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Conservation Effects Assessment Project research in the Leon River and Riesel watersheds

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Abstract: The Leon River basin was selected as a benchmark watershed for the Conservation Effects Assessment Project to complement the historical USDA Agricultural Research Service experimental watersheds near Riesel, Texas. Excessive nutrient and bacteria concentrations contributed by agricultural, urban, and natural sources are the primary water quality concerns. Modeling and field evaluations of the hydrologic impact and soil and water quality response to tillage and nutrient management practices are the primary research themes of this project. Water quality data from 15 Leon River watersheds (0.3 ha [0.75 ac] to 6,070 km^2 [2,340 mi^2]) and 13 Riesel watersheds (1.2 ha [3.0 ac] to 70.4 ha [174 ac]) has improved modeling of phosphorus transformation and transport routines. Modeling research also coupled field- and farm-scale model output to improve the basin-scale Soil and Water Assessment Tool (SWAT) for the national assessment of conservation practices. Additional key products of Conservation Effects Assessment Project research include innovative erosion control methods on military lands, enhanced carbon sequestration estimates for various agricultural land uses, and improved understanding of environmental and economic impacts of organic fertilizer application.

Key words: best management practices—Conservation Effects Assessment Project (CEAP)—soil quality—Soil and Water Assessment Tool (SWAT)—water quality monitoring

Conservation Effects Assessment Project (CEAP) research began in central Texas in 2003 when the Upper Leon basin was designated as one of twelve USDA Agricultural Research Service (ARS) benchmark watersheds to complement the historical USDA ARS experimental watersheds near Riesel, Texas. The benchmark watersheds were established to provide regional assessment of water quality and conservation practice effects in the CEAP Watershed Assessment (Mausbach and Dedrick 2004). At the same time, modeling activities began as part of the CEAP national assessment of conservation practice effects. Conservation Effects Assessment Project research in the Leon River and Riesel watersheds thus focuses on modeling and field evaluation of hydrologic, water quality, and soil quality impacts of agricultural conservation practices related to tillage and nutrient management.

Field and modeling research has been conducted within the Riesel watersheds for more than 70 years and since 1995 in the Leon River watersheds. With the onset of CEAP, these activities were expanded to better address local and national conservation assessment issues. Our objectives are to describe the foundation for this research and discuss CEAP-related results gathered to date within those watersheds.

Materials and Methods

Site Description. The Leon River and Riesel watersheds are located within the Brazos River basin that runs from New Mexico through central Texas to the Gulf of Mexico (figure 1). This area lies within the Grand Prairie, Cross Timbers, and Texas Blackland Prairie Major Land Resource Areas. It is also described as being within the Western Cross Timbers, Limestone Cut Plain, and Northern Blackland Prairie ecoregions (Griffith et al. 2004). Leon River watershed elevations range from 145 m (475 ft) on the flood plain below Lake Belton to 628 m (2,060 ft) above mean sea level. The area has a subhumid climate characterized by hot summers and dry winters. Occasional high-intensity, short duration thunderstorms occur during the spring and summer months. Typically, summers are hot, and winters are mild with intervals of freezing temperatures as cold fronts pass through. Mean annual precipitation ranges from 660 to 1,067 mm (26 to 42 in) within the region, and mean annual air temperature ranges from 16°C to 19°C (61°F to 66°F) (USDA Natural Resources Conservation Service 2007). The annual number of frost-free days typically ranges from 230 to 290.

Three major reservoirs are located on the main stem of the Leon River (figure 1). The largest, Belton Lake, was completed in 1954 by the US Army Corps of Engineers to control flooding within the Brazos River basin. The reservoir receives runoff from 9,220 km^2 (3,560 mi^2), has a capacity of 5.64×10^8 m^3 (457,000 ac ft), and covers 5,000 ha (12,360 ac) at the conservation storage level. The second reservoir (Lake Leon) was authorized in 1952 in response to prolonged drought to provide a reliable water supply in the upper portion of the watershed. Impoundment of water began in 1954. The third reservoir (Proctor Lake) was also built with federal funding and impoundment began in 1963.

Research Expansion for the Conservation Effects Assessment Project. The Brazos River basin has attracted national attention in recent years because of legal battles over water quality in Lake Waco. Within the basin, the Leon River watershed is also experiencing water quality concerns and impairments due to elevated levels of bacteria and depressed dissolved oxygen levels, potentially due to excessive nutrient loading (Texas Commission on Environmental Quality 2007). These constituents originate from a variety of sources including agricultural practices (fertilizer application, manure deposition, confined animal feeding operations), urban areas (waste water treatment plants, septic systems,

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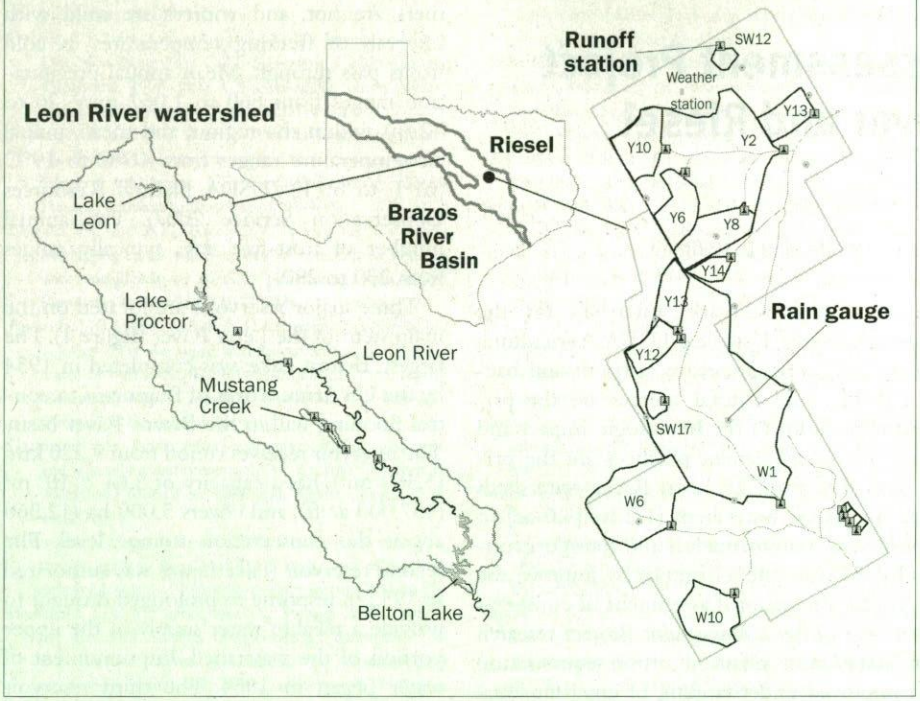
Figure 1
Study sites located in the Leon River and Riesel watersheds.



lawns), and natural sources (wildlife, background). The Leon River basin is located adjacent to the Bosque River watershed, which has experienced intense debate and extensive litigation on the relative contributions of nutrients and bacteria from dairy waste application fields and other sources. Because the Leon River watershed contains similar land uses and constituent sources as the Bosque River watershed, stakeholders in the Leon River basin are paying careful attention to emerging water quality issues, especially related to excessive bacteria and nutrient concentrations. A recent expansion of the poultry industry near Waco brought increased attention to water quality impacts associated with agricultural production in the basin. The socio-economic implications of these issues coupled with attention from local politicians, land owners, communities, water suppliers, and agricultural producers have created an excellent site for applied research.

Another reason for the research expansion is the wealth of legacy data documenting effects of various land management practices on water quantity and quality. Starting in 1995, Texas Agricultural Experiment Station scientists conducted extensive research in the Leon River basin focusing on erosion control, sediment transport, and rangeland rehabilitation in response to grazing and heavy equipment operation at Fort Hood. The US Geological Survey and Brazos River Authority have also conducted flow and water quality monitoring at numerous sites in the basin.

Previous USDA ARS research within the Brazos River basin was concentrated in the Brushy Creek watershed near Riesel, Texas. These watersheds, now known as the Grassland Soil and Water Research Laboratory, were established in 1937 as the Blacklands Experimental Watershed. This facility is one of the longest active hydrologic research sites in the United States (Harmel et al. 2003, 2006b, 2007). The data record for Riesel includes runoff (1,300 site years), precipitation (1,400 site years), and soil loss (750 site years) (USDA Agriculutral Research Service 2008). The early data from Riesel quantified the effectiveness of conservation systems in reducing peak flow rates and soil erosion (Baird 1948, 1950, 1964). More recently, agronomic and environmental effects of tillage, fertilizer, and pesticide alternatives were evaluated (Kissel et al. 1976; Richardson et al. 1978; Chichester and Richardson 1992; Richardson and King 1995; Sharpley 1995; Harmel et al. 2004).

Field Research on Conservation Practices. CEAP-related field research focused on three specific questions in the Leon River and Riesel watersheds. First, what is the effectiveness of erosion control conservation practices on military training lands? To address this question, maneuver access structures (gully plugs) and mechanical treatment (deep soil ripping on the contour) were implemented in the severely eroded Shoal Creek watershed on Fort Hood. Storm runoff volumes and sediment loss data were collected five years prior and four years after implementation. For a detailed description of this research, see Wolfe et al. (2008).

Second, what are the environmental and on-farm economic effects of conservation practices with poultry litter fertilization for crop production? To address this question, litter application was initiated in 2001 on six cultivated field-scale watersheds at Riesel. Since then, soil quality, runoff water quality, and on-farm economic data have been collected and analyzed. For a more detailed description, see Harmel et al. (2004).

Third, how do land management and conservation practices effect carbon sequestration in agricultural soils? To answer this question, soil samples collected in 1949 and in 2004 from fields with various land management histories were compared. In 1949, soil samples were taken from five fields, oven dried, stored for more than 55 years, and compared with samples from the same fields taken in 2004. The predominant management practices for the five sites from 1949 to 2004 were native (remnant) prairie, previously tilled soils planted to coastal Bermuda grass (*Cynodon dactylon* (L.) Pers.) for 55 years and 39 years, and nearly continuous row crop and small grain production (RC1 and RC2). For a more detailed description of this research, see Potter (2006).

Monitoring Infrastructure. To address emerging water quality issues in the region, the existing monitoring network in the Leon River watershed was significantly expanded. Two sites were added on the Leon main stem to quantify large-scale processes and downstream impacts, three intermediate scale sites were added to determine farm to small watershed effects, five field-scale sites were added to examine nutrient dynamics on individual cultivated and pasture fields, and a dairy site was added to examine the direct contribution of nutrients and bacteria from dairy operations (table 1).

Table 1
Watershed characteristics for Conservation Effects Assessment Project data collection sites in the Leon River and Riesel watersheds.

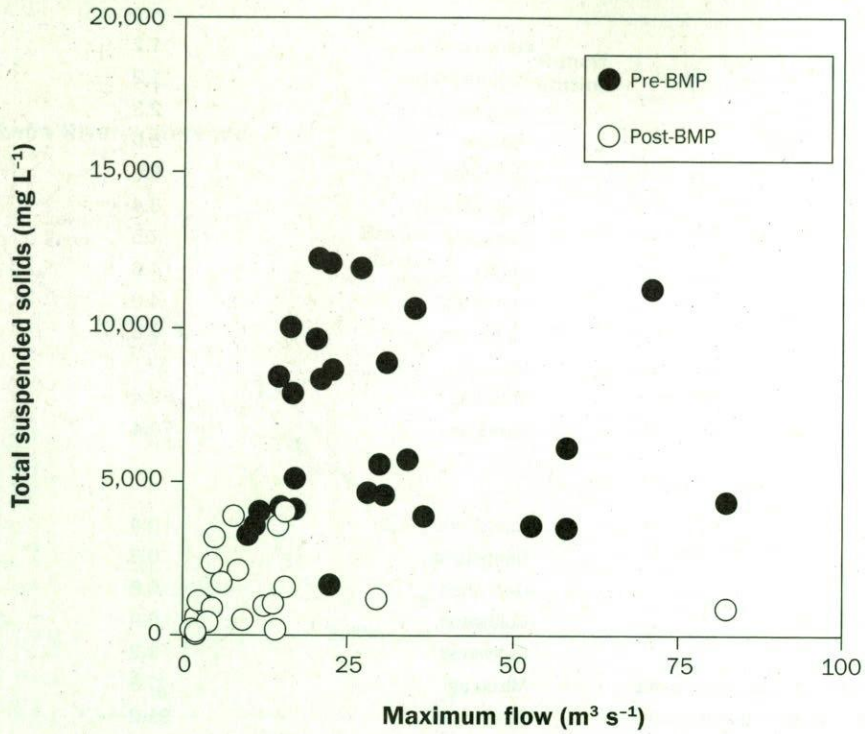
Site	Scale	Land use	Area (ha)
Riesel watersheds			
SW12	Field	Native prairie	1.2
SW17	Field	Pasture-grazed	1.2
Y14	Field	Pasture	2.3
W10	Field	Pasture	8.0
Y6	Field	Cultivated	6.6
Y8	Field	Cultivated	8.4
Y10	Field	Cultivated	7.5
Y13	Field	Cultivated	4.6
W12	Field	Cultivated	4.0
W13	Field	Cultivated	4.6
W6	Farm to small watershed scale	Mixed ag	17.1
Y2	Farm to small watershed scale	Mixed ag	53.4
W1	Farm to small watershed scale	Mixed ag	70.4
Leon River watersheds			
P1	Field	Rangeland	0.4
P2	Field	Rangeland	0.3
SS1	Field	Cultivated	0.9
SS2	Field	Cultivated	0.9
SS3	Field	Cultivated	1.2
M	Farm to small watershed scale	Mixed ag	17.8
Dairy	Farm to small watershed scale	Dairy	91.2
Mustang Creek at 3340	Small watershed	Mixed ag	1,467
Mustang Creek at 101	Small watershed	Mixed ag	5,506
Shoal Creel at Bald Knob Road	Small watershed	Pasture, military	2,219
House Creek at West Range	Small watershed	Pasture, military	15,476
Cowhouse Creek at Pidcoke	Basin scale	Pasture, military	117,746
Cowhouse Creek at West Range	Basin scale	Pasture, military	144,031
Leon River (Hamilton)	Basin scale	Mixed	520,000
Leon River (Gatesville)	Basin scale	Mixed	607,000

The CEAP monitoring network in central Texas now includes 11 new runoff and water quality monitoring stations established by the Texas Agricultural Experiment Station and USDA ARS. These sites complement the four rangeland sites on Fort Hood and 13 historical stations at the Riesel facility. The considerable time and financial investment for site scouting, installation, and equipment purchase for these new stations provides a vivid reminder of the importance of historical watershed research sites, such as Riesel, Texas; Coshocton, Ohio; Tifton, Georgia; and Walnut Gulch, Arizona. Compared to new sites, established sites have many benefits, the most important of which may be availability of historic data and minimal set up and installation requirements so that emerging issues can be efficiently addressed (Harmel et al. 2007).

Monitoring equipment was varied based on site conditions to appropriately assess streamflow and water quality (Harmel et al. 2006a). An Isco automated sampler with a bubbler water level meter was installed at the outlet of each watershed to collect storm water samples and measure water level (stage). An additional inline pump was installed at basin-scale sites to assist sample collection. Hydraulic control structures, generally H-flumes or v-notch weirs, were installed at most of the field-scale and small watershed sites to provide reliable stage-discharge relationships and accurate flow data for many years with minimal maintenance (Brakensiek et al. 1979; Slade 2004). The other small scale sites were established in culverts or stable channels with natural or artificial flow control. At the downstream Leon River site, flow was estimated with the established US Geological Survey gauge data, but no such relationship has been established at the upstream Leon River site. Data collection at such large scales is quite difficult and requires specialized equipment, training, and safety protocols because of the magnitude and variability of flow width and depth.

Data Collection. Various hydrologic, water quality, and meteorological data are being collected at the monitoring stations. At all but one site, flow rate is continuously measured and recorded on 5- to 15-minute intervals. At the upstream Leon River site, stage and flow data were collected to establish a stage-discharge relationship. Baseflow grab samples are collected manually in alternating weeks for perennial flow sites and in every site visit with flow for ephemeral sites. Baseflow samples are analyzed for NO_3-N, NH_4-N, PO_4-P, and bacteria con-

Figure 2
Differences in total suspended solids concentration in pre- and post-treatment periods (from Wolfe et al. 2008).



centrations. A four-parameter multiprobe is also used to collect temperature, conductivity, dissolved oxygen, and pH data corresponding to grab sampling conditions. Automated samplers collect frequent storm water quality samples at small watershed sites (sampling interval 1.32 to 2.54 mm (0.05 to 0.1 in) runoff volumetric depth) and at basin-scale sites (sampling interval eight hours). Storm water quality samples are analyzed for sediment, NO_3-N, NH_4-N, PO_4-P, particulate N and P, and bacteria concentrations.

Modeling Research on Conservation Practices. An important contribution of this research has been the evaluation and refinement of the Soil and Water Assessment Tool (SWAT) water quality model (Arnold et al. 1998; Arnold and Fohrer 2005). Designed to assess nonpoint source pollution, SWAT has been used extensively in the Leon River and Riesel CEAP research. The model is part of the US Environmental Protection Agency Better Assessment Science Integrating Point and Nonpoint Sources software package (Di Luzio et al. 2002) and is being used by many US federal and state agencies. The SWAT model is generally applied to large river basins but has been validated both on the river basin and small watershed scale in terms of annual water and sediment yield (Arnold and Williams 1987; Arnold et al. 1998, 1999).

SWAT Modeling for the Leon River Basin. The SWAT2005 model was used to evaluate point and nonpoint source pollution in the Leon River basin and to compare agricultural management scenarios. The model's simulation accuracy was evaluated with measured hydrologic data collected from the basin. Data from 1967 to 1985 were used for calibration, and data from 1987 to 2000 were used for validation. Results from this evaluation were used to illustrate newly developed model evaluation performance ratings from "unsatisfactory" to "very good" based on Nash-Sutcliffe efficiency (NSE) (Nash and Sutcliffe 1970), percent bias, and the root mean square error observation standard deviation ratio (Moriasi et al. 2007).

SWAT Modeling for the Riesel Watersheds. The ability of SWAT2005 to simulate small watershed hydrology and water quality was evaluated with data from CEAP subwatersheds near Riesel (HUC-8; 12070101). Specifically, Green et al. (2007) compared SWAT model predictions with measured runoff, sediment, NO_3-N, organic N, organic P, and soluble P data from six cultivated subwatersheds that receive annual poultry litter application at rates from 0.0 to 13.4 Mg ha^{-1} (0 to 6 tn ac^{-1}) and supplemental N at recommended rates. Monthly and daily data from 2002 were used for calibration purposes while 2000, 2001, 2003, and 2004 were used for validation.

Results and Discussion

Field Results. Runoff and Erosion Response to Conservation Practices at Fort Hood. Implementing conservation practices on Fort Hood military training lands decreased soil erosion. Maneuver access structures (gully plugs) and mechanical treatment (deep soil ripping on the contour) significantly reduced storm runoff volumes and sediment loss as shown in figure 2 for 29 pretreatment and 22 post-treatment comparisons using a Wilcoxon rank sums test (Ott 1988). Precipitation amounts and intensities were not statistically different between the pre- and post-treatment periods (p = 0.8195 and 0.7826, respectively), but all standardized response variables were significantly different (p = 0.0003 or less). Mean runoff was reduced 61%, mean sediment concentration was reduced 70%, and mean sediment load was reduced 91% by erosion reduction conservation practices. These practices are now in place and part of an active rangeland protection program at Fort Hood.

Environmental and Economic Impacts of Poultry Litter Management. CEAP-related research on land application of poultry litter at Riesel demonstrated both the potential agronomic benefits and the importance of proper management to minimize negative environmental impacts (figure 3). Specifically, proper application rates to meet or slightly exceed crop P requirements are necessary to prevent P buildup in soil and to minimize nutrient loss in runoff (Harmel et al. 2004; Torbert et al. 2005). Similarly, incorporation of applied poultry litter in cultivated fields and split application of N were also effective at reducing offsite nutrient loss. Litter application at 4.5 to 6.7 Mg ha^{-1} y^{-1} (2 to 3 tn ac^{-1} yr^{-1}) plus supplemental N at recommended rates produced the best return per hectare (figure 4), based on total budget and throughput analysis. With increasing fertilizer costs, such information helps farmers optimize nutrient application for enhanced agronomic, economic, and environmental benefits. This

study also supported assessment of environmental and farm management models (Harmel et al. 2005; Wang et al. 2006; Vadas et al. 2007a; Green et al. 2007; Sedorovich et al. 2007) and soil nutrient and microbiological effects (Acosta-Martinez and Harmel 2006; Vadas et al. 2007b).

Soil Organic Carbon. The effects of various agricultural management practices on soil organic C in Vertisols (Udic Haplusterts) (Soil Survey Staff 2004) were demonstrated by comparing historical and recent soil samples taken from five fields at Riesel (Potter 2006). The soil organic C concentration in native prairie was significantly higher in the surface 15 cm (6 in) for the 2004 sampling period (33.1 g kg^{-1} or 3.31%) than in the 1949 sampling period (27.7 g kg^{-1} or 2.77%) (figure 5). Soils under coastal bermudagrass (coastal Bermuda grass grown for 55 years and coastal Bermuda grass grown for 39 years) also increased in soil organic C near the surface (figure 5). Below 60 cm (24 in), the differences between the 1949 and 2004 samples were not significant. The amount of C stored in the surface 30 cm (12 in) of the soils during period of continuous grass cover was estimated to be 5 Mg ha^{-1} (6 tn ac^{-1}) for CBG39 and 19.7 Mg ha^{-1} (8.8 tn ac^{-1}) for Coastal Bermuda Grass grown for 55 years. This indicates that C sequestration increased throughout period of grassland management. The 2004 C content of soils in row-crop fields (RC1 and RC2) had significant increases in C concentration from 0 to 15 cm (0 to 6 in) (RC1) and 0 to 30 cm (0 to 12 in) (RC2) compared to the 1949 samples. The amount of C sequestered by modern farming methods, estimated by the difference in C between the 2004 samples and 1949 samples, was 8.7 Mg ha^{-1} (3.9 tn ac^{-1}) and 6.9 Mg ha^{-1} (3.1 tn ac^{-1}) for RC1 and RC2, respectively. This is an annual rate of 158 kg ha^{-1} (140 lb ac^{-1}) and 125 kg ha^{-1} (112 lb ac^{-1}), respectively, for the surface 30 cm (12 in). It is assumed that this increase would have been even more pronounced with no-till management. It is also possible that the amount of C sequestered by establishing grass may have been underestimated in previous studies because the relative differences between grasslands and agricultural soils did not account for the increase in soil C associated with modern agricultural practices under conventional tillage.

Modeling Results. SWAT Modeling in the Leon River Basin. When applied in the

Figure 3
Effect of increased poultry litter application rate on annual average runoff dissolved phosphorus concentrations ($n = 6$).

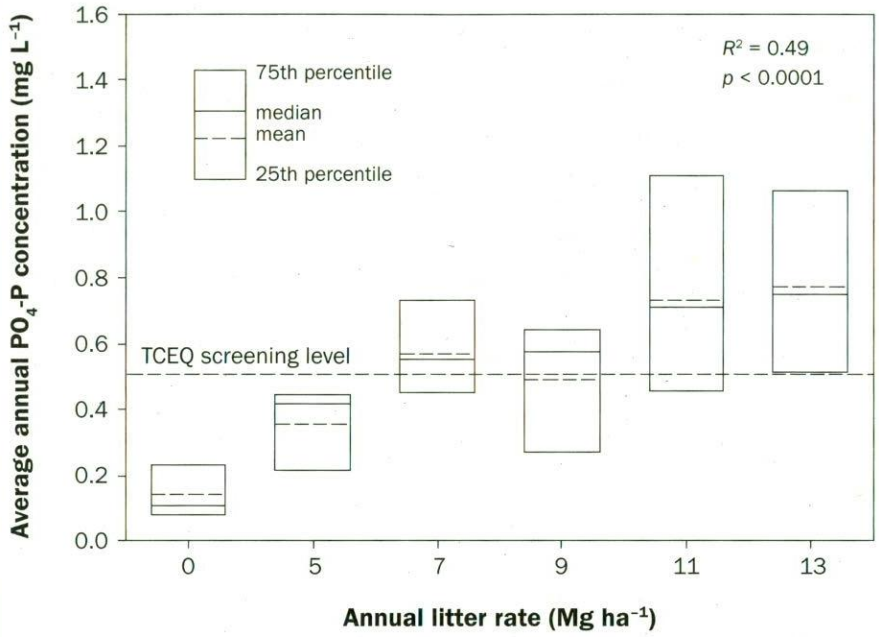
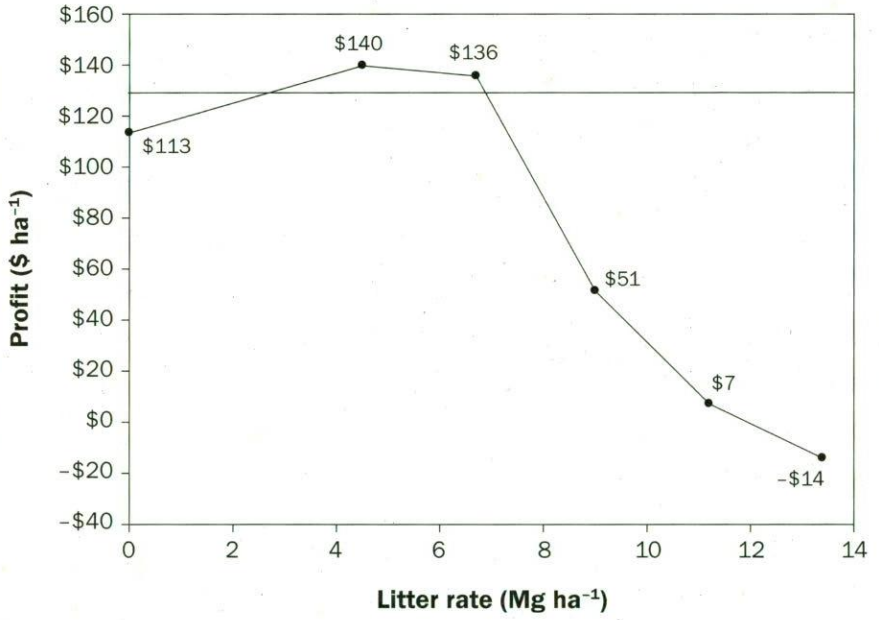
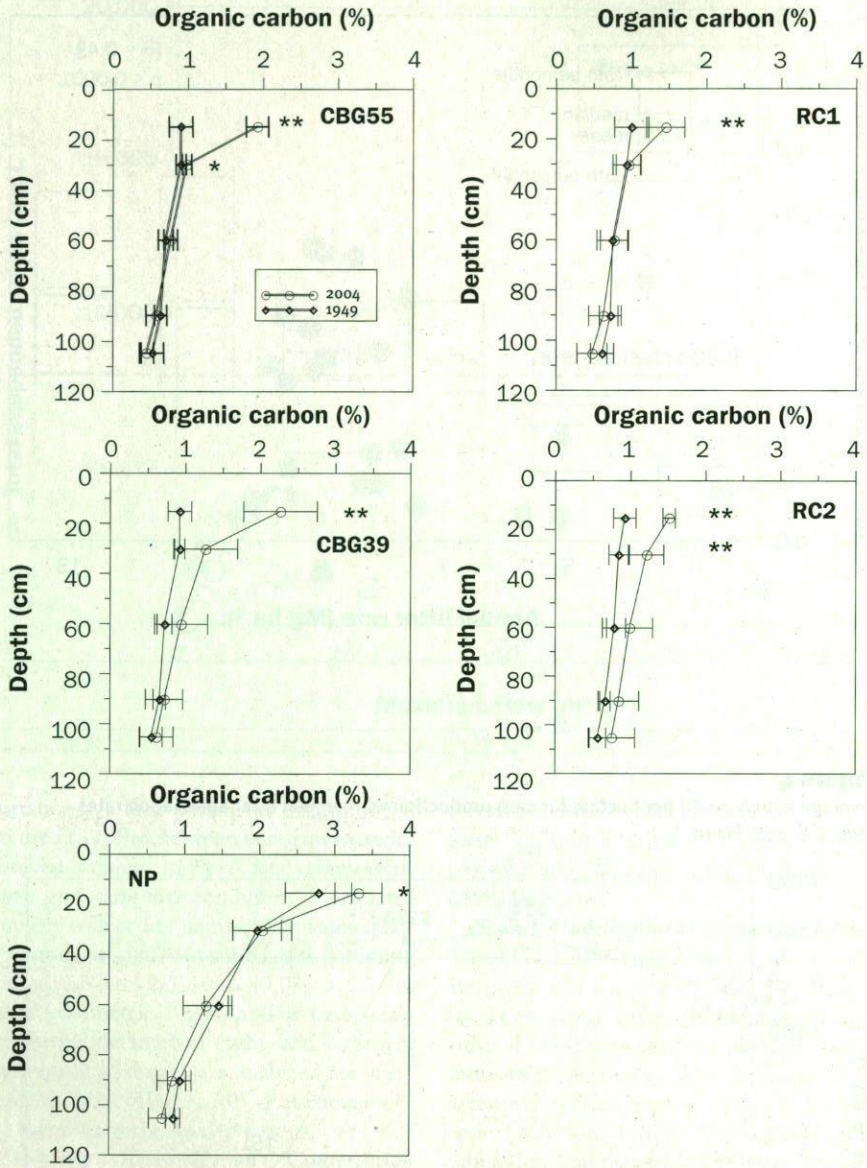


Figure 4
Average annual profit per hectare for crop production with annual litter application rates from 0 to 13.4 Mg ha^{-1}.



Note: The horizontal line illustrates the range of litter rates producing annual profits in excess of $130 ha^{-1}.

Figure 5
Comparison of soil organic carbon in soil samples taken from the same sites in 1949 and in 2004 (from Potter 2006).



Notes: CBG55 = Coastal Bermuda Grass for 55 years. CBG39 = Coastal Bermuda Grass for 39 years. NP = native prairie. RC1 = row crop 1. RC2 = row crop 2. * = significantly different at $p < 0.05$. ** = significantly different at $p < 0.01$.

Leon River basin, the SWAT2005 model performed well in simulating streamflow. Specifically, monthly streamflow calibration and validation simulations produced NSE values between 0.66 and 1.00, root mean square error observation standard deviation ratio values between 0.06 and 0.58, and percent bias values between -29.04 and 12.31. Typical subbasin level results are presented in figure 6. According to the performance ratings of Moriasi et al. (2007), SWAT2005 streamflow simulation was "good" to "very good" in terms of trends (NSE) and residual variation (root mean square error observation standard deviation ratio). Similarly, simulations of streamflow were typically "good" to "very good" in terms of average magnitude (percent bias), although "unsatisfactory" results were obtained in one subbasin.

SWAT Modeling in the Riesel Watersheds. Model predictions from SWAT2005 accurately represented measured runoff, sediment, and nutrient loss from various nutrient management treatments at the Riesel subwatersheds (Green et al. 2007). This assessment of SWAT's ability to accurately represent runoff and water quality at the small scale ensures that these processes were represented correctly, which is important because of SWAT's use in conservation practice evaluation. The monthly and daily runoff simulations for six cultivated subwatersheds resulted in NSE values of 0.59 and 0.53 for calibration and NSE values 0.82 and 0.80 for validation. The monthly and daily r^2 values for runoff were at least 0.60 and 0.53 for calibration and 0.86 and 0.81 for validation. For monthly sediment and nutrient losses, NSE values exceeded 0.4 and r^2 values exceeded 0.5. Paired t-tests for the monthly manually adjusted parameter simulation of sediment, organic N and P, NO_3-N, and soluble P for the 2000 to 2004 period losses showed their respective SWAT predicted means were not significantly different from measured means ($\alpha = 0.05$). A single exception occurred for NO_3-N losses for the Y10 subwatershed ($p = 0.023$).

Overall, SWAT simulated subwatershed-scale hydrology and water quality better when all available data were used in calibration, instead of a subset of measured data. Typical modeling applications use only a portion of available data for calibration and use the remaining data for validation. Green et al. (2006, 2007), however, illustrated that improved prediction is obtained by using all available data for calibration then selecting data from a range of hydro-climatic conditions for validation.

Summary and Conclusions

In a relatively short time period, 11 new watershed monitoring sites were established in the Leon River basin, and model analysis was performed on this site as part of the CEAP national assessment. These CEAP activities effectively complement ongoing field and modeling research on Fort Hood and at the historical USDA ARS watershed at Riesel, Texas. To date, CEAP-related activities in the Leon River and Riesel watersheds have produced important results including (1) determining optimum poultry litter application rates, (2) reducing storm runoff and sediment loss from Fort Hood, (3)

quantifying C sequestration in Vertisols for various management practices, and (4) demonstrating the accuracy of SWAT for small watersheds and a large river basin to enhance its use for national assessments of conservation practices.

The CEAP studies have also identified several issues that need increased research attention. These include (1) quantifying how sources of nutrients and bacteria other than agriculture (i.e., waste water treatment plants, septic systems, and wildlife) are affecting these watersheds; (2) determining bacterial deposition rates, measuring terrestrial and aquatic survival, refining source differentiation techniques, and understanding overland and downstream transport mechanisms; (3) optimizing the location and type of conservation practices within watersheds to maximize water quality benefits and minimize cost; (4) improving spatial representation of landscape effects within SWAT; and (5) testing specific loading transformation routines in SWAT to determine whether the Agricultural Policy Environmental Extender (APEX) model outputs are appropriate inputs in the hydrologic unit model for the United States national watershed system (Arnold et al. 1999) to better assess the national impact of conservation practices.

With new sites established through CEAP to complement historical sites, the USDA ARS watersheds are uniquely positioned with legacy data, established monitoring infrastructure, watershed land control, and scientific expertise. Such sites with a range of monitoring scales and legacy data are particularly valuable for assessment of conservation practice effects as influenced by climatic trends, shifts, and extreme events. As such, the USDA ARS watershed network can be relied upon to continue to provide critical understanding, technology, and data necessary for soil and water resource sustainability.

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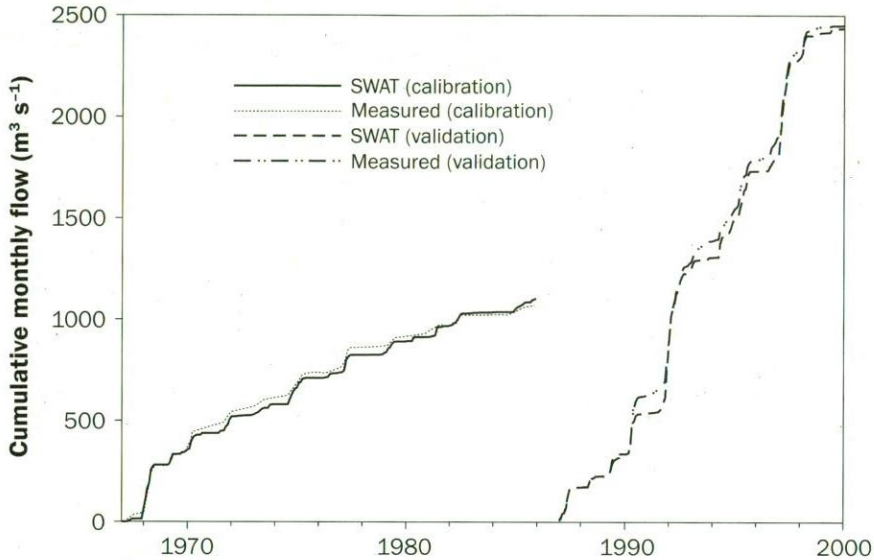
Figure 6

SWAT2005-simulated streamflow versus measured streamflow data for the calibration (1967 to 1985) and validation (1987 to 2000) periods.



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