Chapter 15

Goodwater Creek Watershed, Missouri: National Institute of Food and Agriculture–Conservation Effects Assessment Project

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The overall purpose of the Missouri National Institute of Food and Agriculture–Conservation Effects Assessment Project (NIFA–CEAP), the Goodwater Creek Watershed Project, was to identify the interactions among conservation practices, their biophysical settings, and the socioeconomic constraints in an agricultural watershed in terms of the effectiveness of these practices to improve water quality. The project was intended to result in a watershed plan that integrated research findings to address the issues of excess nutrients, sediment, and pesticides in streams in a comprehensive fashion.

The 10 objectives for the Goodwater Creek Watershed Project included the following:

1. Identify crop and crop management history in the watershed (operational)
2. Detect changes and trends in existing water quality data (research)
3. Model water and contaminant fate and transport under historical land use and land management practices in the watershed (operational)
4. Analyze the impacts of land use and management practices on water quality during the pre- and post-best management practice (BMP) implementation periods (research)
5. Project the environmental impacts from implementing BMPs in specific landscape positions (research)
6. Model and analyze the economic impacts on crop yields and economic returns from implementation of BMPs (research)
7. Identify the economic and sociological factors that lead a farm manager to adopt a management practice (research)
8. Determine the optimal types, numbers, and locations of BMPs that need to be implemented to achieve desirable concentrations of water quality constituents at the outlet of the Goodwater Creek Watershed (research) and incorporate these determinations in a watershed management plan (operational)
9. Develop an alternative optimum water quality sampling design documenting the improvement of water quality (research)

10. Develop and distribute materials and a curriculum for training professionals for reaching farm operators regarding theirs role in reducing and controlling water quality degradation (operational)

The following hypotheses guided the Goodwater Creek Watershed Project's approach:

1. Implementing BMPs in the Goodwater Creek Watershed since 1990 has contributed to a measurable improvement of the water quality in the stream.
2. Implemented BMPs in the Goodwater Creek Watershed have and will continue to contribute to an improvement of the economic return for farmers.
3. Predicting the environmental impacts from implementing BMPs is possible with the Soil and Water Assessment Tool (SWAT) model.
4. It is difficult to detect water quality improvement from a limited monitoring plan.
5. Watershed modeling in combination with limited monitoring data can provide credible information on achieved progress.

Watershed Information

The Goodwater Creek Watershed is located in Audrain and northeast Boone counties, about 45 km (28 mi) north of Columbia, Missouri, and empties into Young's Creek and Long Branch, a tributary to Mark Twain Lake, which serves as a drinking water reservoir and recreation area in northeast Missouri (figure 15.1). Taste and odor problems have occurred since the early 2000s due to excessive nutrient levels; other impairments include sediments and herbicide concentrations in excess of water quality standards.

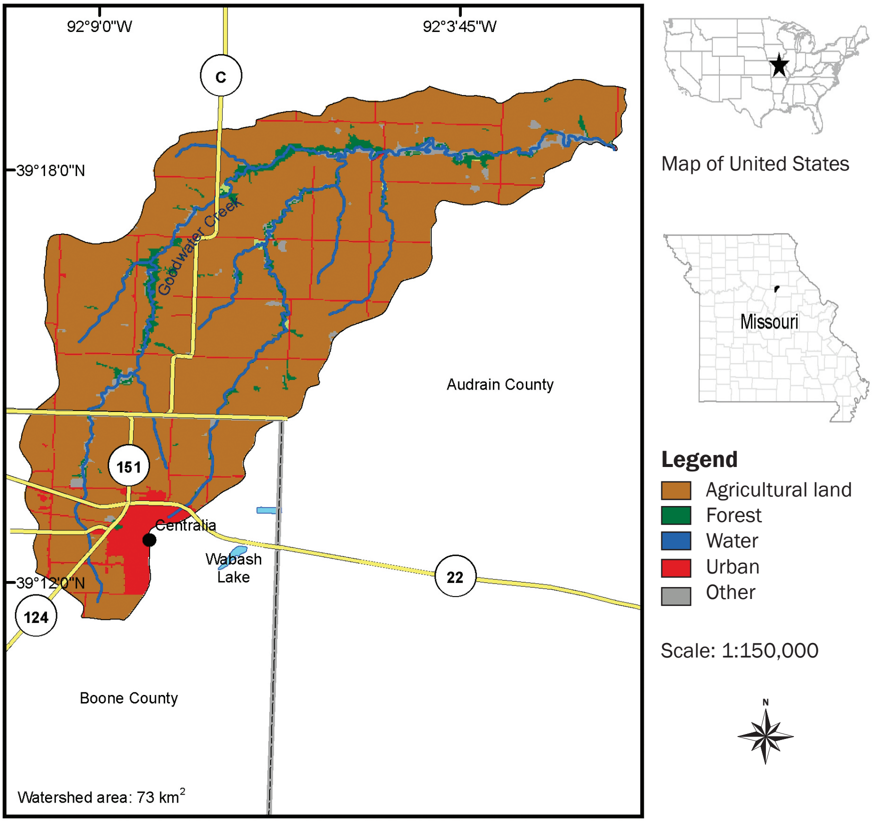
Goodwater Creek Watershed (hydrologic unit code [HUC] #071100060102) is 7,250 ha (17,915 ac) in area and is a tributary of Young's Creek, itself divided into two 12-digit HUC: the Lower (12-digit HUC #071100060104) and Upper Young's Creek (12-digit HUC #071100060103) watersheds. Young's Creek is a tributary of Long Branch, which is part of the Salt River Basin system and drains to Mark Twain Lake (Lerch et al. 2008).

The Goodwater Creek Watershed includes part of Centralia, a small town (population 3,700) located at the southern end of the Goodwater Creek Watershed. The rest of the watershed is mostly agricultural with row crops (74%, consisting of corn, wheat, soybeans, and sorghum), grassland (18%), and woodland (6%). Combined acreage in corn and sorghum increased by 50% between 1992 and 2006. Two-year corn–soybean and three-year corn–soybean–wheat are the dominant crop rotations practiced in the watershed. The majority of cropland in the watershed is under conservation tillage.

The amount of animal agriculture is uncertain. There are reputed to be two exclusively cattle operations in the watershed; however, surveyed farmers reported two hog finishing operations, six cow/calf operations, and three cattle operations. Some of those may have been outside of the watershed because producers were asked about their whole farms, not just the parts that were in the watershed. Livestock was a part of the farm operation for half the watershed farmers surveyed. In one case, livestock production had replaced cropland as the primary farming operation—this farmer had a small acreage of corn for silage. Apart from this, operators with livestock also depended on row cropping as part of their livelihood.

The topography of the watershed is nearly level, with a ~37 m (121 ft) elevation difference from the divide to the outlet, which is at 235 m (771 ft) above mean sea level. The natural

Figure 15.1
Goodwater Creek Watershed, Missouri, land use and stream networks.



drainage system is well developed. Goodwater Creek is in the Central Claypan Soil Major Land Resource Area, an area of about 3 million ha (7.4 million ac).

A distinguishing feature of soils within the watershed is the existence of a naturally formed argillic horizon located 0.15 to 0.30 m (6 to 12 in) below the soil surface (Anderson 2011). These soils are often referred to as claypan soils due to the abrupt and substantial increase in clay content at this horizon. The clay content of the argillic horizon is generally greater than 50%, consisting primarily of montmorillonite. Claypan soils are complex hydrologically because the argillic horizon impedes the movement of water downward and causes lateral movement of soil water. The claypan is the key hydrologic feature of the watershed, resulting in high runoff potential soils that are predominantly classified as hydrologic soil groups C and D. Interflow over the claypan may be a factor in prolonged high atrazine concentrations in surface water. The major soil series include Adco silt loam (0% to 2% slopes; fine, smectitic, mesic Vertic Albaqualfs), Mexico silt loam (1% to 3% slopes, eroded; fine, smectitic, mesic Vertic Epiaqualfs), and Putnam silt loam (0% to 1% slopes; fine, smectitic, mesic Vertic Albaqualfs).

Significant differences in soil hydraulic properties have been documented for the same soil series but with different long term management (Mudgal et al. 2010a). The saturated hydraulic conductivity in the surface horizon under native prairie was about 57 times higher than the saturated hydraulic conductivity in the surface horizon under long-term row crop cultivation. Bulk density was 19% lower, and coarse and fine mesopores were significantly higher under native prairie compared to cultivated cropland. Water retention was significantly higher for native prairie than for soils in row crop cultivation.

The area within the Goodwater Creek Watershed receives an average of about 1,000 mm (39 in) of precipitation each year—75% of it between March and October. The average temperature is 0°C (32°F) in winter and 22.5°C (73°F) in the summer.

Mean annual streamflow (surface runoff plus base flow) is 292 mm (11.5 in) in the Goodwater Creek Watershed, which is about 30% of mean annual precipitation. Base flow accounts for about 15% of streamflow discharge, and surface runoff accounts for about 85%. The claypan layer results in saturated conditions in wet spring seasons and low soil moisture conditions in dry summer periods.

Water Quality Information

Plot, field, and stream sites within the Goodwater Creek Watershed were the principal research sites that were established in 1990 as part of the Missouri Management Systems Evaluation Area (MSEA) Project. An extensive database of meteorological and hydrologic data was developed from the Goodwater Creek Watershed. The monitoring effort started in 1969 for precipitation and in 1971 for flow and weather and was expanded in 1991 with water quality sampling.

The water quality issues in this watershed are representative of those in the Salt River system: high pesticide concentrations and excessive nutrient and sediment loadings in an area where surface water is the only drinking water source (Lerch et al. 2008). The claypan soils are especially vulnerable to soil erosion, which has degraded soil and water quality throughout the basin, and to surface transport of herbicides. In the early 1980s, average soil erosion rates for cropland within the Central Claypan Region were estimated to be 17.9 Mg ha^{-1} (8.0 tn ac^{-1}), exceeding the tolerance factor of 7.6 Mg ha^{-1} (3.4 tn ac^{-1}) by about 2.4 times. Cropland erosion remains a major water and soil quality problem for this area as a whole. Nutrient and pesticide loadings that discharge into Mark Twain Lake affect the quality of the drinking water for 45,000 people served by 22 water distribution systems in northeast Missouri. In 2006 and 2007, there were serious taste and odor problems for the water in the Mark Twain Lake due to excess nutrient loading.

Sources of nutrients, including soluble phosphorus (P), ammonium (NH_4-N), and nitrate plus nitrite-nitrogen ($NO_2 + NO_3$-N), include fertilizers applied to cropland (spring applications of anhydrous ammonia and P fertilizers) and to urban land. Average daily nutrient concentrations at weir 1 between April of 1992 and December of 2004 were as follows: $NO_2 + NO_3$-N was 0.51 mg L^{-1} (base flow) and 1.57 mg L^{-1} (stormflow); NH_4-N was 0.08 mg L^{-1} (base flow) and 0.16 mg L^{-1} (stormflow); P was 0.10 mg L^{-1} (base flow) and 0.15 mg L^{-1} (stormflow) (Baffaut et al. 2009). Most of the dissolved nutrients are from nonpoint sources, but because dissolved P and NH_4-N concentrations and loads in the upper watershed were significantly greater than those at the two downstream weirs, wastewater point sources, lagoon discharge, fields irrigated with effluent from wastewater lagoons, a chemical dealership, individual lagoons, direct sanitary discharges, and failing septic tanks have been suggested as important sources of nutrients.

Atrazine is the most heavily used agricultural herbicide in the watershed, and its use has tended to increase over time. Herbicides, mainly atrazine, but also acetochlor, alachlor, metolachlor, and metribuzin have been detected in Goodwater Creek. Atrazine is consistently present in Goodwater Creek, with maximum concentrations of 23.6 to 149 $\mu g\ L^{-1}$ recorded (Lerch et al. 2011a). These maximum concentrations exceeded the US Environmental Protection Agency (USEPA) level of concern in every year from 1992 to 2006. The Goodwater Creek Watershed has been selected as a watershed for atrazine reregistration. Goodwater Creek was one of two Missouri watersheds cited in 2007 for violation of the agreement between Syngenta and the USEPA for reregistration of atrazine. Because atrazine levels in surface water have exceeded ecological criteria in two successive years (2005 and 2006), the USEPA requires the preparation of a watershed plan for mitigation. The average annual atrazine load at the watershed outlet ranges from 0.6% to 14% of the applied atrazine, and the median is 5.9%. Atrazine delivery is primarily a function of application timing relative to rainfall events.

Three nested watersheds (1,210, 3,160, and 7,240 ha [2,990, 7,809, and 17,890 ac] in area) were instrumented when the watershed was first established. Flow was monitored since 1971, on a 15-minute basis until 1993 and on a 5-minute basis thereafter. Five and 15-minute flow volumes were aggregated to daily flow values. Flow monitoring ceased at weirs 9 and 11 in April of 1997 and in May of 2002, respectively. A network of nine weighing, recording rain gages was installed across the watershed in 1969 for collection of breakpoint precipitation data. An automated weather station, which also included a rain gage, was installed in 1991.

Water quality monitoring efforts started in 1991 with the Missouri MSEA. Water quality data were collected at three landscape scales: watershed, individual fields, and plots. From 1992 to April of 1997 at weirs 9 and 11 and from 1992 to present at weir 1, water samples were collected to characterize storm and base flow. Surface water quality was evaluated from analyses of weekly grab samples (predominantly baseflow) collected at each of the three weirs on Goodwater Creek and from analyses of storm event samples collected with a flow-proportional autosampler installed at each station. Streamflow and water quality (both baseflow and storm event) continued to be monitored at the downstream weir and permitted the calculation of daily flow-weighted concentrations from 1992 to present. Extensive groundwater $NO_2 + NO_3$-N and herbicide data were collected during the MSEA Project (1990 to 1997). However, no additional groundwater data was collected for the CEAP. Water quality data from these stream sites were used for the following:

- Comparison to regional values (Baffaut et al. 2009)
- Evaluation of seasonal, spatial, and temporal water quality trends (Lerch et al. 2011a, 2011b)
- Response to conservation practices (O’Donnell 2010)
- Model calibration/validation (Mudgal 2010; O’Donnell 2010)

Three fields ranging from 20 to 32 ha (49 to 79 ac) in size were instrumented with groundwater wells and concrete runoff weirs. Thirty 0.35 ha (0.86 ac) research plots were also monitored. All water samples were analyzed for concentrations of dissolved nutrients (NO_3-N, NH_4-N, and PO_4-P [orthophosphate]), and dissolved herbicides (acetochlor, alachlor, atrazine, deethylatrazine, deisopropylatrazine, metolachlor, and metribuzin). Field and stream samples were also analyzed for suspended sediment. Chemical analyses were conducted on water samples from fall of 1991 to the present. Some herbicides were not analyzed for this entire period of record, but all herbicides listed above were analyzed for a minimum of nine years.

Water quality data and analyses were summarized in numerous reports and presentations (e.g., Lerch et al. 2008; Lerch et al. 2011a, 2011b; Baffaut et al. 2009). Average monthly spring (April through June) atrazine concentrations decreased from 1993 to 2003; April and May concentrations showed no significant trend, but June concentrations decreased. However, no trend was detected when concentrations were flow weighted. Further analysis of water quality data limited to runoff events showed that no trend could be detected between implementation of conservation practices and monitored atrazine concentrations. Patterns of increasing and decreasing atrazine concentrations were influenced by timing of planting and herbicide application in spring, which may have obscured the effects of conservation practices or rates.

Field-scale data were used to study the hydrologic behavior of claypan soils, understand effects of soil and crop management on soil hydraulic properties, and identify critical management areas (Mudgal et al. 2011). The research plot data were used to calibrate the Agricultural Policy/Environmental eXtender (APEX) model to understand position effects of conservation practices (Mudgal et al. 2010b).

An extensive database of meteorological and hydrologic data has been developed from the Goodwater Creek Watershed. Data are currently stored in the Cropping Systems and Water Quality Research Unit database (Oracle tables) and include meteorologic data, flow data, water samples, and associated analyses. The tables of this database are located in the USDA Agricultural Research Service (ARS) table space leased through a Memorandum of Understanding with the University of Missouri on its data hub. Tables can be queried with appropriate access privileges and Open Database Connectivity or other pathways. All daily flow, precipitation, and water quality data from the Goodwater Creek Watershed have also been entered in the Sustaining the Earth's Watersheds–Agricultural Research Data System (STEWARDS) database and can be easily downloaded by anyone (USDA ARS 2012).

Land Treatment

Like most NIFA–CEAP watershed studies, no new conservation practice implementation was planned for this project. This project relied on data from the USDA Natural Resources Conservation Service (NRCS) for information on past practice implementation, which required multiple types of conservation practice assessments. Coordination between the project and the USDA NRCS was initiated at the beginning of the project, but contacts were made at the proposal stage. Upon initiation of the project, a meeting took place at the USDA NRCS state headquarters, in the presence of the district conservationists. The issue of information privacy was discussed then, which led to the decision to ask district conservationists to provide a map with the necessary information. District conservationists and state personnel were regularly invited to the watershed meetings. The crop history in the watershed from 1993 to 2003 was established by reviewing USDA Farm Service Agency (FSA) records in combination with aerial and satellite images from 1976, 1992, and 2004; agricultural area estimates were available from the Missouri Agricultural Statistics Service; and annual reports of state cost-shared practices were obtained from the Missouri Department of Natural Resources for Audrain and Boone counties from 1990 to 2003. Management practices were assessed for the 1990 to 1993 period through ground truthing and interviews with custom applicators.

Initially, the project asked for and received permission to obtain conservation data through the USDA FSA. However, once the project started, the USDA FSA no longer allowed access to the data. Information was obtained from resource and/or district conservationists from Boone and Audrain counties to establish what management practices had been implemented during the 1993 to 2003 project period. In addition to reviewing annual reports for the Conservation Reserve Program (CRP), the Wildlife Habitat Incentives Program (WHIP), the Grassland Reserve Program (GRP), and the Environmental Quality Incentives Program, USDA NRCS employees were interviewed to identify on aerial photographs the conservation practices that had been implemented since 1990 with the farm programs mentioned. Finally, current management practices were assessed in 2006 through a survey of individual producers in the watershed to identify practices that were implemented and the reasons that led producers to adopt a specific practice (Murphy et al. 2010a). It showed that landowners and farm operators implemented conservation practices both on their own and through participation in USDA programs for cost share.

Clearly, implementation of conservation practices in the Goodwater Creek Watershed increased significantly since 1993. From 1990 through 1993, 361 ha (892 ac) of the watershed area (5%) had conservation practices installed. By 2003, 1,212 ha (2,005 ac), or 17% of the watershed, were treated with conservation practices. Along with implementation of conservation practices, there was a large shift in conservation tillage during 1992 to 1994. Use of no-tillage or conservation tillage from the early 1990s to 2004 increased dramatically: corn—from 15% to 27% of the planted acres; soybeans—from 4% to 75%; and wheat—from 4% to 90%. This change in conservation tillage started through the MSEA Project. Educational efforts were made to promote conservation tillage and no-tillage practices, and better equipment was made available through the Soil and Water Conservation District. These two factors resulted in a large increase in conservation and no-tillage implementation in the 1990s. Data collected for Audrain County show that most of the changes in tillage practices occurred from 1992 to 1994.

The main conservation practices in the watershed included grassed waterways and terraces, with and without underground outlets (table 15.1). Other minor practices consisted of CRP buffers or whole fields, vegetative filter strips, vegetative buffers, water diversions, lagoons, and prescribed grazing. Increases in conservation practices appeared to have been dominated by sediment-reducing conservation practices, but there were no data for conservation practice management and little conservation was targeted at reducing herbicide losses. Because conservation practice adoption was a function of USDA programs, implementation was dependent on voluntary adoptions and conservation practices offered. Motivations to adopt structural conser-

Table 15.1
Increase in conservation practice protected area from 1993 to 2001.

Conservation practice	Area (ha) protected by 1993	2003	Increase (%)
Vegetative waterways	105	410	290
Terraces (all kinds)	224	600	168
Other BMPs	32	202	531
Total	361	1,212	236

Note: BMP = best management practice.

vation practices included the desire to do the right thing and evidence of degradation. Cost share and financial incentives were important motivators for expensive practices.

Unlike most NIFA–CEAP watershed studies, research at the Missouri Project included field- and plot-scale research, which was critically important to understand specific processes of pollutant transport. The smaller-scale results indicated that atrazine losses from no-tillage fields were three times more than losses under mulch tillage; metolachlor losses were two times greater from no-tillage than from mulch tillage fields (Ghidey et al. 2010). Based on this work, the practices recommended in the watershed management plan for reducing the transport of dissolved pollutants into the stream included reduced application rates, incorporation of herbicides, and filter strips. The traditional conservation tillage, terraces, and grass waterways remain to reduce erosion and sediment transport.

Furthermore, the Missouri NIFA–CEAP showed that planting timing and application timing had a major impact on herbicide pollutant transport. Planting and application windows are significantly controlled by weather, soil moisture conditions, and custom applicators schedules, and are therefore beyond the control of farm operators. Soil wetness is an important factor that can prevent field operations in the spring. Conditions in 2008 and 2009 showed that for producers, planting had to happen whenever conditions allowed, even if it lead to increased transport of pollutants.

Incorporation of atrazine was initially discouraged because it increased soil erosion. However, further discussions with the USDA NRCS and Syngenta led to the possible use of a specific tillage implement—the Phoenix harrow—that can incorporate atrazine within a few inches with minimal disturbance of the surface residues. This implement was evaluated against two other implements by students of a Capstone project at the University of Missouri.

Land treatment information was used to develop a Goodwater Creek representative farm for conducting farm-level economic analyses of different crop and management systems with various conservation practices (see the Socioeconomic Analysis section in this chapter). Management information (fertilizer and herbicide rates, crop distribution, and tillage) was used in the hydrologic model for the Goodwater Creek Experimental Watershed (see the Modeling Application section in this chapter).

Water Quality Response

Water quality response was assessed at a watershed outlet station based on response to aggregate practice implementation. Nutrient and herbicide data were statistically analyzed using stationarity and homogeneity tests on the dissolved P, $NO_2 + NO_3$-N, NH_4-N, and atrazine data series. Independence of the elements of each data series at weir 1 was tested with the Wald-Wolfowitz test; annual and seasonal homogeneity were tested with the Mann-Whitney test; existence of trends was tested using the Kendall test.

No major improvements in water quality were observed in the streams or lake, and no shift or trend was detected for any of the monthly nutrient or sediment loads from 1992 to 2004. Atrazine concentrations at the outlet of the Goodwater Creek Watershed in Northeast Missouri decreased from 1993 to 2003, but no significant trend was documented for loads when concentrations were flow-weighted.

Several factors could have influenced atrazine concentrations in different ways: the construction of several grassed waterways and other conservation practices should decrease atrazine concentrations in the stream; a shift to earlier corn planting dates should cause atrazine concentrations to increase in April and decrease in June, and an increase of no-tillage corn in the watershed is expected to cause larger atrazine losses in late March and early April because preplanting pesticide applications are necessary. This mix of factors likely to impact atrazine losses makes it difficult to determine the effects of conservation practices implemented since 1993.

Statistical analysis showed that the temperature factor, which was directly linked to earlier planting dates, was an important but not fully explanatory variable for the decrease of atrazine concentrations. Reduction of atrazine concentrations due to earlier planting dates was suggested by monitoring data. Monitoring data combined with modeling (SWAT) analysis suggested that although installed grassed waterways reduced the atrazine concentrations by 19% on average, the decrease had been more than offset by a large increase in atrazine concentrations resulting from increasing corn acreage. However, this reduction, shown in the modeling results, depended on how grassed waterways were represented in SWAT; they may or may not have caused a reduction in dissolved pollutants.

Model Application

Two models were used in the Missouri NIFA–CEAP: the SWAT (watershed scale) and APEX (field scale) models. The SWAT model was selected to integrate field-scale conservation practices within the watershed and to evaluate benefits that can be expected from their implementation at a larger scale and over a longer period of time. The APEX model was selected to address issues of effects of landscape position on conservation practice effectiveness. In the SWAT model, the subbasins were spatially defined, but the hydrologic response units (HRU) defined by land use/soil/slope combinations were lumped together within each subbasin and were not spatially defined. This limitation of the model impairs the ability to simulate the process involved with runoff from one area running onto another one and, more specifically, limits the simulation of conservation practices, such as filter strips or riparian buffers. To address the limitation about filter strips in SWAT2005, a reduction factor that was a function of the filter width was applied to calculate load reductions. In SWAT2009, routines simulated the processes involved with filter strips. However, in general, SWAT was not able to simulate the effects of a topographic sequence of areas with different soil, land cover, and/or management characteristics. The APEX model, on the other hand, had the ability to specify the landscape position of each subarea and to analyze the large-scale effects of localized poor management or site-specific soil characteristics.

The objectives of modeling were to (1) determine the sensitivity of SWAT and APEX outputs to landscape characteristics, (2) identify critical areas at field and watershed scales, (3) evaluate water quality impacts of conservation practices at both field and watershed scales, and (4) determine the impact of landscape position on the performance of practices at the field scale.

Data for model analysis came from multiple sources. Field data were used to validate the upland processes; stream data were used to validate the channel and groundwater processes. Water quality data from 1992 to 1998 were used to calibrate the model, while data from 1999 to 2006 or 2008 were used for validation.

Physical data necessary for model development include parameters, such as land use and land cover, land management, slope, geology, soils, and weather. Digital elevation maps were available for the whole state of Missouri from the Missouri Resources Assessment Project, and the USDA NRCS soil surveys for Boone and Audrain counties have been digitized by NRCS. Daily precipitation, temperature, and evaporation data were available from the watershed database, which was started in 1970. The ArcView and ArcGIS SWAT interfaces were used to enter and manage the data needed for the development, calibration, and validation of the SWAT model. In some cases, it was also used for the development of the APEX model at field scale but not for its calibration and validation.

Several SWAT models were developed over the course of the project that used detailed input datasets for climate, soil, land use, and elevation to capture the spatiotemporal variability of watershed characteristics:

- US Geological Survey digital elevation models were collected at a 10 to 30 m (33 to 98 ft) resolution.
- Soil maps, both STATSGO (State Soil Geographic Database) and SSURGO (Soil Survey Geographic Database) databases, were adjusted for hydraulic conductivity in the claypan.
- Watershed boundaries were determined by the ArcSWAT model interface based on the 10 m (33 ft) digital elevation model.
- Crop management factors were determined by the survey of operators in the watershed.
- Location and timing of conservation practice implementation were collected from the USDA NRCS district conservationists. They were used to the extent it was possible to represent these conservation practices.

The representation of management practices in the models included a mix of empirical coefficients and process-based approaches. Certain practices, such as change in crop rotations, were always represented through a process-based approach. Tillage practices were represented through a process-based approach when tillage operations were added or removed from the management. However, when one switches from one type of tillage to another, it was represented by altering coefficients. Terraces were represented in SWAT by altering representative model parameters. When using SWAT2009 or APEX, grassed waterways or filter strips were represented through a process-based approach, but in SWAT 2005, representative parameters were adjusted.

Two models, one initial and a later one, were based on SWAT2005. The initial model (Bockhold 2006) was based on the 1992 land-use map developed by the Missouri Spatial Data Information Service. Crop distribution in the watershed was based on the 1990 to 1993 USDA FSA records. Management practices were based on information collected during the MSEA Project. In the later SWAT2005 model (O'Donnell 2010), each field was represented as an individual HRU for which land use and crop rotation were identified from the 1990 to 1993 USDA FSA records and a 2006 windshield survey. Crop management was based on conversations with private crop consultants and work from the MSEA Project. Best management practices (timing and location) were based on the information provided by the USDA NRCS in 2006 to the extent they were able to be represented in SWAT2005, as indicated in our prior discussion on filter strips. Planting and operation dates were distributed across the watershed according to planting progress records obtained by the USDA National Agricultural Statistics Service for the Missouri Northeast District. These records indicated for each crop what was planted at the end of each week of the planting season as a proportion of the total acres planted in the district.

In another model based on SWAT2009 (Mudgal 2010), land use was determined from the 1992 land-use map developed by the Missouri Spatial Data Information Service. Crop distribution in the watershed was based on the 1990 to 1993 USDA FSA records. After sensitivity analysis and calibration, changes were incorporated into the model to improve results. These changes are explained below.

To evaluate the robustness of the SWAT2009 model to simulate the fate and transport of sediment, nutrients, and chemicals, the following variables were considered: flow, pollutant loads and concentrations in the stream, and pollutant loads leaving given areas of the watershed. An extensive sensitivity analysis of the SWAT model applied to the watershed and to one field was performed using the SWAT-CUP SUFI-2 algorithms. These sensitivity analyses were performed to direct the calibration efforts of the model. The calibration criteria included the percent deviation in average annual values, the coefficient of determination (r^2), the ratio of the root mean square error to the observations standard deviation, and the Nash-Sutcliffe coefficient. The original SWAT application was not sensitive to the depth of top soil (i.e., depth to the claypan layer) and saturated hydraulic conductivity, which was contradictory to the findings from APEX. The hydrologic component of SWAT had to be modified in order to simulate saturation conditions and lateral flow that were characteristic of claypan soil conditions. These changes produced both improved simulation of groundwater and surface flow, even though total flow did not significantly change. Additional changes were introduced after initial work showed that atrazine transport and degradation were dominated by the interaction of weather and applications dates. Herbicide modeling improved by considering planting dates that control the timing of herbicide applications. A routine was incorporated into SWAT to schedule planting dates based on heat unit scheduling and planting progress records supplied by the USDA National Agricultural Statistics Service. This routine eliminated the need to manually distribute planting dates throughout the watershed as was done in the previous SWAT2005 model.

The SWAT simulation scenarios in the first model included conservation practices that included grassed waterways, terraces, filter strips, and a change in cropping systems that increased corn acreage while decreasing sorghum/wheat acreage. With the assumption that grassed waterways function as filter strips, the following conclusions were reached (Bockhold et al. 2006):

- The SWAT model estimated that installed grassed waterways reduced atrazine concentrations by 19% to 26% and loads by 18%, for April, May, and June.
- The SWAT model estimated that corn acreage increased atrazine concentrations and loads by 85% and 57%, respectively, relative to 1992 crop distribution practices.
- Combined effects resulted in a 34% and 16% increase in concentrations and loads, respectively.
- The SWAT model estimated a 6% increase in atrazine concentrations due to an increase in conservation tillage.

The modeling indicated that although one conservation practice was effective, the effects were tempered by changes in land use and tillage practices. In the initial model, pesticide management techniques, such as planting dates, timing of application, and split applications were not captured. These important aspects of management were incorporated in the subsequent models.

The second SWAT2005 model of the watershed (O'Donnell 2010) gave the possibility to distribute the timing of planting operations, herbicide applications, and fertilizer applications manually throughout the individual fields of the watershed. The model was calibrated and used to test different practices, including incorporation of atrazine and filter strips. Model outputs at the HRU level were used to identify critical fields in the watershed, and management practices were gradually implemented on the most critical fields. Filter strips were found to be necessary on 19% and 29% of the most critical fields in the watershed to cause reductions in atrazine and NO_3-N loads, respectively, which would be detectable using the monitoring design in place.

The APEX model was calibrated and validated with event data from plots during the corn-growing years from 1997 to 1999 and 2000 to 2002, respectively (Mudgal et al. 2010b). The APEX model reasonably simulated runoff and dissolved atrazine concentrations with annual coefficient of determination (r^2) values ranging from 0.60 to 0.98 (calibration) and 0.52 to 0.97 (validation) and Nash-Sutcliffe efficiency values ranging from 0.46 to 0.94 (calibration) and 0.45 to 0.86 (validation). The APEX model was able to correctly simulate runoff and atrazine loads from field plots once it was calibrated.

Sensitivity analysis of several input parameters of APEX was conducted for the purpose of guiding the model's calibration. In particular, a detailed sensitivity analysis was performed to examine whether the selected parameters for representation of practices had any impacts on the model outputs. In addition, a sensitivity analysis of the arrangement of different landscape components was conducted as a means to understand the relative importance of each landscape position with respect to pollutant transport (Mudgal et al. 2010b).

The calibrated model was then used to simulate variable sequencing of landscape positions and associated soil properties as well as variable lengths of landscape positions. Simulated results indicated that as the length of the backslope increased, while the steepness remained constant, so did the volume of runoff discharged and the atrazine concentrations at the plot outlet. In addition, the highest level of simulated runoff occurred when the backslope position was located adjacent to the outlet. The length of the backslope also had an influence on the simulated flow and atrazine losses. Conversely, the length of footslope positions had no effect on simulated atrazine losses. Results from this study will be helpful to managers to help them determine placement of conservation practices on sensitive landscapes for improvement in water quality.

Different scenarios were determined in cooperation with the steering committee and the farm panel and were evaluated with the APEX model. Scenario analyses showed that planting perennial grasses on the field's backslope, which are the critical areas in that field, would significantly decrease transport of pollutants.

The APEX model was also used to derive indices based on field properties that can be used in lieu of the model to identify critical areas within an area of interest. The analysis was conducted in a well-characterized 35 ha (87 ac) field with high resolution soil and elevation information (Mudgal et al. 2012). The model was calibrated and validated using flow, crop yield, and water quality data from the field during a 10-year period. Model outputs were analyzed to delineate critical management areas within the field. Subsequently, two indices were derived that can be easily calculated using readily available data (i.e., slope, hydraulic conductivity, and depth to claypan) to identify critical areas for runoff and atrazine losses (Mudgal et al. 2012).

The indices were extended to the Goodwater Creek Watershed and were validated using modeling results. The final SWAT model was developed for the watershed with homogenous units (HRU) based on soil, land use, and slope. As explained before, this model was based on SWAT 2009 in which the percolation and lateral flow routines were modified and included consideration of the planting dates in the Missouri Northeast District. The SWAT model was calibrated and validated using flow and water quality data at the outlet of the watershed. Critical areas were determined based on the sediment and atrazine transport from the HRUs. Correlation analysis showed that these critical areas matched those identified with the indices. The fields identified with this model also matched those identified in the SWAT2005 model in which fields defined the HRUs, even though the two modelers used different approaches for model development and calibration. Scenario analyses showed that grassed waterways implemented on all critical areas and terraces implemented on land with slopes greater than 3% would significantly decrease sediment yields and soluble P loadings but not atrazine or NO_2 + NO_3-N loadings. The newer grassed waterway routines considered rilling through the waterways, which significantly decreased their filtering capabilities. In general, the waterways are thought to not filter runoff as much as simulated in the previous model (Mudgal 2010).

No optimization was conducted to reveal the importance of landscape position of conservation practices and interactions between practice and position. Instead, the APEX model was used to understand environmental impact, i.e., water quality impact, from implementing practices on specific landscape positions. The SWAT models were then developed to include a description of these areas, either by delineation of all individual fields or by defining slope and soil descriptions that distinguished these areas from the rest of the watershed. In sum, the critical areas or critical fields identified with either model and with the indices matched. In addition, analysis of the currently implemented conservation practices indicated that only half of them are implemented in critical areas identified with these models. The process is planned for extension to larger watersheds in the Mark Twain Lake Basin.

After SWAT was calibrated and evaluated for the Goodwater Creek Experimental Watershed, its performance was compared with coarser datasets, in prevision of what is likely to happen when simulating larger areas. On one hand, two different soil datasets (high and low resolution) were used; on the other hand, three or seven subbasins were used to delineate the watershed. Both soil datasets were adjusted by specifying a very low hydraulic conductivity in the claypan layer of the soil profile. Then, the performance of SWAT was evaluated for the Long Branch Watershed, a 462 km^2 (178 mi^2) (seven times larger) watershed that has similar soils, land use, and cropping and management systems. Results showed that the performance of the model in simulating streamflow and sediment yields with each soil dataset was similar (Ghidey et al. 2007). The performance of the model in simulating streamflow from the Long Branch Watershed was as good as that from the Goodwater Creek Experimental Watershed. However, winter flows were over-estimated at the larger scale and adjustment of groundwater parameters was required. These results suggest that lower resolution soil datasets and larger subareas can be used for the modeling of the Mark Twain Lake and/or Salt River Basin.

Socioeconomic Analysis

Socioeconomic data were primarily derived from a 2006 face-to-face interview survey of farm operators in the Goodwater Creek Watershed (Murphy et al. 2010a). Respondents included 18 of 24 watershed farmers, who farmed 2,023 ha (5,000 ac) within the watershed (35% of the agricultural land). There was no specific information on the number of farms; however, the report on the producer survey indicated that 29 names were identified in an inventory of farmers who had or who were managing more than 6 ha (15 ac) in the watershed.

The watershed is ~74% agricultural with corn, soybeans, grain sorghum, and wheat as the dominant crops. The average farm size is 616 ha (1,523 ac), of which 66% is rented. The average farm size has doubled since 1992, although the proportion of rented land is similar. Corn–soybean rotations account for 39% of agricultural land use, while corn, soybean, and wheat rotations account for 44% of the land use. Most of the watershed farmers have some pasture and hay fields and own some cattle.

Compared to the farmers surveyed in 1992, farmers in 2006 were older and slightly better educated (Murphy et al. 2010b). Changes in crop distributions included more corn and less wheat and sorghum. However, the annual changes in crop distributions in Audrain County indicated that this change may be an effect of market volatility. Education attainment levels for the surveyed farmers were 28% (high school), 6% (trade or vocational school), 33% (some college), and 28% (college degree). Farm income (US$100,000 to US$500,000) placed these producers in the category of farmers who make most of their income from farming. Their operations were in fairly good financial condition with low debt-to-asset ratios. However, financial outcome and profitability had greater influence in 2006 than in 1992 regarding the choice of fertilizers and pesticides, their application rates, and use of certain management practices.

According to survey data, grassed waterways, terraces, and land conversion (CRP) were among the most prevalent practices implemented in the watershed. The percent of watershed protected by grassed waterways increased from 3% in 1993 to 9% in 2003. Of the acreage reported in the 2006 survey, 80% of soybeans and 96% of wheat were under no-tillage and 61% to 73% of corn and sorghum were under conservation tillage. According to the survey, the percentage of watershed producers using these conservation practices were grassed waterways (>90%), terraces (61%), buffers (50%), filter strips (28%), managed grazing (28%), and erosion control ponds (17%).

Most of the conservation practices were sediment-reducing practices. Incorporating herbicides was probably the best way to reduce their losses; however, many of the practices reduced tillage so they were incompatible with incorporating herbicides. Few pesticide-reduction practices seemed to be used by the USDA NRCS, and some of these practices were not well accepted by producers (e.g., split application of herbicides).

Among surveyed producers, 65% of grassed waterways, 91% of terraces, and 13% of buffers were installed with cost-share assistance. A tour of the watershed demonstrated that practices not installed with the USDA NRCS cost-share funds were not always built to the USDA NRCS specifications, and their effectiveness was uncertain.

Farmers trusted that their practices were environmentally safe as long as label directions were followed and that a decrease in amounts of fertilizers and/or pesticides applied would result in lower crop yields and profits. Few had concerns about specific pesticides or fertilizers. In general, the amount of corn pesticides increased, while it decreased for soybeans because of the use of Roundup Ready soybeans. Farmers obtained and trusted information primarily from labels, custom applicators and chemical dealers. However, the use of these sources had slightly decreased since 1992 (Murphy et al. 2010b). On the other hand, farm consultants were more commonly consulted for information in 2006 than in 1992. In both years, they had limited contact with extension services and the USDA NRCS for information purposes. Overall, their favorite learning format was a face-to-face conversation.

Some practices had been tried in the past and were discontinued: nitrogen side dressing, professional pest-scouting, and split pesticide application. Reasons for discontinuing them included cost or perceived ineffectiveness of the practices. Motivations to adopt structural conservation practices included the desire to do the right thing and evidence of degradation. Cost share and financial incentives were important for expensive practices but were not as important as evidence of degradation.

The concept of performance-based incentives for conservation practices was introduced to producers. Performance-based incentives are awarded to producers based on the improvement in water or soil quality obtained after implementation of the practice. They rely on the definition of a performance measure. These incentives looked preferable to producers over cost-based incentives because they expected to see the results of their actions. However, no program exists at this stage to implement this concept.

While there was no specific cost-effectiveness analysis of the practices conducted, the effectiveness of practices was estimated by model simulation. In a first model, 19% and 29% of the most critical cropped fields in the Goodwater Creek Watershed required establishment of vegetative filter strips to reduce atrazine and NO_3-N loads by 25% based on hydrologic model predictions (O'Donnell 2010). In a second model, a combination of grass waterways, filter strips, and terraces in the approximately 10% to 20% most critical areas would reduce sediment and dissolved P by around 50% and 20%, respectively (Mudgal 2010). No significant reduction in atrazine or NO_3-N loads was obtained with this second model, which simulated waterways and filter strips with a different, process-based algorithm compared to an empirical equation.

The data show that a large fraction of the cropland needs to be treated to produce significant differences at the outlet of this 72 km^2 (28 mi^2) watershed. Grassed waterways appeared to be ineffective for reducing atrazine or NO_2 + NO_3-N loads. However, simulation procedures for grassed waterways may need to be revisited to confirm this result.

Economic modeling of conservation practices was conducted on a constructed 2006 representative farm of the watershed developed from the survey results (Intarapapong 2008). The crop distribution and the practices used on this farm were based on data collected during the survey of Goodwater Creek farm operators regarding the 2006 growing season (Murphy et al. 2010a), which was complemented using county data and information provided by the Food and Agricultural Policy Research Institute and by the USDA NRCS. Crop enterprise budgets for corn, soybeans, wheat, and sorghum were created and combined to reflect the crop distribution in the farm. The costs of a selected number of conservation practices were estimated using a budget analysis that included loss of income caused by land taken out of production. Crop yields resulting from APEX model simulations with and without implemented conservation practices, as well as any needed adjustments in equipment needs and use patterns, were used as inputs to evaluate the economic impacts of implementing conservation practices on the existing representative farms. A report presented the results of the economic analyses for adding a grassed waterway on 2% of the representative farm. The objective of this report was to compare a baseline economic analysis of that farm with economic outcomes when additional management practices were implemented for soil and water conservation. Farm budget analyses were developed to estimate net financial returns of farming operations under typical practices (baseline) and when compared to those expected under a conservation practice (grassed waterway). A grassed waterway on 2% of the farm reduced net income by 20% (Intarapapong 2008).

Outreach

Meetings with farmers to promote conservation practices were conducted by the University of Missouri College of Agriculture, Food, and Natural Resources, the University of Missouri Extension, and the USDA ARS. Project information was presented during meetings. Individual invitations to these meetings were sent to producers and stakeholders in the watershed by mail. These letters included an agenda and a summary of the information presented and discussed at the last meeting. In addition, an article in the *Ag Connection* newsletter was written by Jim

Jarman, extension agronomy specialist for the Central Missouri region. The *Ag Connection* is published monthly for Central Missouri producers.

Meetings usually involved four to six producers, sometimes fewer. One of the first meetings had approximately 25 producers in the room, as well as representatives from the Missouri Corn Growers Association. Unfortunately, there was a mixed message given to the producers by different organizations about the importance of managing herbicides to reduce runoff. Producers were left with the impression that nothing more than following the labels was needed, in contrast to past messages about the need to reduce herbicide applications. This confused the producers, destroyed the perceived usefulness of this project, and significantly damaged the university's credibility.

While the actions of the producers are unknown, the results of this project and the participation of the USEPA did produce some changes. A map of the most sensitive areas was communicated to the chemical dealers, with the expectation that they should avoid spreading atrazine in these areas. The map was also given to the local USDA NRCS office to help prioritize conservation projects. The watershed was selected as a focus area within the Mississippi River Basin Initiative, and a few structural conservation projects (terraces and grassed waterways) have been planned.

Additional outreach included posters and presentations at regional and annual meetings and published papers. Field days and public meetings were conducted, and newspaper articles were published about the watershed.

Goodwater Creek Watershed National Institute of Food and Agriculture–Conservation Effects Assessment Project Publications

This project's results have been published in numerous journal articles, reports, and other publications. The list of these publications is provided below.

Publications and Reports

Because this NIFA–CEAP reports and builds on long-term monitoring efforts in the Goodwater Creek Watershed, there is no way to separate it from the USDA ARS–CEAP research in the Mark Twain Lake Watershed. Therefore, please note that this list includes the 2005 to 2010 work that was done within the Goodwater Creek NIFA–CEAP and the USDA ARS–CEAP studies.

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In addition to funding from the USDA Cooperative State Research, Education, and Extension Service (now NIFA)–CEAP program (Award No. 2005-51130-02380, US$630,000), the project benefited from long-term funding for the monitoring of the Goodwater Creek Watershed and maintenance of the database by the USDA ARS Cropping Systems and Water Quality Research Unit. In addition, there was extensive overlap between this project and the larger CEAP ARS project for the Mark Twain Lake and watershed, of which Goodwater Creek is a subwatershed. The USDA ARS contributed more than US$1 million per year to CEAP over the project period in salary and lab supplies.

Project Personnel

This project was a collaborative effort between the University of Missouri and the USDA ARS. Claire Baffaut (research hydrologist) served as the project investigator. Stephen H. Anderson (soil scientist), E. John Sadler (soil scientist), Robert Lerch (soil scientist), J. Sandy Rikoon (rural sociologist), Laura McCann (economist), and William B. Kurtz (retired) were coproject investigators. Other collaborators included Robert R. Broz (extension assistant professor) and Walaiporn Intarapapong (economist).

The Missouri NIFA–CEAP involved multiple institutions: the University of Missouri (School of Natural Resources and Departments of Soil, Environmental, and Atmospheric Sciences; Rural Sociology; Agricultural Economics; and Cooperative Extension); the USDA ARS, Cropping Systems and Water Quality Research Unit Watershed; the USDA NRCS Missouri state office and Audrain and Boone County offices. In addition, other watershed stakeholders, such as the Missouri Corn Growers Association and the City of Centralia, were included. There were eight PhD candidates, one extension specialist, four graduate students, and two undergraduate or high school students who worked on this project.

The participation of watershed landowners and farm operators was critical because they provided information on their operations, participated in watershed meetings, and provided input and feedback to project personnel for the watershed management plan. Equally important was the USDA NRCS Missouri state and Audrain and Boone County offices that provided information (type, location, and year of implementation) regarding the practices implemented in the watershed from 1990 to 2006.

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