The USDA-Agricultural Research Service Watershed Research Program

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Abstract

Water quantity and quality issues have increasingly become the focus of attention of United States citizens, private and public organizations, and units of government striving to meet competing demands while protecting the environment and public health. Sound agricultural management practices are required to ensure success in maintaining a healthy and productive land and water base that sustains local communities, food and fiber production, and also protects and restores critical natural systems. The central mission of the USDA-Agricultural Research Service's (ARS) Watershed Research Program is to address challenges and solve problems that confront American agriculture enterprises. The ARS accomplishes this mission by using the scientific method to improve our understanding of basic hydrologic processes. ARS and its collaborators use this knowledge to develop new methodologies and technologies to mitigate deleterious effects of floods and droughts, reduce soil erosion and sedimentation on our farms and within our streams and lakes, improve water quality, and enhance water supply and availability. The ARS watershed network is a set of geographically distributed experimental watersheds that has been operational for more than 70 years and is the most comprehensive watershed networks of its kind in the world. The watershed facilities serve as outdoor laboratories that provide an essential research capacity for conducting basic long-term, high-risk field research. The watershed network and its associated historical database from 23 states provide the only means to evaluate the long-term impacts and benefits of implementing agricultural practices on water quality and water availability, documenting effects of global change, and developing new instrumentation and decision support systems to enhance the economic and environmental sustainability of agriculture. More than 140 ARS subwatersheds and related facilities, ranging in size from 0.2 hectares to over 600 km^2, are currently operated from 17 research facilities within the continental United States.

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Introduction and History

The ARS Watershed Network (Figure 1) can be broadly characterized as an *intensive* network where some sets of geographically distributed watersheds are observed and studied in great detail. In an intensive network, numerous observations and dense instrumentation nets are concentrated in relatively small watersheds to support investigations for specific hydrologic process understanding. This is in contrast to an *extensive* network which collects information over a much larger area, at lower instrumentation resolution, for broad interpretation by providing regional "index" information (Neff, 1965).

The ARS Experimental Watershed Program grew out of depression era efforts by the Civil Conservation Corps (CCC) and the Soil Conservation Service (SCS). Kelly and Glymph (1965) described the early history of the watershed program, including research associated with the 1930s conservation motto "stop the water where it falls." The research focused on merits of upstream watershed conservation to reduce runoff and erosion. It was geared to studying on-site problems and concentrated on field-sized watersheds up to roughly 10 hectares and, to a large extent, utilized paired watershed analyses. In the mid-1930s, major research stations were established in Coshocton, OH; Hastings, NE; Riesel, TX, and Watkinsville, GA to examine fields and watersheds up to several hundred hectares in size. Research addressed on-site effects of tillage and management practices, and plot and lysimeter studies were incorporated at some sites. Many of these experimental watersheds were transferred to the newly formed USDA-ARS in 1954.

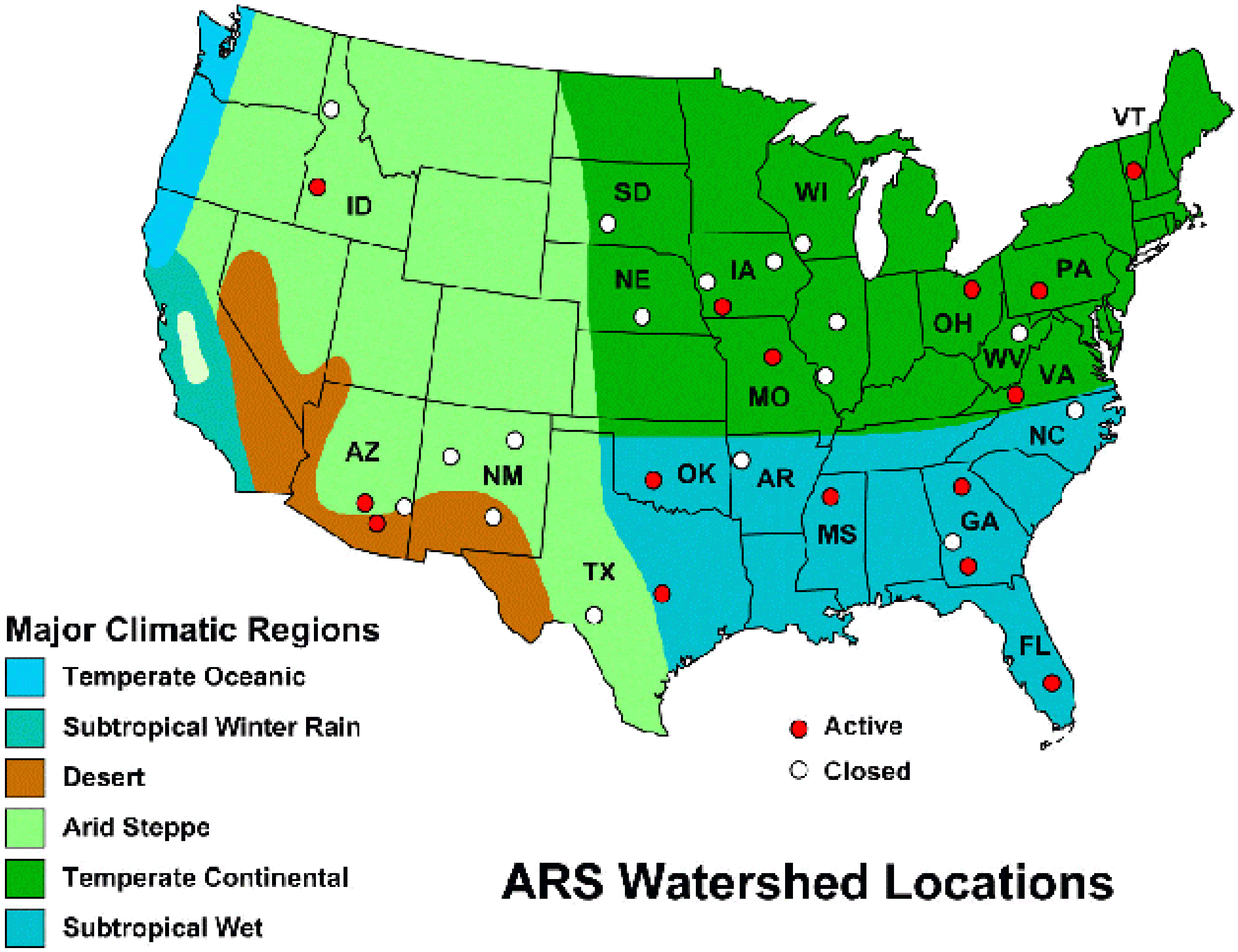

Figure1. Locations of the historical and active Agricultural Research Service experimental watersheds.

There was early recognition of the scaling problems in transferring knowledge from small to larger watersheds (Harrold and Stephens 1965). This problem and growing concern of downstream, off-site impacts of upstream watershed practices resulted in establishment of a subset of larger ARS experimental watersheds associated with new watershed research centers in a number of hydroclimatic regions in compliance with U.S. Senate Document 59 (Great Plains, Northeast, Northwest, Southeast and Southwest Watershed Research Centers in Chickasha, OK; State College, PA; Boise, ID; Tifton, GA; and Tucson, AZ; respectively). The goal in establishing the watershed research centers was to select a representative basin and establish satellite basins, which were less well instrumented, to extend the data and findings from the primary watershed center. Nested watersheds and unit source areas on major soil types were included in the watershed designs to investigate scale effects.

The Current Network

Seventeen locations within the contiguous United States are currently collecting a variety of abiotic and biotic data at 140 subwatershed nested within the larger ARS watersheds. Watersheds are currently being added to the network to address water quality and turf management issues in Iowa, Indiana, Ohio, and New York. Data from these watersheds will be available in the near future. The ARS watersheds represent numerous diverse land uses and agricultural practices and cover a wide range of hydroclimatic conditions. The diversity of observations made at these watersheds is a reflection of the diversity in dominant hydroclimatic processes across locations and evolving research objectives. As research objectives have changed to address problems such as water quality (e.g., biotic, chemical, pathogen, sediment) and global change, instrumentation and observations have been added to the basic rainfall-runoff observation infrastructure. An important component of the network is the ARS Hydraulics Engineering Unit located in Stillwater, Oklahoma which has provided critical expertise and facilities in the development of flood-control and hydraulic structures and runoff measurement devices deployed in many of the watersheds. ARS also conducts hydraulic engineering research on the design and safety issues related to earthen dam flood control structures in support of Public laws' PL-534 and PL-566 at Stillwater, OK. Greater detail on individual ARS watersheds can be found at: http://www.nwrc.ars.usda.gov/watershed/.

Data Availability

The Agricultural Research Service (ARS) is a research organization. Data collected from the ARS Watershed Network should be considered experimental data. While much of the original instrumentation, installation and data processing procedures for basic rainfall, runoff and meteorological data was guided by Handbook 224 (Brakensiek et al. 1979 - revised from 1962), data collection has evolved at individual locations to address regional research needs. ARS watershed data have not historically been collected and reviewed under a national standard set of guidelines and procedures such as those employed by the USGS. Instruments, parameters observed, and data reduction procedures vary from watershed to watershed. A description of data acquisition programs and an assessment of the quality of collected data at many of the experimental watersheds is described in USDA (1982) and at: http://www.nwrc.ars.usda.gov/watershed/.

ARS does not have a mandate to monitor and distribute data collected at its experimental watersheds, availability of data from the watersheds also varies by individual ARS watershed location. Based on data compiled and maintained by Jane Thurman at the Hydrology and Remote Sensing Laboratory in Beltsville, Maryland, as of January 1, 1991, ARS had operated over 600 watersheds in its history. A rainfall-runoff database is available from in the Hydrology and Remote Sensing Laboratory for 333 of these watersheds. In addition, a historical climate database for the United States and the Cligen weather generator develop by Dr. Arlin Nicks is available at: http://hydrolab.arsusda.gov/wdc/arswater.html. About 16,600 station years of data are stored there from watersheds ranging from 0.2 hectares to 12,400 km^2. After 1990, the HRSL no longer archived data but has provided links back to the individual ARS watershed locations. These locations are making a concerted effort to make the ARS Experimental Watershed data more readily accessible and to provide additional types of data (soils, vegetation maps, geology in standard geographic information system formats, etc.) available through a web enabled search and retrieval system but progress varies due to resource constraints. It is anticipated that a prototype system that is currently being developed will be available in late 2004. Furthermore, we exploring methods to link the ARS databases with databases maintained by the U.S. Forest Service and its watershed network (Figure 2) and the Natural Resources Conservation Service Soil Climate Analysis Network (SCAN) (Figure 3) as a means to efficiently access both historical and real-time data on hydrologically important data. Those interested in working with ARS scientists and with ARS Watershed data should contact the Research Leader at that watershed location or can contact Dr. Mark Weltz, National Program Leader for Hydrology and Remote Sensing (maw@ars.usda.gov) for information about the Watershed Program as a whole.

Collaboration / Cooperation

The ARS Experimental Watersheds have been magnets for interagency, and university collaborative research. For instance, these outdoor laboratories have been invaluable for validating remote sensing satellites, aircraft-based instrumentation, and development of retrieval and prediction algorithms that are used by NASA for estimating a variety of biotic and abiotic parameters and conditions.

Several noted examples include interagency interdisciplinary hydrologic, atmospheric and remote sensing experimental campaigns:

I. Mahantogo'90
(Mahantango Watershed, PA)
II. Monsoon'90; Walnut Gulch'92
(Walnut Gulch Watershed, AZ)
III. Washita'92
(Little Washita Watershed, OK)
IV. SGP (South Great Plains, '97, '98, '99)
(Little Washita Watershed, OK)
V. DEC (Demonstration Erosion Control)
(Goodwin Creek Watershed, MS)
VI. SALSA'97-'99
(Walnut Gulch/San Pedro Watersheds, AZ)
VII. SMEX 2001-2002 (Walnut Creek Watershed, IA)
VIII. SMEX 2003

(Little River Watershed, GA)

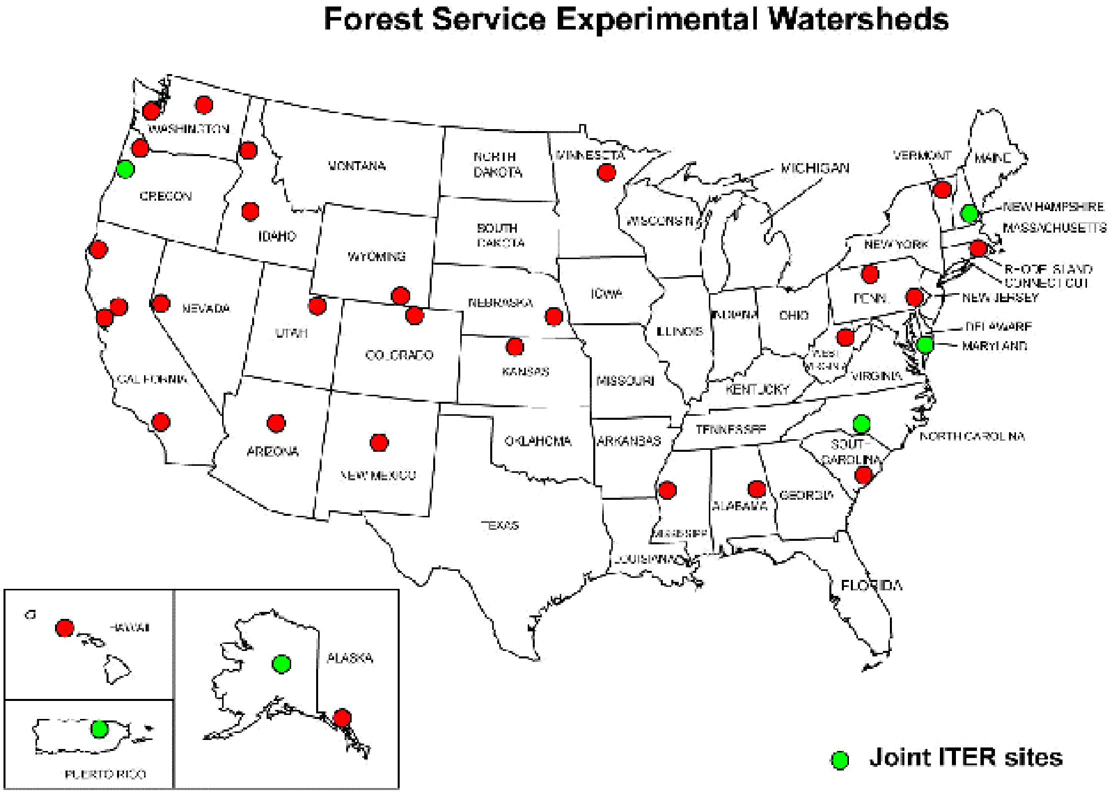

Figure 2. Locations of the US Forest Service experimental watersheds.

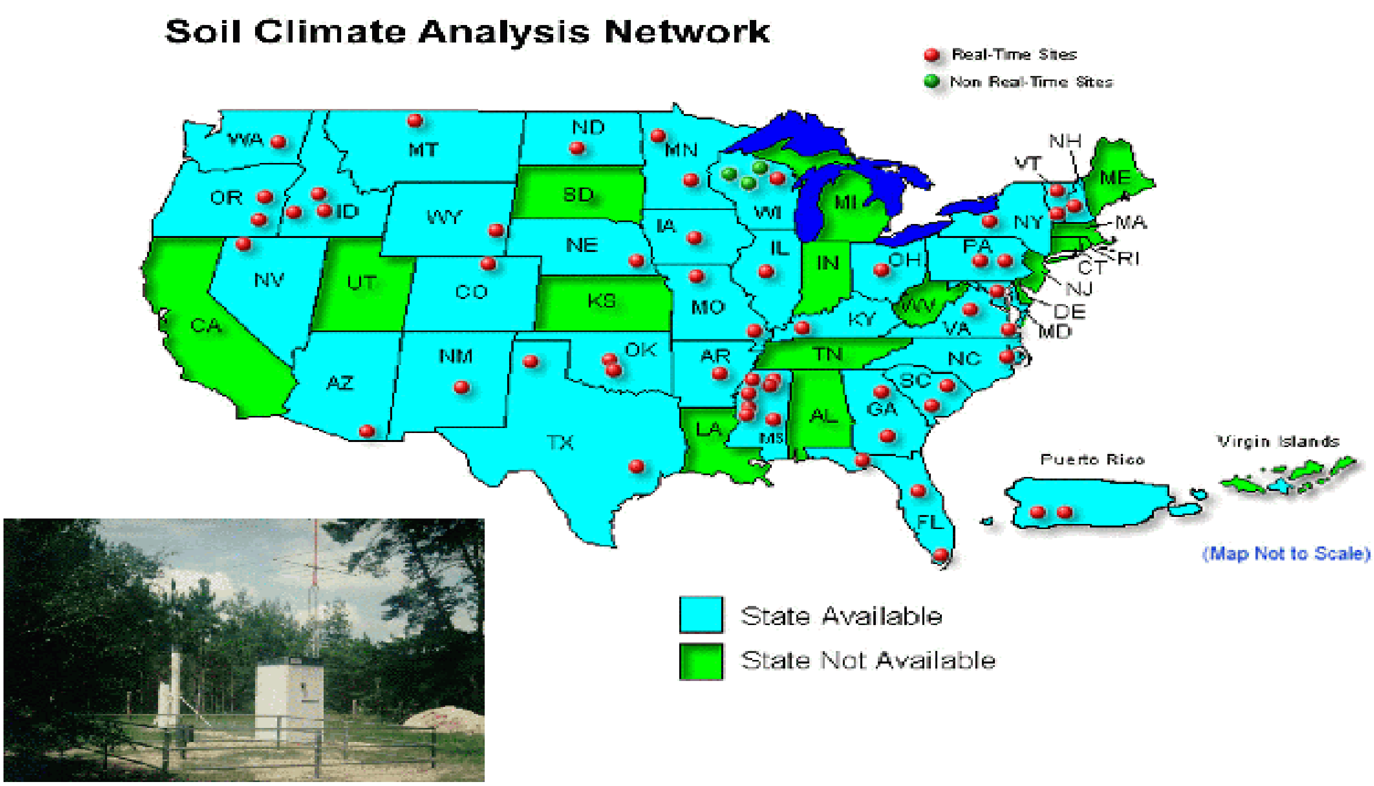

Figure 3. Locations of the Natural Resources Conservation Service Soil Climate Analysis Network many of which are co-located on the Agricultural Research Service experimental watersheds.

The ARS Experimental Watersheds are managed as outdoor laboratories. We stress collaboration with federal, state, and non government agencies in our management of theses facilities to broaden the types of observations being made and to leverage the existing watershed infrastructure to address the challenging questions facing the Nation today. Examples of ongoing collaboration:

- USDA-NRCS Soil Climate Analysis Network (SCAN) http://www.wcc.nrcs.usda.gov/scan/
- UNESCO/WMO Hydrology for the Environment, Life and Policy (HELP) catchments http://www.unesco.org/water/ihp/help
- Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUASHI)
- DOE AmeriFlux
- NOAA Surface Radiation Network (SURFRAD) in the Continental United States
- DOE Atmospheric Radiation Measurement (ARM/CART) site in Oklahoma

A new Joint U.S.-China Center for Soil and Water Conservation and Environmental Protection, was dedicated on May 2, 2002. 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 University of Arizona and the Southwest Watershed Research Center in Tucson, Arizona. ARS scientists are working collaboratively with their Chinese and University counterparts to develop new methods to reduce soil erosion and sedimentation that will benefit both countries in managing soil and water resources at both the field and watershed scale.

Major Accomplishments

Development of innovative instrumentation

ARS watersheds have pioneered the testing and development of stream flow instrumentation including the drop-box weir for high-energy, high-bedload systems, supercritical flumes for arid regions, and small-scale runoff flumes. Stream sampling methods for water quality such as the Coshocton Wheel, traversing slot sediment samplers, and widely used in-stream samplers have also come from ARS watersheds. Other advances include state-of-the-art hydro-meteorological field sensors, watershed-wide telemetry, archival equipment and systems, the dual-gage precipitation measurement system, load cell precipitation gage, radar and acoustics technology to measure sediment transport, snow pillow and advanced snow sensors and programmable, variable rate, rainfall simulators.

Development and testing of remote sensing technologies and applications

Pioneering research in both the theory and application of remote sensing to the use of microwave remote sensing of soil moisture has been conducted by ARS personnel at the ARS watersheds. Results are currently being implemented by both NASA and the Japanese space agency. Large scale soil moisture observations may contribute to major breakthroughs for hydraulic modeling, crop yield forecasting, drought assessment, irrigation management and the ability to detect and model land surface response in climate change studies. In addition, long term acquisition of complimentary remote sensing imagery supported by ground and atmospheric measurements at several ARS watersheds are used as long-term validation for both NASA and European Space agency sensors.

Improvement in agricultural water quality

Nutrients and herbicides related to farming practices have been detected in shallow groundwater and agricultural runoff in many parts of the country. ARS watershed research has led to: (i) buffer system designs composed of grasses and trees that can be used to assimilate nitrogen and phosphorus from both surface water and shallow groundwater and reduce off-site impacts of animal feeding operations, (ii) nitrogen management practices, using the ARS-developed Late Spring Nitrate Test, which have demonstrated reduced nitrate pollution levels, (iii) the development of the Soil and Water Assessment Tool (SWAT) model, which has been applied extensively for policy planning and in developing best management practice alternatives, and (iv) the quantification of water quality impacts of brush control herbicides picloram and clopyralid, which were shown to dissipate quickly in the soil and to be undetectable in surface runoff or subsurface flow. Studies in ARS watersheds were instrumental in obtaining approval of these herbicides for public use.

Rainfall frequency analyses

Analyses of ARS dense rain gauge networks were utilized to modify NOAA National Atlases of rainfall frequency which is utilized to develop design storm characteristics for flood control maps and prevention activities.

Development of hydrologic and natural resource management models

ARS watershed research and data have been critical to the development and validation of natural resource models too numerous to mention in this report in detail (ANAGNPS, CONCEPTS, CREAMS, Curve Number, GLEAMS, EPIC, KINEROS, REMM, RUSLE2, SRM, SWAT, and WEPP). An example of an ARS model that has had tremendous impact is the Universal Soil Loss Equation (USLE) model. The USLE and its replacements the Revised Universal Soil Loss Equation (RUSLE) and RUSLE2 erosion prediction tools are the most widely utilized field scale erosion prediction tools in use around the world today. The USLE model was recently recognized for its outstanding impact on sustaining agriculture production around the world by reducing soil loss by the American Society of Agricultural Engineering. The ARS-developed KINEROS model was utilized by a consulting firm and resulted in construction saving of over $16 million on a series of dams on the Au Sable River in Michigan. More recently, the Simulator for Water Resources in Rural Basins (SWRRB) model and the Soil Water Assessment Tool (SWAT) model have been used by many federal and state agencies to evaluate USDA conservation program effectiveness and the economic and environmental impacts/benefits derived from implementing conservation practices.

Hydraulic structure design

The Natural Resources Conservation Service (NRCS) has used ARS developed procedures for design and construction of more than 800,000 km (500,000 mi) of vegetated channels. The design procedure is listed as one of the top five outstanding agricultural engineering achievements of the 20th century by the American Society of Agricultural Engineering. These and other design criteria are available on the SITES 2000: Water Resources Site Analysis CD from ARS. This expert system is helping NRCS and local sponsors of earthen dam flood control structures design urgently need safety upgrades to the 11,000 structures that have been constructed across the United States. ARS in association with the Oklahoma Conservation Commission has also developed a video that describes the benefits of these small hydraulic structures that explains the importance of maintenance and repair of the structures.

Future Program Direction

The ARS Watershed Program and its Experimental Watersheds provide exceptional **"outdoor laboratories"** to develop knowledge that addresses societal water resource issues in real world settings. The stability of these research platforms, with a high-quality knowledge base and observational infrastructure makes them ideal facilities for collaborative research to investigate the hydrologic cycle and potential changes to it across a wide range of hydro-climatic conditions. There is no comparable network of experimental agricultural watersheds in the world. For a marginal increase in resources, many of these ARS Watersheds can integrate additional observations of critical state, flux and biogeochemical variables to become independent verification and validation watersheds for addressing questions on availability and reliability of clean water and address issues related to Total Maximum Daily Loads (TMDL) and global climate changes that are confronting our Nation. In addition, a number of ARS Experimental Watersheds could potentially partner with the National Environmental Observation Network (NEON) that the National Science Foundation is attempting to implement across the nation (http://www.nsf.gov/bio/neon/start.htm).

NEON is envisioned as a network of networks, a system of environmental research facilities and state of the art instrumentation for studying the environment that will enable integrative research on the nature and pace of biological change at local, regional and continental scales. The ARS watershed network could collaborate with the NSF sponsored NEON partners to develop advanced technologies and measurement capabilities to document the impact and benefits that agricultural production systems have on all factors that affect the structure and function of natural and managed ecosystems and the ability of these systems too sustainable deliver clean and safe surface and ground water supplies to the public.

A second critical role of experimental watershed data in the quest for hydrologic scientific understanding was clearly stated in the 2001 NRC report *Envisioning the Agenda for Water Resources Research in the Twenty-First Century.* The report states the following: "Intensifying water scarcity cannot be successfully addressed in the absence of reliable data about the quantity and quality of water over time and at different locations. The end-of-century trend of investing fewer and fewer dollars in data-gathering efforts...will need to be reversed if availability is to be adequately characterized." In *A Plan for a New Science Initiative on the Global Water Cycle*, Hornberger et al. (2001) emphasized that "beyond the need to collect new data, existing long-term records must be archived and preserved carefully, and observations must be continued indefinitely at sites with long high-quality records, so that patterns of temporal variability, including long-term, low-frequency fluctuations, can be identified and studied."

A third opportunity for expansion and targeting of the ARS experimental watersheds stems from the reauthorization of the 2002 Farm Bill. This act substantially increased funding for the Environmental Quality Incentives Program (EQIP), the Conservation Reserve Program (CRP) and provided continued funding for other conservation programs. Overall, Federal expenditures for conservation practices on farms and ranches in the U.S. were increased about 80 percent above the level set under the 1996 Farm Bill. While it is widely recognized that these conservation programs will save millions of acres from soil erosion, enhance water and air quality, promote wetland and wildlife habitat restoration and preservation, and conserve agricultural water use, the environmental benefits have not been previously quantified and reported at the national level. Tracking the progress of these programs in terms of the environmental benefits will allow policymakers and program managers to implement and modify existing programs and design new programs to more effectively and efficiently meet the goals of Congress.

This new multi-agency program is currently called the Conservation Effects Assessment Project (CEAP). The goal of CEAP is to provide the farming community, the general public, OMB, legislators, and others involved with environmental policy issues an accounting of the environmental benefits obtained from conservation program expenditures. CEAP will also provide an opportunity for increased cooperation and collaboration initially among USDA agencies such as NRCS, ARS, FSA, CSREES, NASS, and ORACBA. As increased funding is provided for the program, cooperation and collaboration will continue to expand with other USDA agencies, including FS, ERS, USGS, and EPA as well as other federal and state agencies and private organizations in the development of scientifically-based practices that provide an optimum to balance environmental benefits, program costs, and food and fiber production.

Note

This material was originally presented by Dave Goodrich, Daniel Marks, Mark Seyfried, and Clarence Richardson as a poster at the December 2000 America Geophysical Union in San Francisco, CA and has been updated for this meeting. We would also like to thank Jane Thurman and all the other ARS employees in the watershed program for the work they have put in developing and maintaining the historical watershed data.

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