The Original USDA-ARS Experimental Watersheds in Texas and Ohio: Contributions from the Past and Visions for the Future

R. D. Harmel, J. V. Bonta, C. W. Richardson

Abstract. *The USDA Soil Conservation Service (USDA-SCS) realized the importance of understanding hydrologic processes on agricultural fields and watersheds in the mid-1930s. Based on this realization, the research program of the Hydrologic Division of SCS established three experimental watersheds across the U.S. to analyze the impact of landuse practices on soil erosion, flood events, water resources, and the agricultural economy. Two of the original watersheds remain in operation today within the USDA Agricultural Research Service (USDA-ARS): the Blacklands Experimental Watershed (now the Grassland, Soil and Water Research Laboratory) near Riesel, Texas, and the North Appalachian Experimental Watershed near Coshocton, Ohio. These original watersheds were designed for collection of hydrologic data on small watersheds and evaluation of hydrologic and soil loss response as influenced by various agricultural land management practices. A major contribution of these experimental watersheds is the quantification of soil loss reduction under conservation management, which has led to a drastic reduction in soil loss from cultivated agriculture in the 20th century. Riesel watershed studies produced the scientific basis for several watershed models that are now used worldwide to manage water quality and also facilitated fundamental analysis of the agronomic and environmental effects of tillage, fertilizer, and pesticide alternatives. Coshocton watershed studies led to the development of no-till and pasture management practices to control runoff, erosion, and chemical loss and were instrumental in understanding water quality and hydrologic effects of soil macropores and mining and reclamation activities. The long-term hydrologic records at each site have also improved understanding and management of water resources in their respective geographic regions. Because of their historical and future value, the USDA-ARS has a unique responsibility to maintain these long-term experimental watersheds, which are vital for addressing emerging research needs to meet future water availability, environmental quality, and food and fiber demands.*

Keywords. *Agricultural runoff, Hydrology, Legacy data, Trend analysis, Water quality.*

In the mid-1930s, the USDA Soil Conservation Service (USDA-SCS), now the Natural Resources Conservation Service (NRCS), realized the importance of understanding hydrologic processes on agricultural fields and watersheds because of their impact on soil erosion, flood events, water resources, and the agricultural economy. As a result, a Hydrologic Division was organized within the SCS Research Program, and several experimental watersheds were established across the U.S. (USDA, 1942). Two of the original watersheds remain in operation today: the Blacklands Experimental Watershed (now the Grassland, Soil and Water Research Laboratory) near Riesel, Texas, and the North Appalachian Experimental Watershed near Coshocton, Ohio. These original watersheds were designed to collect hydrologic data (precipitation, percolation, evaporation, runoff) and to evaluate the hydrologic and soil loss response as influenced by various agricultural land management practices. The SCS Research Division was moved into the newly created USDA Agricultural Research Service (USDA-ARS) in 1954. Congressional legislation in 1959 added six additional USDA-ARS experimental watersheds.

The objective of this article is to review the history of the Riesel and Coshocton watersheds. The review focuses on describing instrumentation and data collection methodology, noting the importance of past achievements and contributions, describing current research designed to address contemporary problems, and emphasizing the value of such watersheds in addressing emerging issues.

Importance of Long-Term Experimental Watersheds

Although private, local, and state entities need watershed research results and data, few, if any, have the resources or stated responsibility to conduct long-term integrated watershed research and monitoring (Slaughter and Richardson, 2000). Thus, the national USDA-ARS experimental watershed network, along with long-term research and monitoring sites operated or supported by the U.S. Geological Survey (USGS), USDA Forest Service, U.S. Department of the Interior National Parks Service (USDI-NPS), and the National Science Foundation, are essential for understanding regional hydrologic processes in the U.S. Long-term rainfall and flow data are valuable for

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management and research related to water supply, water quality, and flood impacts and for calibration, validation, and application of watershed models. Sediment transport and flow data are needed for the optimal design of culverts, bridges, detention basins, and reservoirs (USDA, 1942). Thus, the USDA-ARS and its federal partners have a unique responsibility to sustain long-term watershed networks to meet future water availability, environmental quality, and food and fiber production demands.

The current and unforeseen future value of experimental watersheds should not be disregarded in budget decisions for long-term research and monitoring (Slaughter, 2000). Established watersheds have the benefits of previous infrastructure investment, historical data records, watershed land control, and scientific expertise, which save research time and expense when addressing emerging needs. Sites with continuous records are particularly valuable for studies designed to identify trends or changes caused by climate shift or other factors (Garbrecht et al., 2006) and are necessary to determine the influence of infrequent extreme events, such as floods. According to Slaughter (2000), the National Research Council (NRC, 1999) emphasized the need for long-term research and monitoring that is integrated across time and spatial scales and recommended that maintaining sites with exceptionally long-term records should be particularly emphasized. The USDA-ARS experimental watershed network, with 38 to 71 years of data records from nine geographically diverse locations, fits this profile. These legacy data have enabled long-term analyses of precipitation, discharge and sediment transport, and land management impacts (Edwards and Owens, 1991; Hanson, 2001; Pierson et al., 2001; Nichols et al., 2002; Harmel et al., 2003; Van Liew and Garbrecht, 2003; Bonta, 2004; Harmel et al., 2006). The contemporary relevance of these watersheds is evidenced by ongoing partnerships with numerous universities, federal agencies (e.g., U.S. Environmental Protection Agency, USGS, USDA-NRCS, Bureau of Land Management, and USDI-NPS), and the international scientific community.

The Riesel and Coshocton watersheds are particularly valuable for field-scale to farm-scale research because of their long-term, continuous records on multiple small watersheds within a nested watershed network. Data at that scale are vital to properly evaluate runoff and constituent transport processes from single landuse, relatively homogeneous watersheds and to differentiate mechanisms for various landuse conditions. Data collected at larger scales are often influenced by dams, channel processes, differing landuses, and precipitation variability, which alter flow routing and confound interpretation of management effects.

Grassland Soil and Water Research Laboratory (Riesel, Texas)

Site Description

The Riesel experimental watershed, which is now called the Grassland, Soil and Water Research Laboratory (GSWRL), contains 340 ha of federally owned and operated land. The GSWRL was established on the 2372 ha Brushy Creek watershed near Riesel, Texas, because of its central location in the 4.45 million ha Texas Blackland Prairie (fig. 1). Present day agricultural landuse in this productive region consists of cattle production on pasture and rangeland, and corn, wheat, grain sorghum, and oat production under a wide range of tillage and management operations. The area also contains the major metropolitan areas of Dallas-Fort Worth and Austin. Long, hot summers and short, mild winters characterize the climate. A majority of the annual precipitation (approx. 890 mm; Harmel et al., 2003) occurs with the passage of Canadian continental and Pacific maritime fronts (Knisel and Baird, 1971), but convective thunderstorms and occasional hurricanes can contribute intense rainfall.

Houston Black clay soils (fine, smectitic, thermic, udic Haplustert), recognized throughout the world as the classic Vertisol, dominate the watershed site. These highly expansive clays, which shrink and swell considerably with changes in moisture content, have a typical particle size distribution of 17% sand, 28% silt, and 55% clay. This soil series consists of very deep, moderately well-drained soils formed from weakly consolidated calcareous clays and marls and generally occurs on 1% to 3% slopes in upland areas. This soil is very slowly permeable when wet (approximate saturated hydraulic conductivity of 1.5 mm/h); however, preferential flow associated with soil cracks contributes to high infiltration rates when the soil is dry (Allen et al., 2005).

Instrumentation and Data Collection

The original infrastructure at Riesel included multiple watersheds and rain gauges on private land in the Brushy Creek watershed and on smaller sites on land purchased by the USDA. Hydrologic, soil erosion, and air temperature data

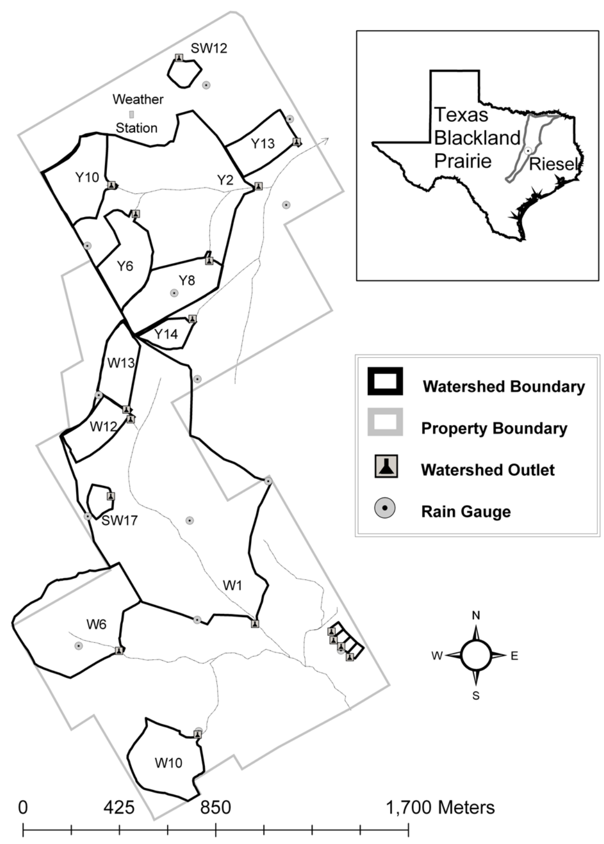

Figure 1. Active experimental watersheds and rain gauges at the USDA-ARS Grassland, Soil and Water Research Laboratory near Riesel, Texas.

have been collected continuously on selected sites since the late 1930s. These data, in addition to periodic water quality, weather, lateral subsurface, shallow groundwater level, and land management data, are publicly available at www.ars.usda.gov/spa/hydro-data. Installation of a VHF radiotelemetry network was completed in 2001 to improve data quality and collection efficiency. From the onsite base station, equipment maintenance and calibration are performed and realtime conditions are monitored. An automated data collection schedule runs continuously and collects data daily from each field station. The base station is linked by phone modem to a dedicated computer at the laboratory headquarters in Temple, Texas, for automated data transfer and manual operation and adjustment of network components.

Runoff data collection began in 1938 and continued in various periods from 40 watersheds (0.1 to 2372 ha). Currently, 17 runoff stations are in operation on remnant prairie, improved pasture, and cultivated cropland. Ten runoff stations are located at the outlet of small, single landuse watersheds (1.2 to 8.4 ha) to measure "edge of field" processes (fig. 1). Four stations are located at the outlet of 0.1 ha plots. Three stations are located at the outlet of larger downstream watersheds (17.1 to 125.1 ha) with mixed landuses to evaluate integrated processes. Each of these runoff structures is instrumented with a shaft encoder as the primary water level (stage) recording device and with a float gauge chart recorder and a bubbler level recorder as backup devices. Historically, float gauges were the primary stage measurement devices. From the continuous stage records, flow rates are calculated with known stage-discharge relationships. A lateral flow station was installed in 1970 to measure lateral subsurface flow from a portion of one watershed. To measure flow, French drains installed perpendicular to the slope collect flow and release it into a boxed, sharp-crested v-notch weir. Since 2000, shallow groundwater levels in seven wells have been monitored twice weekly with a hand-held "e-line" gauge.

Electronic automated samplers were installed in 2001 to collect runoff samples, which are analyzed for nutrient and sediment concentrations. These automated samplers begin collection when activated by a bubbler flow level recorder. From the 1970s to 2001, runoff water samples were taken with Chickasha samplers (Allen et al., 1976). These automated, mechanical samplers were turned on with a float-activated water level switch. Prior to the 1970s, on-call personnel collected runoff water samples by hand at watershed sites (Knisel and Baird, 1970) or with a flow-proportional sampler at field-scale sites. Historically, sediment loss was the water quality issue of concern, but periodic nutrient and chemical data were also collected for specific studies.

Currently, 15 rain gauges are in operation within 340 ha, which makes Riesel one of the denser rain gauge networks in the world. Electronic tipping-bucket gauges were installed with a datalogger in the late 1990s to record rain data on 10 minute intervals. A standard rain gauge at each site is used as a backup and calibration device. Historically, rainfall data were collected by various types of weighing rain gauges in conjunction with chart or electronic data recorders. Since 1990, air temperature, solar radiation, wind speed and direction, precipitation, and soil temperature have been measured by an onsite weather station. Prior to 1990, only daily maximum and minimum air temperature, daily pan evaporation, and precipitation were measured continuously.

Historical Contributions

When the Riesel watershed was established in the 1930s, little information was available on the impacts of landuse and management on runoff, soil loss, and water quality from small agricultural watersheds. Thus, early research quantified the ability of a conservation management system (with terraces, grassed waterways, contour farming) to reduce peak flow rates and soil erosion (Baird, 1948, 1950, 1964; Baird et al., 1970). These results contributed to the scientific basis for the U.S. conservation farming revolution. Research at Riesel also established fundamental understanding on the agronomic and environmental effects of tillage, fertilizer, and chemical management alternatives (Baird and Knisel, 1971; Swoboda et al., 1971; Kissel et al., 1976; Richardson et al., 1978; Bovey and Richardson, 1991; Chichester and Richardson, 1992; Richardson and King, 1995; Sharpley, 1995; Harmel et al., 2004; Harmel et al., 2005).

Research at Riesel was also instrumental in development of the EPIC/APEX (Williams and Sharpley, 1989), GLEAMS (Knisel, 1993), and SWAT (Arnold et al., 1998) watershed models, which are now applied worldwide to manage field-, farm-, and basin-scale water quality. Riesel data have been used to develop model routines (Williams et al., 1971), to calibrate and validate these models (Arnold and Williams, 1987), and to perform subsequent model development and evaluation (Richardson and King, 1995; King et al., 1996; Ramanarayanan et al., 1998; Harmel et al., 2000; Green et al., 2007). The long-term hydrologic record also enabled determination of temporal trends, flood frequencies, and land management impacts related to Vertisol hydrology (Harmel et al., 2003; 2006).

North Appalachian Experimental Watershed (Coshocton, Ohio)

Site Description

The North Appalachian Experimental Watershed (NAEW) is located in east-central Ohio near Coshocton, and originally included two land areas: the Little Mill Creek watershed (19.3 km^2), and the present boundaries of the 425 ha NAEW facility (fig. 2). The facility, located in the uplands west of the northern Appalachian Mountains, has typical slopes of 18% to 25% and elevations from 275 to 393 m. Landuse is dominated by corn, soybean, and wheat cropland (15%), pasture and hay fields (55%), and woodland (26%). The site has a humid-temperate continental climate and is exposed to cold dry air from the northwest and warm moist air from the south. The average annual precipitation is 959 mm, and the average annual temperature is 10.4°C.

The present-day NAEW is composed of small upland experimental watersheds (<1 ha) typically with no well-defined, incised stream channel. Instead, runoff concentrates in swales and minor channels. These upland watersheds generate ephemeral runoff during heavy rainfall, snow melt, and wet antecedent soil conditions. The downstream landscape is dissected by incised stream channels with gauged areas (<121 ha). The primary factor for siting the experimental watershed in the North Appalachian Region

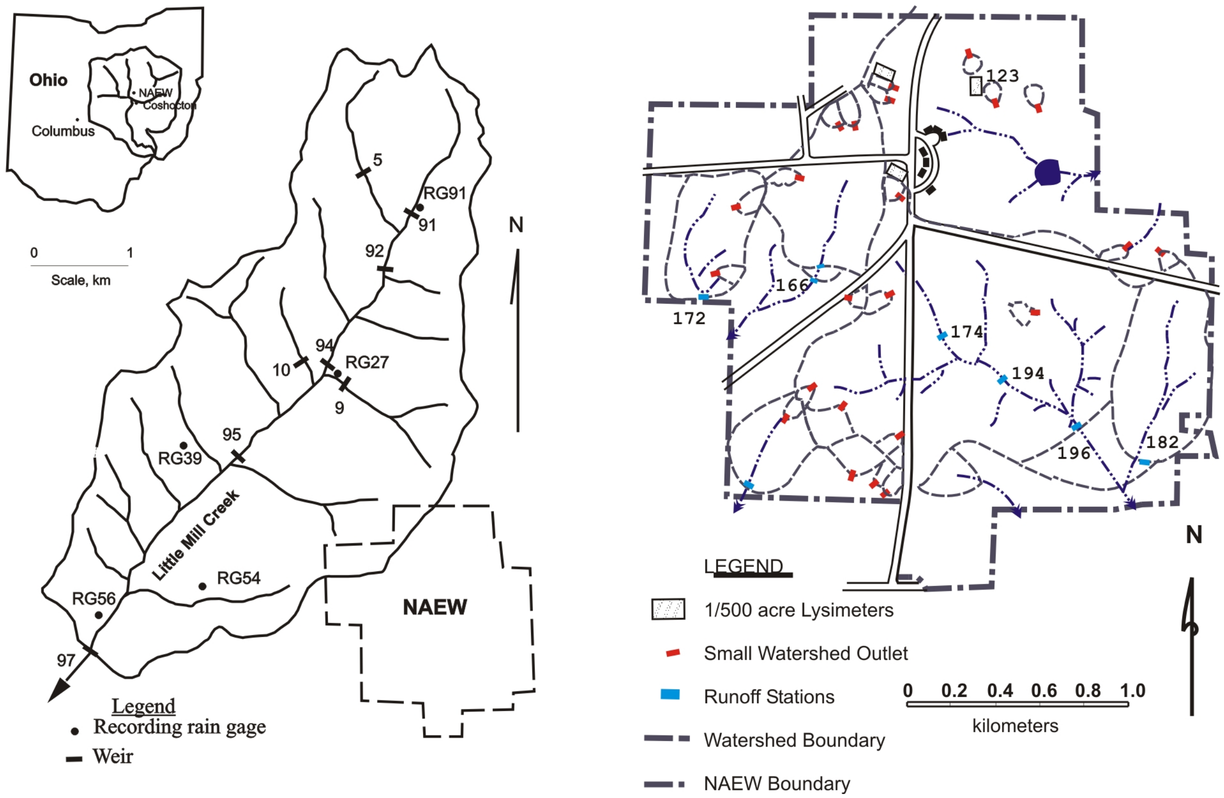

Figure 2. Monitoring infrastructure and experimental watersheds at the Little Mill Creek (discontinued) and NAEW sites near Coshocton, Ohio.

was its “representativeness” of southeast Ohio and surrounding states (Ramser and Krimgold, 1935).

The bedrock on the facility lies within the Pennsylvania System (Allegheny Formation) and is composed of unglaciated, sedimentary strata consisting mainly of sandstone and shale with interbedded strata of coal, clay, and limestone (Kelley et al., 1975). The geologic structure is characterized by an underlying anticline (with local synclines) and by strata dipping to the southeast at angles <1°. The three main soil types are: residual well-drained soils derived from sandstone, shale-derived soils with an argillic horizon, and soils with intermediate characteristics. The principal soil series are Berks, Coshocton, Dekalb, Keene, and Rayne (Kelley et al., 1975). The soils and geology of the NAEW are important in its hydrologic research program. Clay and limestone layers can be spatially persistent, and springs form at the outcrop and land surface intersection. During rainfall events, these wet areas on the landscape generate runoff sooner than surrounding areas, creating variable-source areas. In addition, stream channels intersect these subsurface layers and thus receive increased base flow.

Instrumentation and Data Collection

The original infrastructure included 47 runoff gauges and 28 rain gauges at the Little Mill Creek watershed and NAEW sites (fig. 2). The Little Mill Creek watershed was instrumented with recording rain gauges in eight nested watersheds (39 to 1854 ha). The Little Mill Creek sites were discontinued after about 30 years, but the NAEW sites have remained in operation for more than 70 years. The current infrastructure network at the NAEW consists of 24 experimental watersheds, 11 lysimeters, three spring monitoring sites, 12 recording rain gauges, and two meteorological stations. All measurements from this network are obtained with data loggers and a radio telemetry system.

Twenty-two of the active small watersheds (0.48 to 1.09 ha) are instrumented with H flumes (Brakensiek et al., 1979), and two have drop-box weirs designed for sediment-laden flows (Bonta and Pierson, 2003). Flow-proportional runoff samples for water quality analysis are collected from these watersheds using Coshocton wheel samplers (Brakensiek et al., 1979). The Coshocton wheel sampler was invented onsite and is now used worldwide, particularly in remote areas because it requires no power. The six larger watersheds (17.6 to 123 ha) are instrumented with short-crested V-notch weirs (Brakensiek et al., 1979) and Coshocton vane samplers. The Coshocton vane sampler was also invented by Coshocton personnel (Edwards et al., 1976).

When the NAEW was established, three or four lysimeters (8.1 m^2) were installed at each of three sites representing three major soil types. Each monolith lysimeter is approximately 2 m wide, 4 m long, and 2.4 m deep. One lysimeter at each site is weighed to measure evapotranspiration with a time resolution of 1 min. A 2.8 ha natural lysimeter also exists onsite. This area consists of a shallow, thick clay layer that outcrops along the periphery of an isolated hilltop called Urban’s Knob. The clay layer has a synclinal structure that forces most water to emerge at a gauged single spring; thus, all subsurface water originates from precipitation and cannot be contaminated by adjacent groundwater. This natural lysimeter, which has been instrumented with approximately 40 monitoring wells and piezometers, is ideally suited for “quick” evaluation of land management impacts on the unsaturated and saturated groundwater zones.

Historical Contributions

The NAEW was established to develop land management and scientific techniques to improve water quality and to reduce flood damage and sedimentation. Early crop rotation research at the NAEW established that most agricultural soil loss occurs from row crop production and during infrequent, intense rainfall events. The concept of no tillage, which greatly reduces runoff and erosion, was largely developed and tested at Coshocton. The no-till agronomic system is now used extensively in efforts to improve soil structure, increase biological activity, reduce energy needs, improve yields especially during droughts, and increase soil carbon storage especially with manure application. Much of the original development (and current enhancements, e.g., Bonta, 1997) of the USDA-SCS curve number method, which is now used worldwide to estimate runoff volumes, was also conducted at Coshocton.

Extensive field, lysimeter, and laboratory research on preferential water flow pathways, such as earthworm burrows and soil cracks, has been conducted at NAEW. This research established fundamental knowledge about soil management effects on macropore development and about water and chemical fate below the soil surface (Shipitalo et al., 1990; Edwards et al., 1992; Shipitalo and Edwards, 1996). The macropore flow component of the Root Zone Water Quality Model (RZWQM) was modified based on this research (Malone et al., 2001; Malone et al., 2004). Research at Coshocton also established early knowledge related to the surface and groundwater quality effects of pasture fertilization and established environmentally sound alternatives that utilize grass-legume mixtures (Owens et al., 1994, 1996; Owens and Bonta, 2004). A landmark comprehensive study on the very long-term effects of coal mining and reclamation on runoff and surface and groundwater quality was conducted at the NAEW (Bonta et al., 1992; Bonta et al., 1997; Bonta, 2000). Results from each of these studies have tremendous environmental and agronomic implications related to water movement and chemical transport.

The NAEW is known worldwide for hydrological and water quality instrumentation. Development, adaptation, and/or evaluation of the Coshocton wheel water sampler (Brakensiek et al., 1979; Bonta, 2002), Coshocton vane sampler (Edwards et al., 1976), large particle sampler (Bonta, 1999), drip-flow meter and sampler (Bonta and Goyal, 2000; Malone et al., 2003), and drop-box weir (Bonta, 1998; Bonta and Goyal, 2001; Bonta and Pierson, 2003) can be attributed to the NAEW.

Current Research

The USDA-ARS watersheds at Riesel, Texas, and Coshocton, Ohio, are equipped to address emerging research needs, such as those listed subsequently. Both experimental watersheds benefit from onsite infrastructure, lengthy historical records, watershed land control, and scientific expertise, which facilitate efficient research when needs emerge.

- At Riesel, the most comprehensive, long-term field-scale study of land-applied poultry litter as a fertilizer and soil amendment is ongoing (Harmel et al., 2004). This study is part of the USDA Conservation Effects Assessment Project, which will guide future Farm Bill formulation.
- Research is also ongoing at Riesel to better understand the mechanism and effects of clay (Vertisol) shrink-swell cycles. This seasonal phenomenon has a tremendous impact on pollutant transport, in-stream flows, and road and building infrastructure (Arnold et al., 2005; Allen et al., 2005; Harmel et al., 2006).
- Research at both locations is evaluating the impacts of carbon cycling and climate change, a topic receiving much contemporary attention. The potential effects of changing climate and rainfall patterns on forage production and plant species composition in remnant prairies are being evaluated at both sites and with rain-exclusion shelters at Riesel. At the NAEW, long-term, continuous no-till corn production and other land management activities continue to provide valuable information on soil carbon storage and biofuel production.
- Similarly, both locations are evaluating the impacts of urbanization. Watershed models developed with Riesel data are being used to examine future impacts of urbanization in the I-35 corridor from north Texas and extending into Mexico. Field research at Coshocton is creating an artificial urban environment with increased impervious cover to study and develop best management practices for runoff volume and flood peak reduction.
- Improved modeling methods to simulate precipitation intensities and evaluate land management alternatives are being developed at Coshocton. These improvements will be particularly useful for projects with limited measured data and to account for natural variation due to weather, season, and location.
- Alternative uses and environmental impacts of agricultural, municipal, and industrial byproducts are also being evaluated at the NAEW. This research addresses science-based application guidelines and management-intensive grazing alternatives to reduce nutrient and pathogen transport from land-applied animal manures. Related research is evaluating allowable loading rates of paper mill byproducts for surface mine reclamation. The effectiveness of filter socks filled with wastewater treatment residuals to remove pesticides and nutrients from agricultural runoff is also being investigated. The filter sock research builds on previous research (e.g., Shipitalo et al., 1997; Shipitalo and Owens, 2003, 2006) that investigated pesticide transport from small watersheds.

Visions for the Future

Water is fundamental to life. It is required for all agricultural, industrial, urban, and recreational activity and for healthy function of the natural environment. However, many researchers expect that water supply shortage, flood occurrence, and water quality degradation will increasingly affect the environment and future generations. Thus, watershed-based studies are desperately needed to solve these problems. Because of inherent water resource complexity, efficient management of this precious resource for the future will require dedicated science, wise policy, effective education, innovative technology, and real-world data.

The historical watersheds in Riesel, Texas, and Coshocton, Ohio, are nationally and internationally recognized for a wealth of legacy data and for their role in establishing fundamental scientific understanding related to hydrology and soil erosion. Research at Riesel and Coshocton was also instrumental in developing innovative instrumentation and watershed modeling technology that is now used worldwide. Throughout their histories, these watersheds have remained vital components of the USDA-SCS and now USDA-ARS watershed network. Such networks have a unique opportunity and vital responsibility to provide continuous, watershed-based research and data to universities, government, and industry for developing sound strategies to manage, conserve, protect, and allocate the nation's water resources.

Despite budgetary and political pressures, the demonstrated accomplishments and certain future value cannot be overlooked in decisions related to established, long-term experimental watersheds. The USDA-ARS watersheds are uniquely positioned with legacy data, established monitoring infrastructure, watershed land control, and scientific expertise. As such, the USDA-ARS watershed network can be relied upon to provide science, technology, and data to satisfy competing water resource demands necessary for economic and environmental sustainability. Committed support of the USDA-ARS and other federal experimental watersheds has yielded critical understanding and technology related to water resources. Such commitment must remain a national priority.

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