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WATER AVAILABILITY AND WATERSHED MANAGEMENT

Water is fundamental to life and a basic requirement for virtually all of our agricultural, industrial, urban, and recreational activities, as well as for the sustained health of our natural ecosystems. As Earth's human population tripled during the last century, demand for Earth's finite supply of available fresh water increased six-fold. The United Nations estimates that more than a billion people live without access to clean water, and more than 2.4 billion people lack the basic sanitation needed for human health. The U.S. Environmental Protection Agency has estimated that it will cost in excess of $150 billion to provide clean and safe water to the Nation. Shortages of fresh water—already evident in the drought-ridden western United States—cost the Nation in excess of $8 billion per year in addition to untold environmental impacts. When only freshwater withdrawals are considered, agriculture is clearly the largest user of water in the United States; thus, agriculture has the greatest opportunity to conserve water supplies and improve water quality through scientific discovery.

The goal of the USDA/ARS Water Availability and Watershed Management National Program is to effectively and safely manage water resources, while protecting the environment and human and animal health. This goal will be achieved by characterizing potential hazards, developing management practices, strategies and systems to alleviate problems, and providing practices, technologies and decision support tools for the benefit of customers, stakeholders, partners, and product users. Research in this National Program addresses six component problem areas: (1) the effectiveness of conservation practices; (2) irrigation water management; (3) drainage water management systems; (4) integrated soil erosion and sedimentation technologies; (5) watershed management, water availability, and ecosystem restoration; and (6) water quality protection systems.

The mission of this National Program is twofold: (1) to conduct research on the processes that control water availability and quantity for the health and economic growth of U.S. citizens; and apply the new knowledge (2) to develop new and improved technologies for managing the Nation's agricultural and water resources. Advances in knowledge and technologies provide producers, action agencies, local communities, and resource advisors with the practices, tools, models, and decision support systems they need to improve water conservation and water use efficiency in agriculture, enhance water quality, protect rural and urban communities from the ravages of drought and floods, improve agricultural and urban watersheds, and prevent the degradation of riparian areas, wetlands, and stream corridors.

ARS, in cooperation with the Natural Resources Conservation Service, the Cooperative State Research, Extension, and Education Service, the Environmental Protection Agency, US Geological Survey and other Federal and State agencies, has developed a watershed research program called the Conservation Effects Assessment Project (CEAP). The purpose of CEAP is to provide a methodology for documenting the national and regional environmental effects and benefits obtained from USDA conservation program expenditures, and develop management options to achieve maximum benefit from those expenditures. CEAP cropland assessments have been expanded to the assessment of grazinglands and wetlands. ARS accomplishments related to the CEAP assessment for croplands were published in a special issue of the Journal of Soil and Water Conservation in 2008. Also published in 2008 with the help of the National Agricultural Library, was a CEAP bibliography, "Effects of Agricultural Conservation Practices on Fish and Wildlife"

Interdisciplinary research across natural and social sciences to address challenges in water resource management requires comprehensive and long-term data. As part of CEAP, a database called STEWARDS (Sustaining the Earth's Watersheds, Agricultural Research Data System) was developed to compile, document, and provide access to data from ARS research watersheds. These data represent one of the largest research watershed data collections in the

world, with many of the watersheds offering decades of data required to address issues of climate variability and global change. STEWARDS represents an advance for hydrologic and environmental research by providing access to a multitude of data needed to support complex analyses. Anticipated impacts better data sets against which to test, validate and perfect models which can be utilized in water and land planning and environmental resource protection. These data sets wil also provide a baseline against which new practices and implementation scenerios can be tested and measured by individual scientists, watershed teams, and the ARS water resources program.

The Clean Water Act of 1972 is the cornerstone of surface water quality in the United States; however, water quality and distribution regulation is a complex myriad consisting of a multitude of federal, state and local agencies. Significant coordination with planning, regulatory, environmental and action groups is required to address the needs of the agricultural and public sectors. ARS coordinates with other government agencies to leverage agency resources through its active participation in a variety of intergovernmental committees including: (1) the Committee on Environment and Natural Resources (CENR) (the relevant National Science and Technology Council committee for water research) Subcommittee on Water Availability and Quality (SWAQ), a subcommittee within CENR devoted to water issues that serves as a forum for agency representatives to share information about their respective programs; (2) the National Agricultural Research, Extension, Education and Economics (NAREEE) Advisory Board, which evaluates USDA Research and Development Programs and provides recommendations to the Secretary and REE Undersecretaries; (3) the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, charged by Congress with conducting a reassessment of (i) nutrient load reductions and the response of the hypoxic zone, (ii) water quality throughout the Mississippi River Basin, and (iii) economic and social effects, a draft of which is currently being circulated for public comment (4) the Advisory Committee on Water Information (ACWI) Subcommittee on Sedimentation; (5) the USDA Drought Team and the USDA Working Group on Water Resources;(6) the Conservation Effects Assessment Project Steering; The Subcommittee on Sedimentation, part of the US Department of Interior, Advisory Committee on Water Information; the Ecosystems Working Group of the US Climate Change Science Program, and several others.

Selected Accomplishments

Effectiveness of Conservation Practices

Agricultural conservation practices ensure the sustainability and preservation of our nation's natural resource base, which includes water, soil, and air. ARS has conducted research to develop and improve these conservation practices and to provide environmental benefits in the form of soil and water quality. Crop rotations, contour farming, conservation tillage, cover crops, stripcropping, conservation buffers, residue management, site specific nutrient and water application technologies, and salinity and drainage control practices have played a broad role in increasing crop productivity, maintaining soil organic matter and fertility, and controlling water and wind erosion processes. Implementation of some practices is associated with costs and tradeoffs between maximum productivity and preservation of natural resources. Thus, the implementations of some practices are encouraged through subsidies, which raise the question concerning the value of the practices. Research conducted under this problem component focus on development of improved practices and methods to quantify their effectiveness and value.

Cover crops can effectively reduce residual nitrogen loads. The primary role of ARS's in the interagency CEAP is to develop methods that can be used to assess and quantify the environmental benefits of best conservation management practices at the watershed scale. The Annualized AGricultural Non-Point Source (AnnAGNPS) model was tested as a tool to predict the effectiveness of cover crops and drainage control structures in protecting water quality at the Choptank River Watershed in Maryland. Preliminary model simulations for fifteen sub-basins within the non-tidal zone of the watershed revealed significant nitrogen load reductions due to

increases in cover crop acreage. Simulations with increased cover crop implementations from 40 to 70 percent showed nearly 58% N reduction. Such large amount of N load reductions suggested by the model must be validated with data collected in the watershed. The ultimate goal is to develop enough confidence in AnnAGNPS and other models to support decisions faced by land managers and policy makers in selecting conservation practices and incentives to reduce nutrient loads into the Choptank River and ultimately the Chesapeake Bay watershed.

Combining erosion control structures with reduced crop acreages eliminates most sediment flows to streams. Scientists in Oxford, MS evaluated in-stream grade stabilization structures on the 2,132 ha Goodwin Creek Experimental Watershed in north Mississippi. Measured rainfall, runoff, and sediment concentration data were applied to model simulations to demonstrate that the combined effect of grade control structures and conversion of croplands into the Conservation Reserve Program (CRP) (reducing cultivated land from 26 to 8%) was to reduce sediment yields by 78% near the outlet of the watershed. The evaluation was a successful real-world test of watershed simulation models that are intended to help watershed managers choose combinations of practices to increase environmental benefits.

Radar aids mapping of hard-to-find forested wetlands. Wetlands have the potential to remove agrochemicals before they enter streams and degrade the biological health of estuaries. However, the majority of wetlands in the Chesapeake Bay Watershed are forested, and this type of wetland is difficult to map and monitor using existing methodologies. ARS scientists developed a new methodology to map forested wetland hydrology at a watershed scale using satellite-borne radar data. Forested wetland hydrology maps produced using radar data were well correlated with in-situ measurements of soil moisture and inundation. Next-generation wetland maps produced by radar will provide a water quality management tool that can be used to quantify the proportionate contributions of various types of land uses to nutrient, and sediment loads in the environment. These types of assessments are critical in the calibration of models that can be used by land managers and regulators in their efforts to improve the health of the Chesapeake Bay.

RZWQM Model confirms effectiveness of cover crops to reduce nitrate leaching. Additional field-scale model evaluation is needed to quantify the effects of cover cropping, water table and nitrogen management, and other management practices under tile drainage conditions to further support regionalized watershed model development for Midwest conditions. ARS scientists measured nitrate reduction in tile drainage with a rye winter cover crop in a corn-soybean rotation when different levels of nitrogen fertilizer were applied in the corn year. A calibrated model developed by combining the Root Zone Water Quality Model (RZWQM) and the Decision Support System for Agrotechnology Transfer (DSSAT), a model developed for analysis of precision agriculture datasets, was modified to simulate a rye winter cover in a corn-soybean rotation. Simulation results were verified against field measurements. When simulations were run at various nitrogen-fertilizer application rates, using a long-term climate record, results showed that percentage reduction of nitrate in tile drainage due to the cover crop remained relatively constant over a wide range of applied nitrogen rates. This indicates that rye winter cover crops will reduce nitrate in tile drainage water even at relatively low nitrogen application rates.

ALMANAC (Agricultural Land Management Alternatives with Numerical Assessment Criteria) Model adapted for grasses. Simulation of growth and yield of grasses for conservation assessment requires an accurate, realistic model that describes various grass types as well as competition among species in complex grass mixtures. ARS scientists in Temple, TX, parameterized the ALMANAC model for the major improved grass species and several common native grasses, as well as for switchgrass cultivars (a promising biofuels crop) in Texas and in the Upper Midwest. Parameters derived for these important grass species, when incorporated into the ALMANAC model, provided simulations of grass growth and productivity in a wide range of soils and climatic conditions. Model results were validated with NRCS data for ecological sites in diverse regions and using measured data at a wide range of latitudes, from Texas to North

Dakota and Wisconsin. The model will be useful for assessing the impacts of biofuels production on the management of natural resources in grasslands

Successful conservation planning more likely with improvements made in method that enables model combinations Improved plant growth modeling is needed to better assess the impacts of implementing conservation practices at field to watershed scales. PhenologyMMS Version 1.2.2 was released and can be used as a stand-alone tool or incorporated into existing crop simulation models and decision support tools to simulate changes in multi-crop phenology due to varying levels of soil water availability. Version 1.2.2 provides the complete developmental sequences of the shoot apex correlated with different developmental events for winter and spring wheat, winter and spring barley, maize, proso millet, hay millet, and sorghum. The Unified Plant Growth Model (UPGM) has been developed and tested for corn and wheat across a range of environments and successfully merges different versions of the EPIC-based plant growth model that exist in many agricultural system simulation models (e.g., GPFARM, WEPP, WEPS, SWAT, and ALMANAC). Improvements in simulating plant growth have been made using this stand-alone foundation, giving it a higher degree of utility (more crops) and portability (can be incorporated as a modular component in other models).

Successful conservation planning more likely with improvements made in method that enables model combinations. A modular simulation framework is greatly needed to facilitate the development of the regionalized watershed models for CEAP (Conservation Evaluation Assessment Project). ARS scientists at Ft. Collins, CO enhanced the Object Modeling System (OMS) development framework to allow flexible simulation management, self-contained model run-time execution, and improved data file handling for input parameter sets and simulation output. The OMS was also extended to transfer and retrieve science modules to and from a USDA CoLab-based component library. A prototype OMS component for visualization and manipulation of geospatial data was developed using NASA World Wind geospatial technology. NRCS has agreed to use the OMS to streamline development of customized field to watershed agricultural system models that address regional soil and water conservation and water quality needs. The ability to easily combine or substitute models under OMS will provide a foundation for improved conservation planning through future addition of customized science

Extensive data set for semi-arid rangelands made available . Short and long-term predictions of climate change effects are dependent upon models, which are dependent for validation ondata sets. ARS scientists in Tucson, AZ completed a multi-year project with the goal to improve data access to promote analyses and interpretations of historic and current data on the Walnut Gulch Experimental Watershed. Although current data is being collected in easily –retrievable form, the historic data set required extensive transcription and compilation. The collection of geo-spatial referenced data describing rain, run-off, sedimentation, meterology, soil hydrology, and vegetation changes is the most extensive data set in the world for a semi-arid area in a watershed greater than 10 Km2. A special section of the Journal Water Resources Research and the associated Web site (http://www.tucson.ars.ag.gov/dap/) describe 50 years of data collection and the most recent research results. These data will be invaluable for developing and testing rangeland erosion and sediment yield models and assessment tools.

Problem Area 2—Irrigation Water Management

Development of a process-based model for contaminant transport. Process-based computer models are important tools for studying and predicting the fate and transport of agricultural contaminants in soils and groundwater, and for designing optimal soil, water or crop management practices. Scientists at Riverside CA released a new version that of the HYDRUS-1D software package that includes new or improved capabilities for simulating: vapor flow; coupled water, vapor, and energy transport; dual-permeability type water flow and solute transport; evapotranspiration, transpiration, and precipitation; and biogeochemical reactions and transport.

The new features make the software more suitable for application to a broad range of agricultural and industrial subsurface pollution problems.

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

Unmanned aerial vehicles used to improve crop water management. Thermal infrared (TIR) emittance has been well-correlated with canopy temperature and often used as a measure of dissipation of excess energy from plants. However, until recently, field-scale estimates of TIR emittance have been too expensive, lacking inf temporal resolution, and generally impractical. Recent advancements in TIR cameras mounted in small, unmanned aerial systems have allowed researchers to assess crop response to irrigation and winter cover crop management at the field scale. TIR data acquired in this way by ARS scientists at Tifton, GA were more sensitive to crop response to microclimate conditions compared to traditional, and more time intensive, methods of assessment. Practical implications of this tool include in-season mitigation of crop stress, improved irrigation strategies, and an assessment of landscape level effects on crop productivity. This leads to lower risk for the grower, potential savings in water, and reduction in nitrogen loss from fields.

New irrigation management software helps conserve water. Performance of gravity (surface) irrigation, the prevalent method of on-farm water application in the U.S. and worldwide, typically is low (as measured by water used by the crop as a ratio of that delivered to the field). ARS researchers at Maricopa, AZ, have released Version 3 of WinSRFR, a surface-irrigation software program that substantially improves irrigation system design and operation based on hydraulic engineering principles. The program can analyze field evaluation data, estimate field infiltration properties from this data, analyze design alternatives, optimize operations, and conduct simulation studies. The new release includes new design and operations analysis procedures for irrigation system types that were not included in previous versions of the software (open- and closed-ended furrows, close-ended borders). Intended users include university extension agents, farm advisors, irrigation consultants, and irrigation specialists. Previous versions of the software have been used throughout the U.S. by NRCS.

Both yield and water use are important considerations in selecting a crop to grow. Changing cropping systems to improve profit and/or conserve water. Rising energy costs for pumping the diminishing water resources of the Ogallala Aquifer is a major concern of agricultural producers in south-central regions of the U.S. Crop simulations show that switching from corn to early-maturing cotton varieties would save water and energy costs and improve chances of higher economic returns in 91 out of 131 counties in the panhandle regions of Texas and Oklahoma and southwest Kansas. In other experiments by ARS researchers in Bushland, TX, in-season yield of forage sorghum (1,700 g per sq m) was less than corn for silage (2,400 g per sq m), but sorghum had 27 percent lower evapotranspiration per unit production. As pumping costs escalate and aquifer water availability decreases, sorghum is an attractive alternative to corn for silage production in the Southern High Plains. However, corn yields and respective economic returns increase at a higher rate than with sorghum, therefore corn would be preferred if water is not a

limiting factor. This kind of research information allows growers to make informed decisions as they weigh options between risk and profitability.

Wireless technology facilitates automatic irrigation scheduling . Infrared thermocouples (IRTs) have proven reliable for remote measurement of crop canopy temperature as an indicator of crop water stress. However, wired IRTs would be cumbersome for the grower to set up, maintain, and dismantle each irrigation season in a commercial system. ARS scientists at Bushland TX, have developed a prototype wireless sensor device that interfaces an off-the-shelf IRT with an off-the-shelf radio frequency module to sample, average and send data to an embedded computer at the irrigation center pivot. This technology will improve automatic irrigation scheduling using sensor network systems resulting in more reliability, more accurate and efficient site-specific water application and greater savings in water

Breeding lines of short-season, stress tolerant corn save the stressed Ogallala Aquifer. Plant breeders and Texas A&M University have developed drought- and high temperature-tolerant corn germplasm that requires less water to produce equal yields, and value-added germplasm (supersweet corn) to increase crop value. The shrunken (sh2) gene was stacked into drought- and heat-tolerant and insect-resistant lines, and four supersweet corn inbred lines adapted to the High Plains also were developed. Multiple-stress-tolerant corn hybrids yielded well under full- and limited-irrigation conditions. The average silage yield of 20 corn hybrids at two locations in the Texas High Plains was 26.84 tons/acre under 75% evapotranspiration (ET) irrigation, not significantly different from 27.49 tons/acre under 100% ET irrigation. A significant amount of Ogallala Aquifer water can be saved by using new stress-tolerant corn germplasm and adopting modifications to irrigation recommendations.

Animal wastes a valuable nutrient source for forage crop via subsurface drip irrigation. Land application of animal waste from livestock treatment systems is an environmental and social concern in the eastern US. ARS scientists in Florence, SC evaluated the potential of using a subsurface drip irrigation (SDI) system for application of animal waste effluent to bermudagrass hay. Plots receiving treated effluent had significantly greater hay yields than plots supplied with recommended levels of inorganic fertilizer. Moreover, effluent-treated plots had significantly greater nutrient biomass removal than the commercial fertilizer plots. The plant nutrient removal prevented adverse impacts on soil or water quality.

Salt tolerant plants improve quality of drainage water for reuse. High salinity and selenium (Se) contents are major concerns for drainage water reuse in the west side of the San Joaquin Valley of California (SJV). ARS scientists in Parlier, CA identified plant species and poplar tree clones that were well adapted to sustainable drainage-water reuse strategies and for growing in areas with underlying poor quality waters in the west side of the SJV. Seed yields for oil crops ranged between 1.0 and 1.5 tons/acre, while poplar trees were annually cut and cuttings were considered for gasification uses. Over 6 years, salt-tolerant plants lowered total soil Se via plant accumulation and volatilization; however, some leaching of newly deposited extractable Se also occurred. Improved options for sustainably using an agronomic-based system for drainage water reuse strategies can encourage more widespread usage in the regions of central California.

Saline water acceptable for reuse on some floriculture crops. Water reuse can extend available fresh water supply and decrease drainage disposal requirements. Whereas many floral and ornamental crops are susceptible to salinity and specific ion toxicity and do not grow well using saline recycled waters, opportunities exist to use such degraded waters on tolerant species or during more tolerant growth stages. ARS researchers at Riverside, CA produced premium stems of snapdragon with moderately saline waters and commercially acceptable stems of marigold with waters of low salinity. Three marigold cultivars maintained high aesthetic value and are appropriate for salt-affected landscapes. Drainage water releases are prohibited in nursery crop production areas. These findings provide a method to economically re-use drainage water and thereby reduce the disposable volume.

Problem Area 3—Drainage Water Management Systems

Bioreactors developed for improved water quality. Loss of nutrients from heavily fertilized or manured fields can lead to water quality degradation and hypoxia in waterways. Nutrient contamination is a major water quality concern and its remediation a national priority. A novel approach to drainage water management is to filter the runoff in areas where diffuse flow is concentrated through low-cost materials such as industrial byproducts and agricultural waste products. ARS scientists at Columbus, OH have screened 55 industrial byproducts and found five that hold promise for removing nitrate, phosphate and atrazine from drainage waters. ARS scientists at University Park, PA have evaluated filter designs and materials for phosphorus removal, and in Florence, SC, ARS researchers have denitrified drainage waters by directing flow through biofilters filled with immobilized sludge. In field tests, the immobilized sludge removed 50 percent of the nitrate-nitrogen from drainage water. The calculated removal rate was 94 g nitrate per day per square meter, which is significantly greater than treatment wetlands.

Problem Area 4—Integrated Soil Erosion and Sedimentation Technologies

Modelling of land cover change can be used as a management tool to reduce erosion. Growth and development in environmentally sensitive areas can lead to high rates of erosion. ARS scientists in Tucson, AZ used landscape metrics (soil type, elevation, and contour detail) in conjunction with hydrological process models to predict effects of land use/land cover changes to water and sediment yield. Sub-watersheds in the Willamette River Basin OR were modeled based on three possible future growth and development scenarios to the year 2050. Variables included differences related to conservation, planning, and open development as compared to 1990 land cover. Results identified potential water quality problems that would result from land cover changes in sensitive environmental areas. Such analyses could be applied to both urban and agricultural development in a large river basin.

Erosion prediction technology improved for frozen soils. Erosion prediction has consistently performed poorly for areas dominated by frozen soil conditions, in which processes including freezing, thawing, snow accumulation and snow melting significantly affect soil loss. Scientists at West Lafayette, IN and Pullman, OR have collaborated to release of an updated version of the Water Erosion Prediction Project (WEPP) model with improved winter hydrology/erosion code, providing the many users of this technology with better predictions of soil freezing, thawing, and snow melt driven runoff and erosion, which are very important in more northern latitudes. Energy-based winter routines reproduced with reasonable accuracy snow, frost and thaw depths, and runoff from two widely different treatments.

Starch/polyacrylamide can be used as an amendment to prevent erosion.. Water flowing in irrigation furrows can erode soil and transport sediment and associated nutrients off the field. A new starch/polyacrylamide amendment was compared against polyacrylamide-treated and untreated furrows in a field test in Kimberly, ID. The new amendment, which is a blend of potato starch and polyacrylamide (PAM), increased infiltration 20% and reduced soil erosion 65% compared to untreated furrows. When applied at the same rate, PAM treatment increased infiltration 13% and reduced erosion 98% compared to untreated furrows. The new polysaccharide/PAM amendment can be used as an alternative to PAM for improving infiltration on furrow-irrigated fields, although greater application rates will be needed to provide erosion control as effectively as PAM.

Sediment retention ponds provide added insurance against erosion losses. Conservation tillage, vegetative buffers and controlled irrigation offer effective measures for reducing erosion losses and maintaining high soil productivity. But these systems are somewhat ‘leaky’, especially on highly erodible soils. Additionally, high rainfall events can bypass these systems and deliver

substantial sediment load to surface waters. The Upper Snake-Rock (USR) Conservation Effects Assessment Project (CEAP) was initiated in 2005 to determine the effectiveness of conservation practices in an irrigated watershed. Water flowing back to the Snake River from the 200,000-acre watershed is being monitored by ARS researchers in Kimberly, ID. Sediment retention ponds have been found to be an effective conservation method. Suspended sediment loss decreased from 400 lb/acre in 1971 to 50 lb/acre in 2005. Sediment retention ponds installed in 2006 on one return flow stream reduced annual average sediment concentration from 400 mg/L in 2005 to 70 mg/L in 2007 and reduced sediment load by 5500 tons. This work provides much-needed quantification of the value of retential ponds to control sediment loading.

Sediment identification techniques provide an effective tool for targeting conservation practices.. Sediment is a major pollutant in many watershed streams, and identification of sediment sources is critical to provide cost effective management to these watersheds and reduce sediment pollution. Using sediment identification techniques, ARS scientists in Tucson, AZ determined that three subwatersheds on Walnut Gulch Experimental Watershed were contributing 86% of the sediment load from the watershed and that 65% of the stable carbon isotope leaving the watershed was from shrub plants that dominate the vegetation on the three subwatersheds. Land managers and landowners using the sediment identification techniques can now determine areas where they should focus their limited resources to produce the greatest reduction in sediment loads.

Paper mill sludge enhances surface-mine reclamation. Paper mills generate a large amount of byproduct that consists of, clay, lime, and fibers too short to make paper. Paper mill sludge (PMS) can improve reclamation of surface-coal mines where low pH and organic-carbon levels in the spoil cover material can inhibit revegetation. However, PMS may adversely impact the water quality when used at high rates. Scientists at Coshocton, OH found that rates as high as 672 Mg/ha drastically reduced runoff and erosion and improved soil quality and plant growth compared to standard reclamation practices, while not increasing the load of other pollutants to runoff. These results will aid in establishing regulatory guidelines for PMS use and potentially increase applications of this byproduct.

Increasing the flow capacity of small watershed flood control dams. The USDA-NRCS provided technical and financial assistance on design and construction of nearly 11,000 flood control dams, installed in 47 states since 1947, and half of these will reach their planned service life by 2018. Stepped spillways offer a cost savings relative to other rehabilitation methods, but there are design issues that need resolution. Convergent stepped spillways are one potential configuration but result in increased flow depth near the training wall, so the height of the training walls to retain the flow in the spillway chute must be determined. ARS engineers at Stillwater, OK developed an equation for designing the dimension criteria of converging vertical sidewalls. The training wall height equation for converging spillways will provide design guidance so that the spillway adequately operates and protects the remainder of the embankment. Stepped spillways will be placed over about 10% of the existing dam embankments as a solution to rehabilitation and safety needs.

Bank-Stability and Toe-Erosion Model (BSTEM) improved. Suspended sediment is one of the leading causes of surface water-quality impairment, and recent studies have shown that stream banks are often the major sediment source in disturbed systems. ARS scientists at Oxford, MS enhanced BSTEM to predict sediment loadings from stream banks in a variety of environmental conditions by conducting simulations under existing and mitigated conditions. Using the model's improved root-reinforcement algorithms that account for plant species, vegetation types, and plant ages and distributions, riparian buffers that maximize bank stability can be designed and evaluated before they are actually built. Sedimentload reductions of 50-85% to the streams were predicted in different environments. BSTEM has been distributed to stakeholders in state and federal agencies and is taught in workshops at academic institutions and at national technical meetings.

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

Irrigation scheduling through remote sensing from aircraft. The ability to map evapotranspiration (ET) and soil moisture availability via satellite has broad applications in monitoring drought and consumptive water use, administering irrigation projects, predicting local and regional water demand, and in providing important boundary conditions to hydrological and weather forecast models. ARS scientists in Beltsville, MD, and Tifton, GA, have developed algorthims that relate real-time thermal measurements acquired from saltellite and unmanned aircraft to crop water need and crop production projections in both irrigated and rain-fed agricultural landscapes. Thermal infrared data acquired from unmanned aircraft are more sensitive to crop response to micro-climate conditions compared to traditional, and more time intensive, methods of assessment. Practical implications of this tool include in-season mitigation of crop stress, improved irrigation strategies, and an assessment of landscape level effects on crop productivity.

Satellite data used to assess adoption of conservation practices. Conservation tillage is a commonly adopted best management practice for improving soil quality and reducing erosion; however, there are currently no methods in place to monitor conservation tillage adoption at the watershed scale. A mapping algorithm, using commonly available satellite imagery, has been developed to depict conservation tillage adoption within the Little River Experimental Watershed in Georgia. The resulting map identified farm sites using conservation tillage with 71-78 % confidence. Results suggest that currently available satellite imagery can be used to map conservation tillage adoption with a minimum amount of ground truth collection. The effectiveness of conservation practices can be better correlated with changes in water quality and sediment within watersheds.

Airborne measurements successfully used to classify riparian vegetation. Better methods are needed for estimating water use in semiarid riparian systems so that regional water balances can be monitored and healthy riparian flows maintained. Airborne and ground based LIDAR (LIght Detecting And Ranging) technology was used by ARS scientists in Tucson working with the Universities of Arizona and Florida. LIDAR-derived estimates of canopy height, crown and trunk diameters, and canopy cover were used quickly and accurately to differentiate age classes of cottonwood trees for riparian areas in the San Pedro River Basin near Benson, AZ. The mean intensity of return laser pulses from the canopy surface was well correlated with ground measurements. The LIDAR-derived canopy information has the potential to improve riparian corridor water use estimates for the Upper San Pedro Basin and other semiarid riparian systems. Accurate water use information is valuable to regional water districts so that efficient and timely releases of water can be made for urban, agricultural and ecosystems purposes..

carbon dioxide over large areas can be monitored by satellite. There is a need for techniques to quantify accurately carbon dioxide (CO_2) sources and sinks over large areas because of the importance of atmospheric CO_2 levels on the climate. ARS scientists in Tucson, AZ developed an approach for producing estimates of daily net CO_2 flux using a combination of satellite imagery, the Water Deficit Index, and Bowen ratio energy balance measurements. This approach can be used to map daily net CO_2 flux at the landscape scale for a better understanding of the role semiarid grasslands play in the carbon cycle. The information is valuable in monitoring carbon sequestration in grasslands and evaluating the effects of global climate change.

Natural river wetlands help control pollution. Natural wetlands occurring in the flood plain near rivers can be modified and used as management practices to improve and sustain river water quality. Studies conducted at Oxford, MS by ARS researchers in a modified natural wetland near the Coldwater River in northern Mississippi demonstrated how effectively a wetland could trap three commonly used agricultural pesticides (atrazine, metolachlor and fipronil) and prevent them

from entering the river. Such an approach may represent an additional tool to improve and sustain river water quality and overall environmental quality.

Model developed to evaluate overtopping potential in dams.. ARS scientists at Stillwater, OK, have collaborated with NRCS and Kansas State University to complete the alpha test version of the computer engineering application tool WinDAMa+. Enhancements to the application software WinDAM,, Windows Dam Analysis Model, allow users to evaluate overtopping limits of vegetated embankments and to evaluate the integrity of the earthen spillway in one computational package. The software will determine the amount of flow through the principal spillway(s), auxiliary spillway(s), over the vegetated or rock rip-rap-protected earthen embankment and erosion of the auxiliary spillway. This computer tool will be important in evaluating existing structures, with potential of reducing costs associated with rehabilitation.

Dam and levee models help to predict breaching and improve dam design. Most global climate change predictions agree that floods and droughts will increase in severity. The potential for increased flooding places great emphasis on predicting and managing dam-break and levee breeching events..The original CCHE1D and CCHE2D Free Surface Flow Models were developed for unsteady turbulent flow, but not for rapidly varying surface flows, which require a significant advancement of the numerical methods. The National Center for Computational Hydroscience and Engineering, working with ARS at Oxford MS, and other world organizations, recently have developed, verified and validated advanced numerical solution methodologies that have been incorporated into CCHE1D and CCHE2D. The free surface flow models are now capable of simulating the rapidly varying unsteady flows. This effort shall enable better decisions in planning of dam/levee designs and managing dam-break/levee-breaching events.

Economic models are being developed to assess the socio-economic impacts of depleting groundwater from the Ogallala Aquifer. Economic analysis indicates that water costs per acre using conventional irrigation systems and techniques range from $11.70 to $13.40, whereas the costs using sprinkler systems range from $12.53 to $15.47. However, pumping costs, due to high pumping rates under conventional irrigation systems, are higher ($345 to $243 per acre) than for sprinkler systems ($158 to $120). Pumping costs decrease from $38 to $102 per acre from conventional irrigation systems if Low-Energy Precision Application (LEPA) techniques are adopted, while saving ranges for Subsurface Drip Irrigation (SDI) save $10 to $82 per acre. Comparison of irrigation systems indicates that sprinkler systems have advantages over drip irrigation systems. However, the trade-off between water use efficiency and potential water conservation needs to be thoroughly evaluated before suggesting irrigation technology as one of the policy options for water conservation purposes. Optimization models serve as a valuable tool to analyze alternative water management strategies.

Optimization models are improved for socio-economic decision making in the Southern Ogallala Aquifer Sub-region. Baseline socioeconomic IMPLAN models were modified and validated for the Northern, Central, and Southern sub-regions of the Southern Ogallala Aquifer Region. The results of optimization models, along with other county-level economic data, are used to compute projections of the effects of the decline of water in the Ogallala Aquifer on the regional economy with respect to industry output, employment, and value added. Baseline regional economic impacts with respect to industry output over 60 years for three sub-regions of the Southern Ogallala are $2.1 billion for the northern region, $929 million for the central region, and $3.1 billion for the southern region. The results reflect more accurate estimates of the economic impacts from the natural decline in the Ogallala Aquifer and can help regional water managers and government leaders make informed decisions.

Best Management Practices (BMP) are promoted to conserve Ogallala Aquifer water. Ogallala Aquifer Program participants are required by Congress to transfer technology developments to the public and to eductate the public on needs to conserve valuable ground water resources. The participants have worked together to develop reports, technical papers, and journal articles describing research results, new developments, and recommendations for practices that support water conservation. Some products and resources are being adapted for general audiences and

converted to electronic format through the Ogallala Aquifer web site and other electronic media resources. Materials include a new comprehensive agricultural irrigation curriculum, training manual and workshop series. Information on management practices for soil water conservation, tillage and residue management, and irrigation (system efficiencies, evapotranspiration, water balance methods) have been presented at workshops reaching about 125 consultants and producers, 500 Master Gardeners, lawn and tree care professionals, homeowners, 5400 K-12 students, and 200 K-12 teachers. This effort involved more than 40 undergraduate and graduate students. In addition, Dr. Dirt's K-12 Teacher Activities website was developed to assist teachers with instruction material for soil and water management concepts. Dr. Dirt's K-12 Teaching Activities website materials were used by teachers in Illinois, Indiana, Texas, Alaska and New York. Others users include: The Globe Project at NASA Goddard Space Flight Center-Biospheric Sciences Unit, environmental science departments at University of California Berkeley and the University of San Francisco, and a multitude of other groups at universities, colleges, and miscellaneous private and public entities.

Problem Area 6—Water Quality Protection Systems

Microbes responsible for Bt endotoxin degradation in soils. The use of genetically-modified crops that contain the gene that produces *Bacillus thuringiensis* (Bt) insecticidal endotoxins has raised the concern that the endotoxin may persist in the environment. In soil, there is conflicting information on persistence that is partly due to methodological limitations. ARS scientists at St Paul, MN, used labelled endotoxin to study its mineralization in soil incubated under controlled conditions. Fifty-nine percent of the label was recovered as $^{14}CO_2$ at the end of the 20-day incubation period, indicating a significant degree of degradation of the toxin. Corn residues added to the soil further stimulated mineralization of the toxin. Since low mineralization (approximately 6%) of the toxin was observed in autoclaved soil, the findings indicate that microbial processes play a major role in the dissipation of the Cry1Ac endotoxin in soil.

DNA-based fecal test may be inaccurate. Fecal contamination in streams and water bodies is routinely tested, and DNA primers have been used to identify sources of fecal contamination. The results of the tests can be the basis for important management decisions. Although the accuracy of a set of Bacteroides-specific primers currently used to distinguish human and non-human fecal contamination in the environment was previously tested and validated using multiple fecal sources, ARS scientists in Maricopa found that the human primers cross-amplified with fish fecal DNA. The primers in question have been used in dozens of fecal source tracking studies, many performed in natural waters where fish could potentially contribute significantly to fecal contamination. These studies point to the need for additional testing of the primers and will be useful information for researchers, fish farmers, and public health managers

Vegetative buffers reduce herbicides in soil and groundwater. Vegetative buffers can be used to sequester and degrade deposited herbicides, but information is lacking on effective buffer design. Results with five forage species in Columbia MO indicated that the majority of applied atrazine remained in the soil, and only a relatively small fraction of herbicide leached to shallow groundwater (<15%) or was taken up by plants (<4%). The grasses enhanced atrazine degradation in soil through their ability to increase microbial growth and activity in surface soil. Because of its ability to tolerate high levels of exposure to atrazine, switchgrass is recommended for use in vegetative buffers designed to reduce atrazine transport to surface or ground waters. ARS research in Miami demonstrated that switchgrass buffers effectively stopped endosulfan and its major degradation products from moving down a 5 percent slope. This research benefits conservation agencies, such as NRCS and state conservation departments, since it provides the needed science for improving vegetative buffer designs for improved protection of water resources impacted by row crop production.

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