined that yield and water efficiency of soybean and corn could be maximized through use of an automatic irrigation system that uses plant temperature measurements (Time-temperature threshold, or TTT method), increasing yields up to 67%. Research conducted in Texas and in Arizona extended the technology for detecting plant stress by using non-contact plant temperature measurements from sensors mounted on moving irrigation systems. A combination of measurement improvements and modeling allowed measurements from a single spot and time in the field to be extended to give plant temperatures for the entire daylight period, a pre-requisite for successful implementation of the TTT irrigation technology throughout an entire field. At the other Texas location, the BIOTIC (Biologically Identified Optimal Thermal Interactive Console) irrigation scheduling protocol was developed using the TTT irrigation technology. BIOTIC was used to schedule subsurface drip irrigations where decisions were made each day. This irrigation controller has been favorably demonstrated on a commercial farm for several years where the operator compared its performance with his method of irrigation timing. These improvements, including the development of a wireless infrared thermometer system via a contract with Accent Engineering Co., has increased the potential for commercialization of this technology, which can be used to reduce management effort and labor, increase water use efficiency, and reduce the potential for water and chemical movement to the groundwater. Farmer interest in this technology is high, as evidenced by the large number of recent magazine articles. Potential users include farmers and irrigation systems manufacturers (Valmont, Reinke, Wade Rain, DripTape, etc.).

Canal automation saves irrigation water. ARS engineers developed canal automation technology consisting of field hardware, communications, Supervisory Control and Data Acquisition (SCADA) software, and Software for Automated Canal Management (SacMan). Low-cost hardware was developed through a CRADA with Automata, Inc. Application can help reduce distribution system losses and unaccounted for water, which are common. Benefits of this technology include: reduce the amount of water spilled from water distribution systems (often more than 10% of the water supply), reduce the amount of water that is delivered to users, and improve the service to users so that their on-farm systems can be more efficient. Current users include the Maricopa Stanfield Irrigation and Drainage District, the Central Arizona Irrigation and Drainage District, and other U. S. and international water districts (e.g. several very large projects in India and Pakistan are now considering using this canal automation system). Beneficiaries are farmers, USBR, NRCS, water purveyors, and State water resources agencies.

Efficient fertigation available for all irrigation methods. Fertigation brings both nutrients and water to plants and at the same time saves money by combining two tasks into an efficient system. ARS scientists at three locations have found different ways to improve the application of fertilizer and at the same time apply water more efficiently for the three irrigation methods. Researchers from Phoenix, Arizona, found that improved fertilizer mixing and injection procedures can be used to improve the uniformity of the fertilizer applications to within 10 to 15 percent variation for surface irrigation practice. Scientists in Nebraska working with industry cooperators developed a new electronic sensor that can be placed atop a center-pivot irrigation system to apply variable rate fertilizer and water applications for precision farming. This same sensor can be used on a high-clearance sprayer or other types of farm implements to precisely and accurately apply variable rate fertilizer applications on both irrigated and non-irrigated (rainfed) croplands. Also, Researchers in California have demonstrated that applying both fertilizers and water on a continuous basis through subsurface drip irrigations, which can prevent seepage of excess nutrients into ground waters. Current estimates are that various fertigation techniques will be used on 50 percent of the irrigated lands in the U.S. by 2010 for an additional increase in farm profits of at least $600 million dollars per year based on conservative estimates for fertilizer savings and increased yields with consideration given to environmental benefits. Farmers, NRCS technical specialists, university extension specialists, private consultants, and irrigation company representatives are now recommending fertigation regardless of the method of irrigation.

<u>New pressure tester helps fine-tune irrigation systems.</u> Currently, there are no easy, nondestructive methods for measuring pressure in drip tubing to assess uniformity. ARS scientists in the Western United States have developed a simple device called the “Squeezer” for measuring pressure in drip irrigation tubing in the field without puncturing the tube or installing special fittings. The device provides growers with a convenient means of assessing drip irrigation system performance by measuring pressure variations within the irrigation system. A patent is pending, and a California company is developing an electronic version for commercial sales.

<u>Subsurface drip irrigation becomes a cost-effective alternative.</u> Subsurface drip irrigation systems have high initial cost, which must be recovered through a combination of higher water-use efficiency and yield. In Texas, ARS scientists have developed a method of using canopy temperature to schedule daily subsurface drip irrigations. Among a range of water stress times and amounts, the highest water-use efficiency was achieved at near the high yield (98 percent of maximum) and (21 percent less than maximum amount applied) on cotton. Subsurface drip irrigation yielded greater grain sorghum yields and water efficiency than the commonly adopted Low Energy Precision Application (LEPA) and surface irrigation methods. This research demonstrates that under a declining and very limited water supply, which is the case for the Ogallala aquifer, subsurface drip offers a unique opportunity to produce adequate yields while applying water more efficiently than other irrigation methods.

Outcome #8: Modernization of drainage management systems that improve soil and water resources, agricultural production practices, and cost-effective use of agricultural chemicals.

ARS scientists are providing the tools and techniques to agricultural producers to cost-efficiently improve the management of water on site. Examples of how ARS designed systems are improving agricultural production and reducing transport of agricultural chemical both domestically and in Canada through controlled water management are list below. A more detailed presentation of accomplishments is listed in Appendix B.

Controlled drainage reduces nitrogen loadings to the Gulf of Mexico. Nearly a third of the farmers in the Midwest rely on underground, or subsurface drainage to keep their plants healthy. ARS scientists in Ohio have shown that controlled subsurface drainage systems can increase corn and soybean yields and reduce nitrate losses by 30 to 40 percent. Under entirely different conditions, ARS researchers in Louisiana, found that improvements in water quality with controlled drainage systems depend highly upon climatic conditions and that deep chiseling is required to reduce both nitrate losses from surface and subsurface drainage systems. ARS scientists in Iowa, found that wood chips and other types of biological materials can act as filters when placed in shallow drainage systems to decrease nitrate losses under controlled drainage practices. The biological filters increased denitrification once the water becomes ponded above the drainage tile. All of these locations are currently cooperating on new experiments that compare these new technologies with conventional drainage systems to continue reducing water pollution hazards. This research along with university drainage research was the basis for forming the Agricultural Drainage Management Systems Task Force (ADMS). In 2002, cost sharing for drainage water management did not exist in any of the States. However, four Midwestern States are now cost sharing on controlled subsurface drainage in accordance with approved practice standards that met the conservation requirements of the FY 2002 farm bill. (See page 36 for more information on ADMS technology transfer activities.)

Alternative drainage-irrigation approach decreases nitrogen loadings and increases yields. Throughout the Midwest, drainage systems have been shown to be the major source of nitrate nitrogen contamination for the Mississippi River. Research on the use of subsurface drainage systems to provide both drainage and subirrigation in corn-soybean crop rotations has been conducted near Columbus, Ohio. This water table management approach resulted in a lower residual nitrate in the soil, a 75 percent reduction in the nitrogen loadings in the subsurface drainage waters, and a 50 percent increase in soybean yields compared to conventional subsurface drainage practices. Wherever existing or new subsurface drainage systems can be employed by Midwest producers to manage both drainage and irrigation practices simultaneously, the impact will be a significant improvement in ground and surface water quality along with an increased economic return from increased crop yield ands lower fertilizer costs. With the help of the ADMS Task Force, drainage equipment manufacturers, land improvement contractors, and university extension specialists are promoting water table management or controlled subsurface drainage systems.

Controlled drainage and plant stress indicators reduce drainage discharges and improve irrigation efficiencies. Traditional passive drainage systems often result in excessive quantities of poor quality water being discharged from the subsurface drainage system that can be significantly reduced by using controlled drainage systems. ARS researchers found that using plant stress indicators to schedule irrigation in fields with shallow groundwater could reduce the total applied irrigation water and total drainage flow. In areas with shallow ground water, replacing surface irrigation with pressurized (sprinkler, drip) irrigation systems can also decrease deep percolation and increase crop water use from shallow ground water. Control structures at the outlets of subsurface drains increased use of shallow ground water by crops, reduced applied irrigation water, and reduced subsurface drainage flow. The results of these studies are included in the Integrated Farm Drainage Management (IFDM) program sponsored by the California

Department of Water Resources and the NRCS and were incorporated in a set of best management practices (BMPs) for the design and management of drainage systems. These BMPs are being implemented in irrigated areas of Australia with the Murrumbidgee Irrigation Area (NSW, 288,000 hectares), where all new subsurface drainage systems are required to follow the BMPs produced. The World Bank has picked up on the BMPs and has them as recommended reading in the World Bank Agriculture Investment SourceBook. Drainage control technology is also being used in Egypt and Pakistan. Subsurface drip irrigation (SDI) has been installed on 6,000 acres in the Westlands Water District as a control measure to limit deep percolation losses. SDI is being considered for implementation on 40,000 acres of irrigated land in the Panoche Water and Drainage District in California.

<u>For better surface water quality, dig ditches.</u> Drainage ditches are a common feature in agricultural landscapes. ARS researchers in the Southeast have documented the efficiency of properly-managed ditches in keeping nutrients and pesticides from getting into water bodies, they found the surface drains can trap 60 to 90 percent of commonly-used herbicides and insecticides carried in runoff water. Thus, ditches appear to be a simple, low-tech, inexpensive way to improve water quality if properly managed. The use of this technology is expanding rapidly in the Lower Mississippi River Valley and is being promoted by NRCS, FSA, university extension, and private consultants for primarily water quality and wildlife habitat improvements.

<u>Water management reduces methane emissions from rice.</u> Rice is the primary food for about 50 percent of the world's population, and nearly all the rice is produced under paddy or ponded conditions. Rice may also have a major impact on global warming by contributing to the emissions of an important greenhouse gas: methane. In recent studies, ARS scientists in Florida conducted studies where the rice was flooded for different time periods. The studies showed that rice yields decrease when the plants are exposed to short, two-week droughts when the plants are flowering. However, when the researchers doubled CO_2 levels, the plants maintained yields, used less water and endured a longer drought period. They also discovered that periodically draining the soil to aerate roots with atmospheric oxygen drastically decreased methane emissions. Controlling water table depths at the right time and not maintaining paddy rice fields year-long has international implications for maintaining rice production and at the same time reducing methane emissions from rice fields. [This research is coded to the ARS Air Quality (NP 203) and Global Change (NP 204) National Programs. However, this is also a significant finding for the tremendously large acreage of irrigated rice throughout the world.] NRCS, USEPA , and University extension specialists have been made aware of this finding for the benefit of the rice producers in California, Arkansas, Louisiana, Texas, and Mississippi.

<u>Locating old tile lines enables better drainage management.</u> Existing tile drain lines must be detected before controlled drainage or improved drainage management systems can be installed. ARS and University scientists in Ohio have successfully modified ground penetrating radar equipment to locate operational and non-operational tile lines. Extensive studies at thirteen sites throughout Ohio showed that this geophysical method located an average 72 percent of the old buried tile lines. Current estimates are that this detection method will save farmers and land improvement contractors about $10 million dollars per year throughout the United States. The primary cooperators in developing this technology have been several drainage companies along with USGS.

Water Quality Protection and Management Component

Outcome #9: Improved technologies for maintaining the viability of agriculture while protecting water quality from degradation by excess nutrients, pesticides and other synthetic chemicals, pathogens, sediments, and trace elements.

ARS scientists have provided national leadership in the development of many USDA thrusts to maintain the economic viability of agriculture while protecting and enhancing the environment. The assessment techniques, rating tools, and prediction models develop by ARS in partnership with its colleagues have in many cases become the standards that States and Federal agencies have used in developing, or monitoring regulations aimed at improving the quality of the nation's water supply. Examples of the most prominent tools developed by ARS are provided below. A more detailed presentation of accomplishments is listed in Appendix B.

<u>Pinpointing where phosphorus comes from</u>. Studies of phosphorus and nitrogen transport from Northeast watersheds provide a basis for integrated nutrient management strategy. The ARS scientists tracked the sources and fate of phosphorus and nitrogen transported from several agricultural watersheds in Pennsylvania, New York, and Maryland. Most phosphorus loss came from small, discrete areas of the watersheds and was transported during a few, intense storm events. However, nitrogen leaving the watersheds originated from most of the watershed area, and moved independently of specific storm events at a much slower rate, taking years to flow from fields to surface water. These results show the need for site specific and nutrient specific management to mitigate nutrient loss from agricultural fields to surrounding waterways. With sources of nutrient loss identified in time and space using simple models and indexes, farmers can avoid phosphorus applications to sensitive areas to reduce phosphorous runoff. Phosphorus (P) sources, such as barnyards, may represent a relatively large source of P loss in many area of the Nation. Dramatic improvements to water quality may not be achievable by addressing nonpoint sources alone. Widespread adoption of the P Index is expected to lead to significant reductions in nonpoint source exports of P from agricultural lands with corresponding improvements in water quality. ARS scientists used the P Index approach to assess relative risks of P loss from agricultural fields across the state of Pennsylvania. The highest observed P levels in soils that are nonpoint source areas for P export in runoff from agricultural fields were observed in southeastern and east-central Pennsylvania. These areas correspond spatially to areas of intensive livestock production and to high densities of nutrient-impaired streams. However, land characteristics that affect the potential for nutrient transport in these areas are relatively low, and the overall risk of P loss from nonpoint sources in these areas does not appear to be much greater than other parts of the State. The users of these findings include NRCS, USEPA, university extension personnel , and other Federal and State agencies.

<u>Reducing phosphorus loadings to the nation's streams.</u> In response to mounting water quality concerns, many states have developed guidelines for land application of phosphorus (P) based on the potential for P loss in agricultural runoff. These actions have been spurred, in part, by a federal initiative in which the USEPA and USDA created a joint strategy to implement Comprehensive Nutrient Management Plans (CNMPs) on Animal Feeding Operations by 2008, both agronomic and environmental impacts of applied P. To address this need, ARS led the

development and refinement of a P Index to rank the vulnerability of fields to P loss in runoff and identify those at greatest risk for loss. The NRCS has adopted the use of the P index in 47 States as the basis for development of CNMPs, and over 2000 NRCS field agents and nutrient management consultants across the U.S. have received training. Workshops, fact sheets, and on-site demonstration programs were developed by ARS, NRCS, and university extension personnel to train field agents and farm advisors on the use of the P Index when writing nutrient management plans. By better targeting resources to the largest operations and areas at greatest risk of water quality impairment, comprehensive nutrient management strategies that include the P Index have saved the CAFO industry $625 million per year. It is estimated that this approach will reduce P loadings in water by 26 million kilograms (56 million pounds) annually and reduce sediment released by over 1 billion kilograms (2.1 billion pounds) from CAFOs to the environment. These efforts have resulted in the Phosphorus Indexing Research Group receiving the USDA Secretary's Plow Honor Award for Group Achievements in "Maintaining and Enhancing the Nation's Natural Resources and Environment" and the ARS Technology Transfer Award "For development and implementation of a Phosphorus Indexing procedure to target remedial measures for nutrient management strategies that maintain productivity and protect water quality."

Innovative tools developed to assess nitrogen management and leaching. Proper management of nitrogen in agricultural systems while understanding its transport and transformations is becoming increasingly important to agricultural producers and to modern society. ARS scientists developed a book entitled "Managing Nitrogen for Groundwater Quality and Farm Profitability" that included the Nitrate Leaching and Economic Analysis Package (NLEAP) computer model developed earlier by ARS. Since their release, NRCS and others around the worldwide have used both the book and the NLEAP model. ARS scientists continue to update the model in response to user requests to address special situations or unique applications. The improved model, NLEAP-GIS, is a powerful tool that can be used to conduct precision conservation evaluations and identify areas that are sensitive to nitrate leaching losses, and is listed as one of the Best Management Practices for the Cooperative Extension Service, Colorado State University, and Best Management Practices Bulletin. This information has contributed to the formation of a national working group composed of NRCS and university extension specialists to develop a new generation of the nitrate-leaching index.

Management tool developed to reduce water quality effects from turfgrass systems. Large quantities of fertilizer are used to maintain turfgrass on golf courses, and operation of turfgrass systems for water quality protection has been hampered by a lack of models or decision support systems sensitive to enhanced turfgrass management practices. Data to quantify surface water nutrient loads from turfgrass systems were collected, and the Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) model, which was developed by ARS scientists, was modified to evaluate turfgrass fertilization strategies. This model provides a new tool for assessing turfgrass fertilization from the scale of a single golf course to that of an entire watershed and has been transferred to the golf industry for operational use in managing private and public golf courses. This information has been provided to the National Turfgrass Federation, Inc., the United States Golf Association, and the Golf Course Superintendents Association of America.

Pasture management for forage grass production and reduced nitrate leaching. A simple model, relating nitrate-leaching loss from pastures to the stocking density of grazing cattle, was developed and transferred to LEACHM (Leaching Estimation and Chemistry Model) and NCSWAP (Nitrogen and Carbon in the Soil Water and Plant system) models for use as NRCS planning tools. ARS scientists at several locations quantified the interactive effects of environment, soils, nitrogen management, and intensive grazing on the biomass accumulation rates and nitrate leaching in the humid grasslands. They found that a rotational grazing or haying system reduces nitrogen in groundwater to acceptable levels when no nitrogen fertilizer is applied. However, a substantial fraction of the nitrogen recycled in a pasture leaches beneath the root zone and can have a negative impact on water quality. This research has changed the NRCS and regulatory agency view of management intensive grazing from a practice that is inherently environmentally benign to one that must be properly managed if water quality is to be maintained. Results of the work have also been used to adjust the output of the ARS Dairy Forage System Model (DAFOSYM) to reflect nitrogen loss under grazing. The results of this and earlier pasture research have been used by the NRCS in Virginia and West Virginia in developing grazing management guidelines.

Detect and Modeling transport and survival of bacterial human pathogens in the natural environment. ARS scientists have developed a novel method for the quantitative detection of E. coli O157:H7 in water because of increasing concerns regarding water-borne pathogens on human health. At present, the risk from water-borne transmission of this pathogen cannot be estimated because there are no reliable methods for the detection and enumeration of small numbers of these organisms in water samples. ARS scientists at Beltsville, Maryland, developed a novel method for the quantitative detection of E. coli O157:H7 in water samples using commercial antibodies coupled to magnetic beads (IM) and a light producing catalyst (ECL). The method is relatively fast (< 24 hours) and inexpensive, allowing for the analysis of multiple water samples daily for the detection of as few as one viable bacterium per 100 mL **3.4 oz.** of water. This assay is currently being used to screen samples from watersheds with different land uses (animal agriculture, urban/suburban, forested) for the prevalence of this pathogen. A Cooperative Research and Development Agreement (CRADA) was initiated with Creatv MicroTech.

A model developed for predicting pathogen concentrations in water. Reliable data on the environmental factors which affect the release and loading rates of pathogenic parasites, such as Giardia and Cryptosporidium *oocysts*, from animal manure is needed to accurately assess and minimize contamination potential to surface and drinking water supplies. A conceptual model was developed to describe and predict manure and protozoan parasite oocysts (*Giardia* and Cryptosporidium *oocysts*), release rates, and cumulative loading. Assuming a diffusion process for manure release into water, the pathogen concentration was predicted from the dissolved manure concentration, the initial pathogen concentration in the manure, and the release efficiency of the pathogens (relative to that of manure).

The HYDRUS model now includes a pathogen component. A conceptual pathogen model was incorporated into the HYDRUS soil water and solute computer model. The calibrated model yielded a significantly improved description of both the effluent concentration curves and the spatial distribution of variously sized colloids (a surrogate for pathogenic microbes) in four soils compared to conventional pathogen transport models. The new model provides an improved characterization of the processes that control pathogen transport, and will, therefore, aid researchers to assess the vulnerability and minimize the potential of pathogen contamination to water supplies. This model has been disseminated to various users in the United States, Germany, the Netherlands, and New Zealand. The users of this information in the U.S. include NRCS, USEPA, Federal and State agency, and university extension personnel..

<u>A new paradigm for controlling agricultural chemical losses on claypan soils.</u> ARS researchers in Missouri have investigated the processes governing water contamination on claypan soils for more than two decades. They have identified that for Missouri streams: (1) herbicide metabolites make up the majority of the total herbicide load during the pre-plant period with atrazine dominating the load for 6 weeks following planting; (2) the key variables affecting chemical losses from fields are time between chemical application and rainfall, rainfall intensity and duration, soil moisture, tillage practice, and chemical degradation rates; and (3) the high residue, no-till systems will provide erosion control and reduce sediment losses for claypan soils, but at the expense of creating greater water runoff, nitrate-nitrogen leaching and runoff, and herbicide loss than other minimum till systems. These results shift the focus from land-use, as the primary factor governing chemical runoff vulnerability, to a hierarchical framework dominated by the chemistry determining potential hydrologic loss pathways, the soil determining the hydrologic pathways, and finally, land-use. The new strategies are not limited to a single set of practices and include precision application of agricultural chemicals, modification of minimum tillage systems, new and improved drainage systems, biological control of weeds, genetically-modified crops that require reduced amounts of pesticides and fertilizers, and an immediate improvement in the design, placement, and management of riparian buffers at the edge of the field. NRCS, USEPA, other Federal and State agencies, and university extension personnel are currently using these findings in many parts of the Midwest, where NRCS has recently begun cost sharing on precision agriculture for water quality improvements in Missouri.

<u>Water-treatment residues help to reduce water pollution.</u> ARS scientists in the Eastern United States have found that residue from water-treatment processes, often discarded as waste and placed in landfills, may make a great soil amendment for preventing loss of phosphorus (P) in runoff from agricultural fields. ARS scientists have found an alum-based water-treatment residual that can increase the soil's capacity to bind phosphorus, a vital plant nutrient. The results should benefit states along the nation's mid- to-southern-Atlantic seaboard, where sandy soils generally take up and hold less P than finer-textured soils. In laboratory tests with sandy soil, the treatment increased P-binding potential four- to five-fold over that of untreated soil. If successful, this use for a water-treatment by-product not only could reduce costs for disposal, but would also hold P on the land until a crop uses it. Economic benefits to the U.S. of reducing P in runoff are estimated to exceed $200 million in addition to improving the quality of drinking water and ecosystems. NRCS, USEPA, and other Federal and State agencies have recently begun using this technology on a pilot scale project.

<u>Remote-sensing technologies shown to improve nitrogen application practices, increase yields, and reduce water quality contamination hazards.</u> The integration of geospatial technologies, such as the Global Positioning System, Geographic Information Systems, remote sensing, and variable rate fertilizer application technologies, has fostered site-specific nutrient

applications based on nutrient deficiency measurements of the crop itself. ARS researchers in Colorado, Nebraska, Missouri, and Maryland have teamed up to developed procedures using remote sensing to measure crop nitrogen deficiency, which can then be used to generate maps of nitrogen status and ultimately control spatial applications of fertilizer. To date, the site-specific application of nitrogen fertilizer has been shown to reduce the total amount of nitrogen applied, increase yields for both irrigated and nonirrigated cropping systems, and reduce excess nitrogen loadings to surface and ground waters.

Sensor developed for applying nitrogen fertilizer to cotton and corn crops. A patent (U.S Patent #6,393,927) was issued for the apparatus and methodology of real-time, non-destructive determination of nitrogen need. The sensor developed through a CRADA with Holland Scientific and two related SBIR grants became commercially available in June 2004. Technologies are needed to facilitate in-season application of nitrogen fertilizer to crops to reduce fertilizer input costs and the potential for nitrate losses. ARS scientists used aircraft and ground-based sensors to identify key wavebands that are indicative of crop nitrogen status and need and biomass production. Working with Resource21 and Holland Scientific (both private companies), in conjunction with extensive ground-based crop and soil measurements, ARS scientists developed and tested requirements and specifications for passive and active crop canopy sensors for corn. ARS scientists demonstrated that monitoring plant nitrogen status by spectral reflectance and chlorophyll meter measurements in cotton could be used to make real-time nitrogen management decisions to significantly reduce nitrogen application rates. The users of this technology include NRCS, UEPA, private consultants, and other Federal and State agencies.

Outcome #10: New and innovative concepts, assessment tools, and integrated farming systems that predict and improve water quality at the field, farm, and watershed scales.

ARS scientists have produced a number of assessment tools and integrated farming systems that are designed to protect and enhance the quality of the nation's fresh water supply. Many of the accomplishments are documented in other National Programs within ARS, NP 207 Integrated Agricultural Systems and NP 202 Soil Resource Management, and other sections of this report (Outcomes 9 and 11). Below are listed accomplishments that are associated with NP 201. More detailed examples are listed in Appendix C.

Best management practices found to improve water quality and ecology in the Mississippi Delta. The Mississippi Delta Management Systems Evaluation Area (MD-MSEA) project was initiated as a regional effort to evaluate best management practices (BMPs) to improve surface water quality in the lower Mississippi Delta. Three lakes and their respective surrounding watersheds provided systems that were manageable and hydrologically isolated. In the first 5 years, major findings include: (1) BMPs reduced sediment in MSEA lakes, resulting in improved water clarity, plankton growth, and fish stocks; (2) total phosphorus in lakes decreased 39 to 50 percent following BMP implementation; (3) pesticides were detected in fewer ground water samples with BMP implementation; (4) conservation tillage and cover crops reduced fluometuron herbicide loss in runoff by 50 percent; (5) glyphosate application was reduced 50 to 70 percent when sensor sprayer technology was used; and (6) riparian areas mitigated the transport of sediment in runoff and enhanced the degradation of pesticides. The project continues to demonstrate that lake water quality can be improved for fish and wildlife habitat and BMPs can be designed to address other Mississippi Delta water quality issues. many farmers, pesticide companies and dealers, private consultants, university extension personnel, and NRCS technical specialists are using this information to develop watershed plans for meeting TMDL and other water quality related requirements.

Studying the differences among watersheds. ARS scientists in Missouri have studied the Goodwater Creek watershed in north-central Missouri for some 30 years, and ARS scientists in Iowa, have studied the Walnut Creek watershed in central Iowa for some 13 years. The researchers learned that two watersheds, which are closely located geographically, have significantly different water quality issues. At Walnut Creek, the soils require tile drains in order to grow row crops. Because nitrate is very mobile in the soil, it moves quickly through the drains, resulting in high levels of nitrate contamination. At Goodwater Creek, tile drains do not work well for the soils within the watershed, and subsurface drains are not needed for row crop production. Unlike nitrate, atrazine stays near the soil surface where it can be moved by surface runoff. This resulted in high atrazine levels in Goodwater Creek, but its nitrate levels were much lower. Thus, crop rotation, cover crops, and nitrogen and pest management plans need to be tailored for specific geophysical conditions if they are to be effective. Plans that are beneficial in central Iowa will not work in Missouri. For these reasons ARS has developed decision support systems like RZWQM, NLEAP and other tools to assist producers in developing site specific plans without having to wait 30 years of research under local conditions. This is the type of information that has resulted in the development of the Conservation Effects Assessment Project (CEAP) that is co-led by NRCS and ARS.

All Three Components

Outcome #11: Comprehensive databases, models, and decision support systems for use in promoting sound water policies and strategies for managing the nation's water resources and mediating conflict resolution.

ARS scientists are leading the world in developing user-friendly models and decision support systems to understand and predict the impact of agriculture on our environment. Through the development of fundamental scientific principals to the integration of systems models, ARS has develop a suite of decision support tools that are used by agricultural producers and action and regulatory agencies to more effectively manage and protect the Nation’s scare natural resources. Listed below are selected examples of ARS models and decision support systems that are being used around the globe to protect the environment and enhance the production of agricultural goods and services.

SWAT is used worldwide to assess environmental benefits. SWAT, which stands for Soil and Water Assessment Tool, was developed over the past 30 years by a team of ARS researchers at Temple, Texas, in cooperation with other ARS scientists in Bushland, TX, El Reno, OK, Tucson, AZ, Ft. Collins, CO, Miami, FL, Ames, IA, and Tifton, GA. Over the past 4 years, the USEPA and ARS have made SWAT available to State agencies and consultants throughout the nation to evaluate and assess water quality impairments and to assist in developing watershed plans for addressing specific problems. The NRCS used the SWAT model in its 1997 Resource

Conservation Appraisal, in which the first national assessment of agricultural water use, tillage systems and fertilizer management was made. Recently, Texas legislators, water districts, and river authorities were impressed enough by SWAT numbers to pay part of the costs for farmers in these areas to apply conservation measures that SWAT showed would work. Some of the newest attributes of the SWAT model include terracing and other erosion-control measures to hold soil in place and show its journey into reservoirs; better nutrient management on agricultural land and on confined animal feeding operations to prevent algal blooms that impact aquatic life; and removal of juniper and mesquite brush to increase flow in drought-stricken areas in the Southwest. In 2004, NRCS and ARS again SWAT to work together to quantify the environmental benefits of conservation practices at the national scale and the watershed scale for the Conservation Effects Assessment Project (CEAP). A comprehensive database is provided to make SWAT both a teaching and assessment tool. The newest version of SWAT has been distributed to hundreds of scientists and engineers at universities, government agencies, and consulting firms throughout the world and several international training conferences have been held over the past 2 years.

Helping States to slow sediment movement. The focus on sediment pollution criteria has been fueled by a renewed effort for states to identify pollution-impaired water bodies and develop plans for meeting TMDLs as specified by the Clean Water Act of 1972. Current estimates are that physical, chemical, and biological damage associated with sediment flow costs about $16 billion annually in the United States. ARS scientists in Oxford, Mississippi, have recently developed a two-pronged modeling approach to identify sediment movement in streams and other water bodies. The AnnAGNPS watershed model first evaluates loadings within a watershed and the effect farming and other activities have on pollution control. Then, the Conservational Channel Evolution and Pollutant Transport Systems (CONCEPTS) model predicts how channel evolution and pollutant loadings will be affected by bank erosion and failures, streambed buildup and degradation, and streamside riparian vegetation. By combining the field measurements, geomorphic analysis, and the numerical models, agricultural specialists are now able to make effective recommendations on the type and placement of conservation practices either in the watershed or the stream channel that will provide the greatest benefits. This combined decision support system is primarily being used by NRCS, USACE, and USEPA.

RUSLE2 developed for soil erosion predictions. The NRCS and other State and Federal Action Agencies have a critical need for an effective tool to predict upland soil erosion (interrill and rill erosion) for farm planning purposes for a wide range of soil, weather, topography, and agricultural conditions and practices that exist across the Nation. ARS scientists have guided the Revised Universal Soil Loss Equation (RUSLE2) model project since July 1998, in cooperation with the University of Tennessee and the NRCS. The new model RUSLE2 is a land use independent management tool and has been implemented across the United States by the NRCS as its newest tool to manage and reduce water induced soil erosion. The ARS led Development Team enhance the existing RUSLE model by: (1) improving scientific relationships in selected areas including the disaggregation of monthly weather values into bimonthly and daily values; (2) formulating new equations for temporally variable soil erodibility factors; (3) developing new relationships for the effect of ridges on soil loss and decay of ridges with time; (4) developing new relationships for surface cover, land management, and use; (5) using new relationships for computing particle distributions where deposition occurs; and (6) developing a new routing procedure for strip cropping and terraces. During the enhancement of the existing RUSLE model, some 70 major science improvements were incorporated into RUSLE2. These improvements have substantially broadened the usefulness, versatility, and accuracy of RUSLE2 as a soil erosion prediction and soil erosion control management tool. Development of RUSLE2 as an independent land use conservation planning tool for erosion by water has been one of the most significant accomplishments of a practical nature in erosion prediction technology. RUSLE2 has been implemented in all NRCS field offices and has been adopted by the USDI Office of Surface Mining (OSM) and USBLM. It is also the key component in the AnnAGNPS watershed water quality model.

Root Zone Water Quality Model (RZWQM) enhanced with new crop, macropore flow, and deep vadose zone components. RZWQM is one of the commonly used water quality models focused on management effects on crop production, soil, and water quality by the scientific community. This model has had a strong impact on other scientists and is widely used by US Geological Survey, USEPA, Department of Energy, and the NRC, and by researchers in Germany, Netherlands, Canada, and Portugal. An MOU was established with the Chinese Academy of Sciences to use RZWQM for natural resources evaluation in the North China Plains. The tile drainage component of RZWQM has been incorporated into the APSIM model used in Australia and New Zealand. Our improved understanding of macropore flow resulted in Bayer CropScience using RZWQM for USEPA registration of new herbicides for use in corn production in subsurface drained landscapes, and an agreement has been established between the USEPA and ARS to explore the possibility of using RZWQM for other pesticide registrations. A CRADA has been established between ARS and Water Resources Publications to commercialize RZWQM. Users are supported through manuals, training sessions, phone and email support, as well as short-term collaborative efforts. Colorado State University is using RZWQM as a teaching tool for graduate students.

SALSA speeds solutions for water-scarce Southwest. The upper San Pedro River Basin of southeastern Arizona is perhaps best known for its lack of water. Recent estimates set this water debt at about 2.4 billion gallons a year for the entire basin, which extends from the state of Sonora in northern Mexico into the Gila River north of Tucson, Arizona. ARS scientists are leading an initiative, which includes nine Federal agencies, and four private organizations. This initiative, known as the Semi-Arid Land-Surface Atmosphere research program, or SALSA for short, has developed technology to estimate evapotranspiration for riparian systems and methods to document basin recharge. A major product from this program has been the Spatially Explicit Hydro-Ecological Model, called SEHEM, which has gone a long way toward helping prevent the overgrazing that has occurred on some of the grasslands in southeastern Arizona and other parts of the Southwest. A second major product has been the development of a partnership to develop a basin wide water resource management plan that accounts for water use by rural domestic wells, water used by the city of Sierra Vista, the military base, and the in-stream water requirements of the San Pedro River to protect endangered and threaten species that managed by the USBLM.

A decision support system for water management and restoration in south Florida. Beginning in 2000, the Everglades National Park and adjacent lands have begun undergoing a Comprehensive Everglades Restoration Plan. The Everglades Agro-Hydrology Model was developed by an ARS scientist at the Subtropical Horticultural Research Unit in Miami, Florida, in cooperation with ARS scientists from the National Soil Erosion Laboratory in West Lafayette, Indiana; the Grassland, Soil and Water Research Laboratory in Temple, Texas; and the Southeast Watershed Laboratory in Tifton, Georgia. The model currently is being linked with the regional model developed by South Florida Water Management District (SFWMD) in Palm Beach, Florida. This will significantly improve agricultural planning and decision-making with regard to Comprehensive Everglades Restoration Plan (CERP) implementation. When completed, this model will be used by the SFWMD, USACE, USEPA, and USGS to plan and improve water deliveries to all the users in south Florida.

A solution to the nitrogen problem in the western Corn Belt. Over-application of nitrogen fertilizers typically results in elevated levels of nitrate in ground and surface waters especially in continuous corn systems throughout the western Corn Belt. ARS researchers in Nebraska, have analyzed results from 20 years of data from a long-term rainfed study and 10 years of data from a long-term irrigated study that showed the soybean contributing an equivalent of 60 pounds of nitrogen per acre to the following corn crop. This means that excess nitrogen available for leaching loss and input costs of at least $30 per hectare ($12 per acre) can be saved if fertilizer recommendations include this nitrogen credit for corn grown in two-year rotations with soybean on medium to fine textured soils. Farmers and university extension specialists working to conserve nitrogen fertilizer and improve water quality are currently using this information.

Outcome #12: Improved linkage of water resource information systems and technology transfer to national and international customers.

ARS scientists are often sought by other government agencies to assist them when they are confronted with urgent agricultural and natural resource issues. In the last 4 years ARS has been requested by numerous USDA agencies to assist them with domestic issues on how to quantify the impact or benefit derived from implementing USDA funded Farm Bill programs. ARS has responded to requests from the State Department to provide scientific support to countries around the world. Listed below are selected examples of how ARS has responded to requests to improve the use of water resource information to improve our ability to protect and enhance the environment while managing to continue to produce agricultural goods and services.

In late 2002, the Office of Management and Budget asked NRCS to quantify the benefits of Farm Bill funded conservation programs and NRCS asked ARS to assist in this activity. The ARS in cooperation with the NRCS, Cooperative Research Extension and Education Service, USDA Office of Risk Assessment and Cost Benefit Analysis, Environmental Protection and other Federal and State agencies have developed a watershed water quality assessment program and a national assessment effort. This program is the Conservation Effects Assessment Project (CEAP). The purpose of CEAP is to provide the farming community, the conservation community, the general public, the OMB, legislators, and others involved with environmental policy issues an accounting of the environmental effects or benefits obtained from USDA conservation program expenditures.

The centerpiece of the watershed assessment program is the ARS "benchmark" watersheds. The term benchmark is used to distinguish the ARS watersheds from other watersheds where watershed assessment research is being initiated under CEAP. Also, the concept of benchmark watersheds is used to differentiate the larger scale ARS watersheds from field scale ARS research activity. ARS has 60 scientists, $16 million per year, at nine locations contributing to the research activity on 12-benchmark watersheds. The locations are: Ames, IA, Tifton, GA, El Reno, OK, Temple, TX, Oxford, MS, University Park, PA, Columbia, MO, West Lafayette, IN, and Columbus, OH**.** The 12 benchmark watersheds represent primarily rain-fed or non-irrigated cropland. In addition to these locations, ARS scientists from Ft. Collins, CO, are coordinating a portion of the modeling activities using the newly developed ARS led software tool called the Object Modeling System (OMS).

The research assessments on the ARS benchmark watersheds are intended to determine an optimal selection and placement of conservation management practices to achieve specific water quality and other environmental goals, as well as provide initial information important to assessing the economic and social factors that facilitate or impede implementation of these conservation practices. ARS is developing plans to partner with ERS, NRCS, and several universities to enhance the economic and social science efforts within the CEAP program.

An ARS research plan for the 12-benchmark watersheds has been peer reviewed and is being implemented in 2005 as the first national watershed project aimed at quantifying improvements in soil and water resource derived from implementing economically feasible conservation practices. Two technical conferences have been held at Soil and Water Conservation Society Annual meeting in 2003 and 2004 on CEAP. Recently, the ARS- National Agricultural Library, Water Quality Information Center published 4 bibliographies on what is known about environmental impacts and benefits of conversation practices. The bibliographies offer more than 2,700 citations, with abstracts where available, and with URLs when the documents are freely available online. The bibliographies are available in four volumes, all on the Web:

Environmental Effects of U. S. Department of Agriculture Conservation Programs is a guide to literature examining environmental effects of USDA conservation programs--information useful for assessing on-the-ground results of conservation programs from various environmental perspectives.

Implementing Agricultural Conservation Practices: Barriers and Incentives is a guide to recent literature examining agricultural producers' views of conservation programs and practices--information helpful in developing conservation programs and practices to fit the needs of agricultural producers.

Data and Modeling for Environmental Credit Trading is a guide to literature on the data and modeling requirements for environmental credit trading, to help interested people become informed about the current state of data acquisition and use of simulation models in environmental credit trading.

Agricultural Conservation Practices and Related Issues: Reviews of the State of the Art and Research Needs is a guide to the recent literature covering agricultural conservation practices and associated issues, focusing on where information has been combined and synthesized from many sources.

ARS is leading the development of a state-of-the-art synthesis book with the Soil and Water Conservation Society on the impact of conservation practices at the edge of farmer's fields. This book will be released in July of 2005. An international conference focusing on Impact of

Conservation Practices in North America is being organized for October of 2006. The first report from this effort is scheduled in late 2006.

The Agricultural Drainage Management Systems (ADMS) Task Force was fully implemented in 2004 by ARS, NRCS, and CSREES in cooperation with land improvement contractors, drainage industry representatives, private consultants, and farm organizations in seven Midwestern States of Iowa, Illinois, Indiana, Minnesota, Missouri, Ohio, and Wisconsin. The new era for agricultural drainage is based on removing a minimal amount of excess surface water and managing shallow water tables to achieve an optimal mix of economic and social benefits while safeguarding key ecological functions. The initial focus has been highly successful where, under the lead of ARS, NRCS and State Agriculture Extension Engineers, drainage contractors and farmers have rapidly begun to install controlled drainage systems on existing and new surface and subsurface drainage systems. Numerous workshops/meetings were held in 2004 and many more workshops and conferences are being planned for 2005. The ADMS Task Force has been designated as the first technical working group for the ARS, NRCS, CSREES Partnership Management Team, where a charter, action plan, flyers, posters, and several technical documents have been implemented. Numerous educational brochures and handouts have been developed and distributed to the public via two specialty conferences in 2004.

International activities have also been expanded over the last five years with the signing of a Memorandum of Understanding between the United States-USDA and the Chinese- Ministry of Science and Technology (MOST). Under this agreement, five cooperative projects related to soil erosion by water and wind were developed with the U.S.-China Center for Soil and Water Conservation and Environmental Protection. This center is located on the campus of the Northwest Sci-Tech University of Agriculture and Forestry (NWSUAF) in Yangling, China. The U.S. counterpart is located at the Colorado State University, Fort Collins, Colorado. In November of 2004 ARS scientists from West Lafayette, Indiana traveled to Yangling, China to provide a 2-week workshop on how to use the Water Erosion Prediction Project model. In 2005, ARS scientists traveled to Yangling to provide training in the use of the Revised Universal Soil Loss Equation model, the Wind Erosion Prediction System model, and AnnAGNPS water quality model. Chinese scientists are helping ARS scientists design state-of-the art gully erosion experiments that will be conducted in China. Results from these experiments will be then integrated into the ARS erosion and waters quality models for use in the United States as well as China.

The project was fully developed by three ARS locations in 2003 in cooperation with partners from Israel, the Palestinian Territory, and Jordan. A successful Workshop was held in Jordan with full participation from Middle East partners. The USDOS has provided funding for the multi-location Middle East project. In addition, the USDOS is funding a series of projects with Pakistan and proposing similar activity with Mexico to share technology on water quality and management practices in arid and semi-arid landscapes.

An ARS-Mexico Workshop on Water and Environmental Impacts was held in Tucson, Arizona, in May 2003. Since the workshop, ARS and scientists have successfully developed five funded projects where ARS scientists will be training Mexican scientists and participating is cooperative research between both countries. The projects range from development of efficient irrigation systems to revegetation of drastically disturbed native rangelands to control of upland erosion and sedimentation within vital flood control and water supply structures.

The National Program Team

The following ARS National Program Leaders provide program planning, priority setting, resource allocation and/or re-allocation, and research coordination for this national program: Dale Bucks (Co-Leader), Mark Weltz (Co-Leader), Evert Byington, Ernest Delfosse, Mike Jawson, Nancy Ragsdale, Jane Robens, and Robert Wright.

Acknowledgements

The input of Carlos Alonso, David Bjorneberg, James Bonta, Steven Evett, David Goodrich, Dale Heermann, Philip Heilman, Chi hua Huang, Dan Jaynes, Nadine Kessler, William Kustas, Terence Lynch, Andrew Simon, and other ARS scientists are acknowledged for their contributions and ideas towards this report and the organization and planning of the NP 201 Customer Workshop.

References

National Research Council. 2001. Envisioning the Agenda for Water Resources Research in the Twenty-First Century. National Academy Press, 500 Fifth St. N.W., Washington, D.C. 20001.

National Research Council. 2004. Confronting the Nation's Water Problems: The Role of Research. National Academy Press, 500 Fifth St. N.W., Washington, D.C. 20001.