Missouri Watershed Water Quality Initiative

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College of Agriculture, Food and Natural Resources
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FAPRI
At the University of Missouri
Food and Agricultural Policy Research Institute

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FAPRI - Environmental Team – Russell Mills, Verel Benson, Claire Baffaut, Walaiporn Intarapapong, Wendi Rogers, Todd Farrand, Ervin Schmid, Vern Lansford, Lynn Heidenreich, Donald Schuster, Amy Bross; **Representative Farm Team** – Peter Zimmel, Brent Carpenter, Joe Trujillo; **Econometric Modeling Team** – Abner Womack, Willi Meyers, Robert Young, Pat Westhoff, Scott Brown; and Editorial, **Production, and Operations staff** – Kay Maas, Pamela Donner, Judy Richards, Vicki Trower, Cindi Kelly, Linda Careaga, Bert Miriello

University of Missouri Cooperators - Regional Economics – Thomas Johnson, Dennis Robinson, and Morgan Mundell; **DNA Source Tracking** – Andy Carson, Helen Yampara-Iquise, and Jessica Christiansen; **Monitoring** – Jack Jones, Bruce Perkins, Matthew Knowlton, Daniel Obrecht; **Long Branch Missouri Watershed Initiative** – William Kurtz, Tony Prato, Dave Connett, Sandy Rikoon, Robert Gronski, Rob Cheshier, John Rockaway, Jeff Cawlfield, Kendra Bowen, Syed Hasan, Patrick Osborne; Charles Rabeni, Gray Henderson, R. David Hammer, Ranjith Udawatta, Stephen Schmitt, Douglas Noltie, Chris Riggert

Texas Agricultural Experiment Station Cooperators – Wyatte Harman, Jimmy R. Williams, and Avery Meinardus

USDA, ARS Temple, TX – Jeff Arnold and Nancy Sammons

University of Maryland, College of Agriculture and Natural Resources, Wye Research and Education Center Cooperators – Ken Staver and Russ Brinsfield

Farm Panels, Steering Committees, and other stakeholders – This group included farmers, legislators, federal and state agency staff, agricultural and environmental organizations, and local residents.

This project is a cooperative effort of the Food and Agricultural Policy Research Institute at the University of Missouri and the Natural Resource Conservation Service. The work is supported by EPA grant X997396-01, Region VII U.S. Environmental Protection Agency, under section 104 (b). The Missouri Department of Agriculture appropriated funds to support the work in this report.

DEDICATION

This report is dedicated to Russell C. Mills in recognition of his efforts to promote whole watershed environmental and economic assessments with local stakeholder participation.

Russell C. Mills was born and raised in Mount Vernon, Ohio. He earned a BS degree in agriculture from Ohio State University. Later he received a MPA from the University of Missouri in Columbia. Mills began his career with the United States Department of Agriculture, Soil Conservation Service, now known as the Natural Resources Conservation Service, in 1957 as a Student Trainee in Ohio. He served as a Soil Conservationist, District Conservationist, and Area Conservationist in Ohio. He came to Missouri in August 1977 as Assistant State Conservationist for Programs. He was named Deputy State Conservationist for Missouri in October 1982 and State Conservationist in March 1988. In August 1995 Russ became a Special Assistant to the Regional Conservationist and served in that role until his retirement in January 1996.

After retirement, Russ joined the Food and Agricultural Policy Research Institute at the University of Missouri-Columbia, where he led the development of whole watershed environmental and economic assessments with local stakeholder participation until failing health forced him back into retirement.

EXECUTIVE SUMMARY

This project was funded by an EPA grant in 1997 and five annual amendments from 1998 through 2002. The 1997 grant and the five amendments contained a total of 36 objectives. For the last decade the Missouri Watershed Water Quality Initiative project has assessed alternative programs and practices that protect the common good of natural resource use while minimizing negative economic impacts on free enterprise. The assessment:

- identified natural resource use decision makers and the decision processes they use,
- estimated environmental impacts of alternative strategies,
- examined the impact of alternative programs and practices that protect the environment,
- estimated the impact of alternative programs and practices on the economic well-being of individual entrepreneurs, communities, and regions; and
- provided information to local decision makers to help them work together in finding solutions acceptable to individuals and the common good that local people will accept as feasible.

The major components of this analysis include economic analyses at farm and regional levels; monitoring; source tracking; soil characteristics and sensitivity; model calibration, validation, and enhancement; and technology transfer and implementation. Each component is an integral part of a holistic process. From the beginning of this project, a number of venues for research and stakeholder participation have been established within the state. The issues addressed by this project were geographically distributed across Missouri and state lines. The Arkansas Water Resources Center and the Watershed Initiative led by the Upper White River Basin Foundation cooperated with FAPRI in the Upper White River Basin area.

The initial watershed projects focused on the reduction of the herbicide atrazine in drinking water sources. Watershed modeling was combined with farm-level economic and environmental modeling to estimate field runoff and the farm-level economic impacts of stakeholder-proposed alternatives designed to reduce nutrient and pesticide loads at the edge of a field, outlet of a farm, and in the streams. Analyses showed that the atrazine runoff was greatly affected by soil types, application rates, and timing of application. Farmers modified cropping patterns and practices and reduced atrazine applications. Farmers changed both the timing and the rates of atrazine application resulting in reduced atrazine loadings.

The “Missouri Water Quality Initiative” in the Long Branch watershed was an interdisciplinary effort that encompassed monitoring, environmental and economic modeling, and local stakeholder actions. The Long Branch watershed was selected by the Missouri Watershed Initiative leaders because it serves as the drinking water source for a large portion of north central Missouri and a significant recreation source for water sports and fishing. Following the first phase of the Long Branch watershed initiative, 3,168 acres of private farmland were enrolled in the Missouri Enhanced Conservation Reserve Program and converted to grassland and trees. FAPRI used the SWAT model to assess the impacts of the enrollment. The results showed that the proportions of pollutant reductions are directly related to the acreages of specific crops removed : sediment loading was related strongly to soybean acreage and atrazine

loading to corn acreage. Incorporation of atrazine into soil instead of surface application will decrease the percentage loss of atrazine; however, incorporation may lead to higher erosion.

To increase the understanding of the multi-faceted linkages between the environmental and economic aspects, FAPRI conducted a holistic research effort in the Upper Shoal Creek watershed. The FAPRI team, Dr. Jones' monitoring team, and Dr. Carson's DNA tracking team collected fecal coliform, E. coli, and nutrient data in the Upper Shoal Creek watershed, compiled other sources of fecal coliform and E. coli data including EPA developed data, and conducted many different levels of DNA analysis including participation in a national study of 19 laboratories. FAPRI modified and calibrated fecal coliform equations in the SWAT model and cooperated with the USDA, Agricultural Research Service and Texas A&M Experiment Station modelers in Temple, Texas.

The Upper Shoal Creek holistic assessment validated bacteria fate and transport equations within the SWAT model. These equations are now integrated in the latest version of SWAT (SWAT2005). This model has now been used in the Little Sac River watershed and in Kansas. It also assessed what can be expected if poultry litter is removed from the watershed. It found significant water quality improvement within 10 years; however, goals such as Oklahoma's standard of 37 ppb of phosphorus will not likely be met in 10 years. An input/output model of southwest Missouri (10 counties) estimated the regional economic contributions of recreation and the poultry industries to be $1.4 and $1.8 billion, respectively. Marketing poultry litter outside the southwest Missouri region was estimated to create 182 jobs and $15.9 million of economic growth.

The assessment was used to produce an approved TMDL for Shoal Creek. A local watershed group is addressing bacteria and nutrient issues in Shoal Creek. Although the highest fecal loads came from cattle, human fecal loads were unusually high, and other sources including wildlife were present.

The bacterial source tracking efforts also helped Dr. Carson's laboratory to develop a new human/nonhuman source identification method called Bacteroides thetaiotaomicron. The Bacteroides thetaiotaomicron method is currently being used in a project with the St. Louis Metropolitan Sewer District and the United States Geologic Survey.

FAPRI helped set up a Southwest Missouri Animal Manure Phosphorus Recycling Initiative workshop to find positive approaches to balancing phosphorus in Missouri. Participants established two teams to address "Use of Poultry Litter for Bio-Energy Production" and "Litter Hauling and Adding Value." The latter team conducted local fertilizer demonstrations that used various types of poultry litter and commercial fertilizer.

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Introduction

The Constitution of the United States strongly supports the principal of individual rights and the importance of free enterprise. Our founders also recognized the potential for individual rights and free enterprise to be in conflict but that the common good must prevail. This potential conflict is especially present in the allocation and use of natural resources across the landscape and across generations. The challenge is to develop programs and practices that protect the common good of natural resource use while minimizing negative economic impacts on free enterprise.

For the last decade the Missouri Watershed Water Quality Initiative project has addressed that challenge by:

- identifying the decision makers and the decision processes they use,
- estimating the environmental impacts of alternative strategies,
- examining the impact of alternative programs and practices developed to protect the environment,
- estimating the impact of alternative programs and practices on the economic wellbeing of individual entrepreneurs, communities, and regions; and
- encouraging local decision makers to work together in finding solutions acceptable to individuals and the common good that local people will accept as feasible.

This project began in the mid-1990s when Senator Christopher Bond asked the Food and Agricultural Policy Research Institute (FAPRI) leaders to establish a team of analysts. The mission was to quantitatively assess environmental policy in a manner similar to FAPRI's assessment of agricultural policy (Figure 1). In 1997, the first of a series of grants was established to create this project. FAPRI and its cooperators have used these grants as seed funds to develop many collaborative efforts. The resulting jointly-funded efforts expanded the scope of these grants over the past ten years.

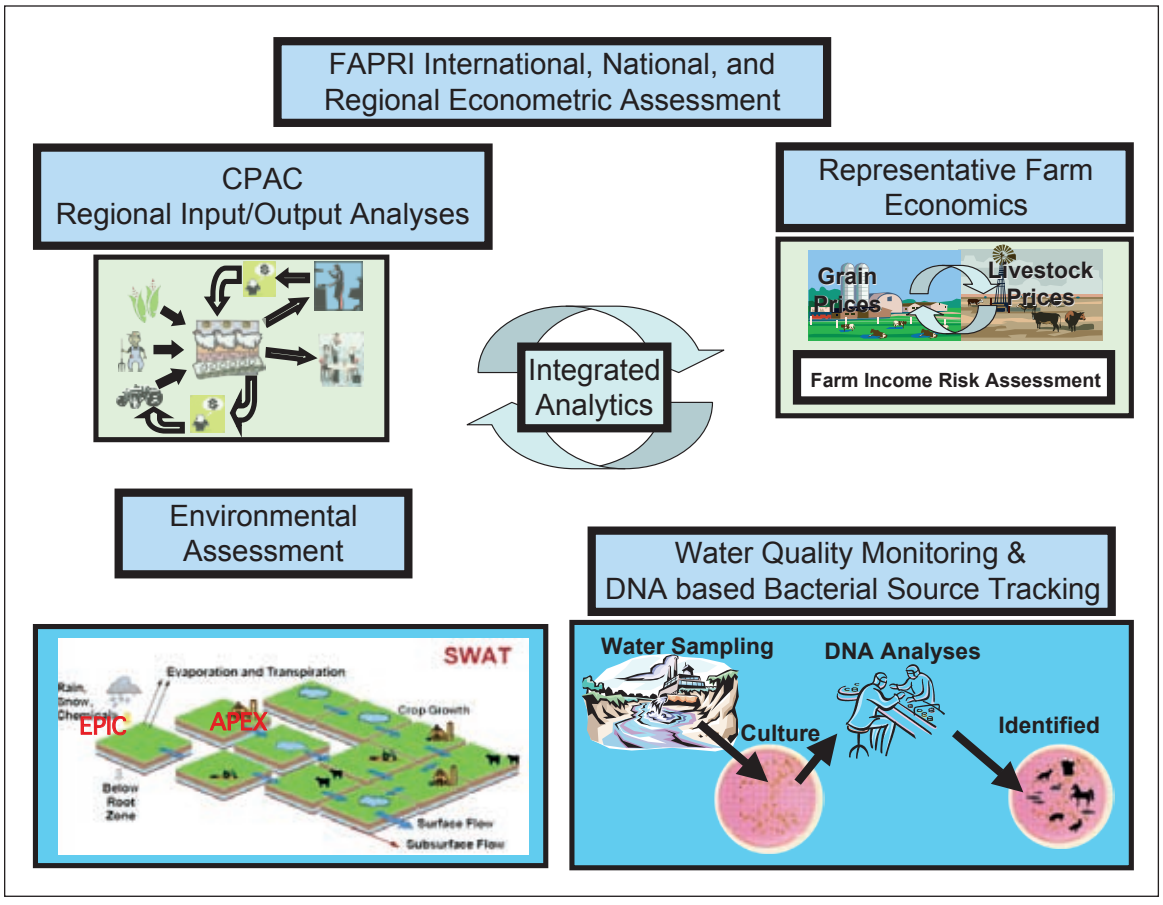


FIGURE 1. FAPRI and cooperators' analytical processes

This final project report identifies the combination of methods used to conduct assessments and transfer results to stakeholders. It then presents project-related examples of the types of research, assessment, and technology transfer encompassed by this effort. Each component is an integral part of a holistic process. The components include: monitoring; source tracking; soil information and/or analyses; economic analyses at farm and regional levels; model calibration, validation, and enhancement; and technology transfer and implementation.

The report then briefly summarizes the many objectives and accomplishments of nearly ten years of effort by many scientists, research associates, and stakeholders. It is designed not only to describe what was done but also to illustrate how future projects can be accomplished. The report illustrates potential blends of methodologies that can be used in future projects in Missouri and other states. Across the country, some components of the water quality initiative described here have been accomplished and will be integrated into future projects without redevelopment.

Many of these efforts have stimulated the development of new science, new techniques, and much cooperation in the process of assessing and improving environmental policies.

The techniques developed for this project are available to all researchers. This project's major goal was to illustrate how analyses can be integrated at the watershed level to provide a quantitative basis for local stakeholder decision making.

Methods Used In Missouri Watershed Water Quality Project Related Studies

The Environmental Protection Agency's (EPA) multi-grant project has served as a foundation for numerous studies. The Farm Level Income Simulation Model (FLIPSIM)[1] was used to create representative farm financial statements to simulate farm level decisions. FAPRI expanded farm level modeling in Missouri. Some representative farms are added or dropped periodically to focus farm level analyses on current issues.

The following physical process modeling tools were all modified and enhanced as they were used to assess the impacts of many alternatives practices examined by this project: the Environmental Policy Integrated Climate (EPIC) model, a field level analytical tool; the Agricultural Policy Environmental eXtender (APEX) model, a farm or small watershed level analytical tool; and the Soil and Water Assessment Tool (SWAT), a watershed level analytical tool. These models simulate many of the physical processes that impact soil nutrient accumulation and water quality as shown in Figure 2.

APEX was used in the Upper Shoal Creek Watershed holistic assessment to simulate alternative practices on poultry, dairy, and beef farms in or near the watershed. SWAT was used to model the entire Upper Shoal Creek watershed and was used to prepare a Total Maximum Daily Load (TMDL) assessment for the EPA. FAPRI has completed the Upper Shoal Creek and the Little Sac River TMDLs. FAPRI is nearing completion of nine watershed projects with joint funding from other sources in Missouri, Arkansas, and Maryland. FAPRI has also begun a new agro-forestry assessment in cooperation with the Missouri Agroforestry Center.

Fecal coliform/*E. coli* subroutines were added, debugged, and calibrated for the SWAT model. Then they were combined with water quality monitoring and DNA source tracking in the Upper Shoal Creek and Little Sac River watershed assessments. DNA source tracking identified the likely sources of *E. coli* and model analysis allowed estimation of the impacts of alternative control practices. When sources are identified, remediation efforts can be implemented using the most beneficial practices in locations that will have the greatest response. FAPRI is helping to create the Scientific Assessment of Fecal Effluent in Water Center (SAFE Water Center) in cooperation with the Deans of the College of Agriculture, Food and Natural Resources and the College of Veterinary Medicine at the University of Missouri-Columbia.

This grant and other funding have supported the extensive water quality monitoring efforts in Missouri led by Dr. Jack Jones, (Figure 3).

[1] FLIPSIM is the property of the Texas Agricultural Experiment Station maintained at the Agricultural and Food Policy Center, Texas A&M University, College Station.

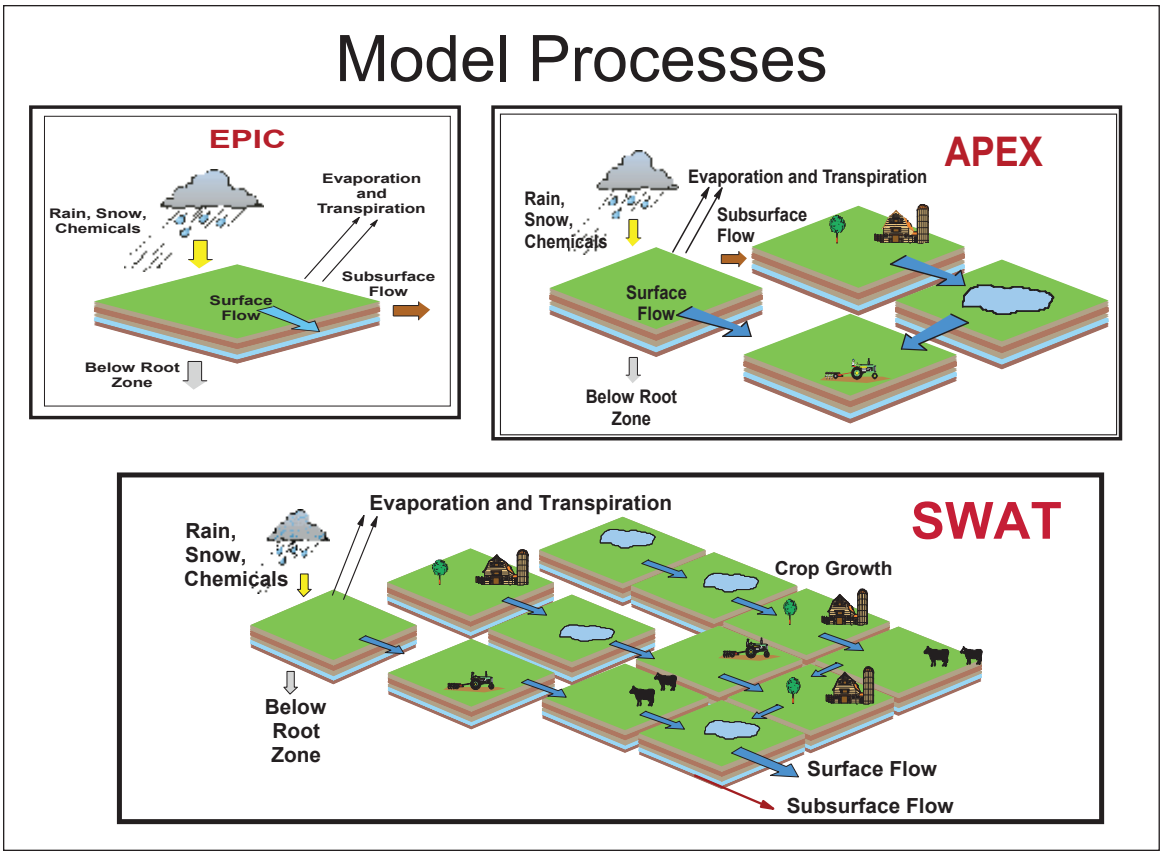


FIGURE 2. EPIC, APEX, and SWAT model descriptions

Extensive stakeholder involvement proved to be a crucial element of the project success. FAPRI efforts include steering committees of local stakeholders, state and federal agency staff, and environmental organizations. FAPRI has conducted workshops that develop locally-led teams of stakeholders and scientists to identify feasible approaches to environmental issues. For example, FAPRI set up a poultry litter recycling meeting that brought together members of the Missouri legislature, state and federal agencies, area farmers, and poultry industry representatives. The purpose of the meeting was to share accomplishments and identify strategies for using animal waste as a source of bioenergy and fertilizer.

FAPRI is working with the Missouri House of Representatives Agriculture and Natural Resources Committee developing regional workshops that will disseminate information to the general public as well as to animal producers. These workshops will bring the groups together, provide scientifically based information, and address the environmental and economic welfare of small and large farm meat production.

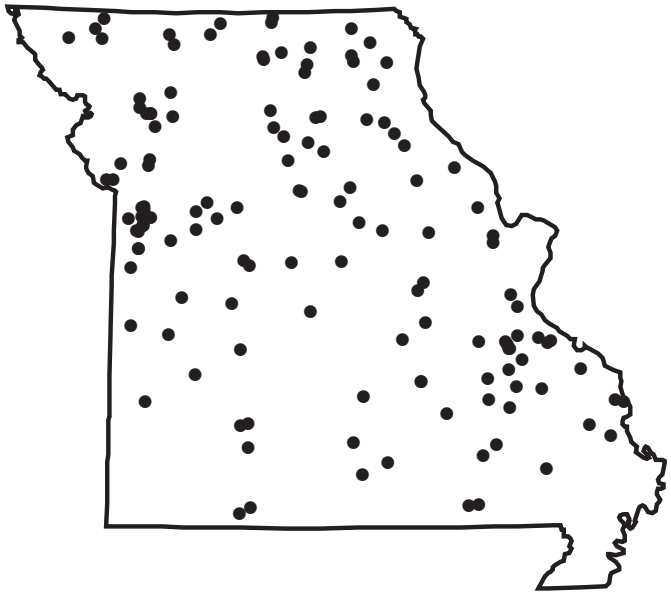


FIGURE 3. Location of the 135 Missouri reservoir monitoring sites

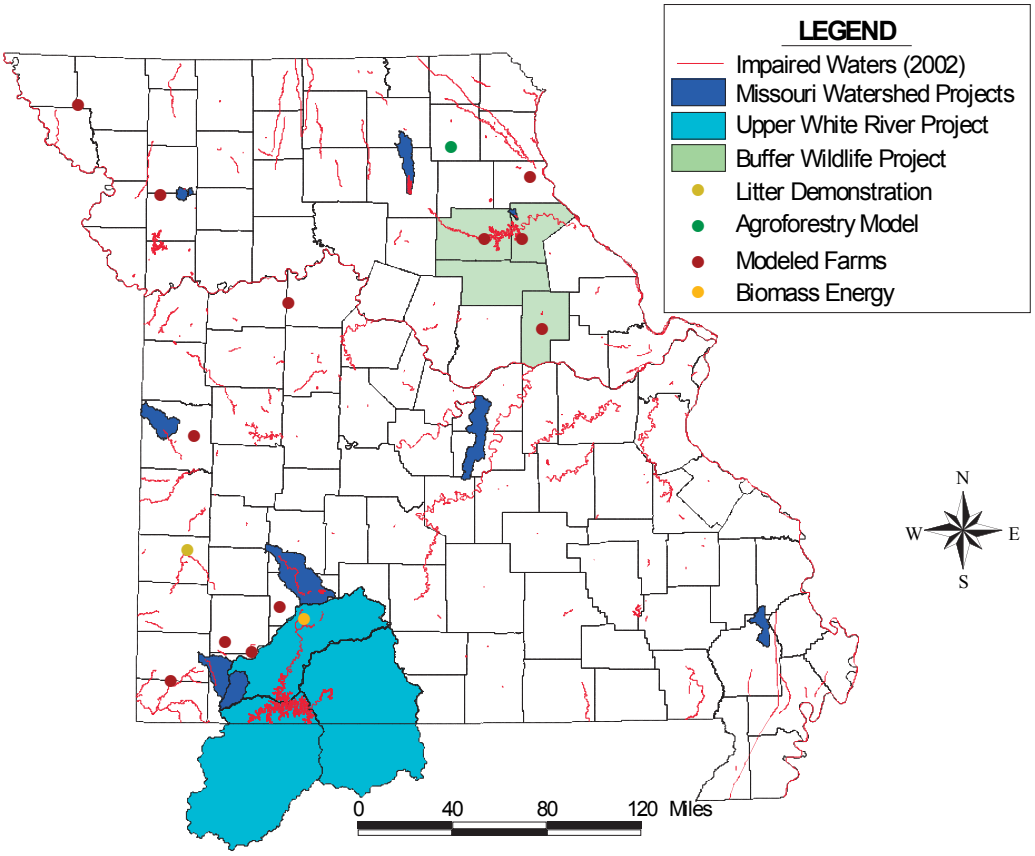


FIGURE 4. Location of FAPRI's Missouri projects

From the beginning of this project, a number of venues for research and stakeholder participation have been established within the state. The issues addressed by this project were geographically distributed across Missouri (Figure 4). The cooperation was not limited by state lines. FAPRI initiated multi-state cooperative efforts that developed cooperative environmental and economic assessments of the Upper White River basin strategic plans. The Arkansas Water Resources Center and the Watershed Initiative led by the Upper White River Basin Foundation cooperated with FAPRI through joint meetings, data and model sharing, and co-sponsorship of an Upper White River Basin Forum for stakeholders.

Major Components of Analyses

Each component is an integral part a holistic process. The components include:

- economic analyses at farm and regional levels,
- monitoring,
- bacteria source tracking,
- soil information and/or analyses,
- model calibration, validation, and enhancement, and
- technology transfer and implementation.

Farm level economic assessment

Farm level economic assessment determines the likely farmer response to farm policy. A description of the farm-level financial assessment process follows.

Representative farms, also referred to as panel farms, rep farms, or sentinel farms, are constructed to simulate historical and future economic performance of a defined farm business under certain economic and environmental conditions. To measure impact, a baseline reflecting current conditions is estimated and published semi-annually. Simulation produces a set of financial statements for each scenario.

The rep farm approach treats a farm business unit as a unique system characterized by local features and resources that are adapted to by the farm manager.

Primary data are initially developed and continuously validated by Missouri producers via a consensus process. Producers establish farm structure, size, farming practices, costs of production, and associated financial requirements for the representative farm based on their individual operations. In some cases, data points are cross-referenced with published sources to test assumptions or to verify and explain differences.

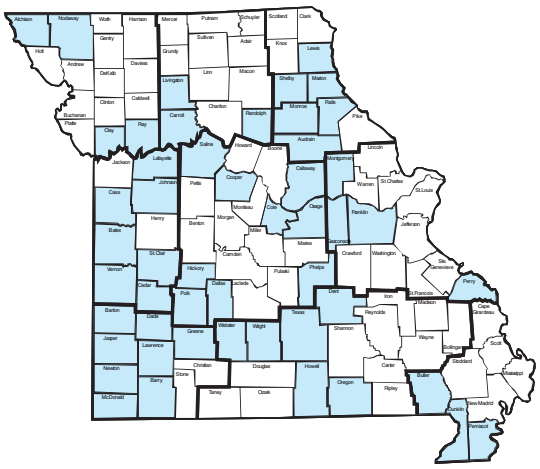
Farm financial statements are generated using FLIPSIM software. National price estimates are generated by the FAPRI consortium at UMC and Iowa State University. The accounting method used to model rep farm financials is a cash-basis, whole-farm, after-tax approach. Business size, structure, and management practices are held constant for the simulation period. The cash flow statement is the primary tool of this analysis and returns to family living are considered to be the bottom line, i.e., cash *available* for owner withdrawal from *current year* earnings.

Figure 5 shows the location of the panel farms in Missouri. Shaded areas are the home counties of representative farm panel members. Bolded lines on the map are boundaries for USDA-Missouri Ag Statistics Service crop reporting districts which correspond to rep farm regions.

Table 1 summarizes receipts and operator assets for the rep farms by type of production. For the spring 2006 baseline, 36 farms of various sizes were included in the database. Projected receipts for 2006 are expected to range from $121 thousand to $4.27 million. Ten of the rep farms (28 percent) fit the definition of a small farm

April 2006 baseline:
36 representative farms
200 active panel members

- 8 Feedgrain-soybean
- 3 Rice and cotton
- 8 Crop-beef
- 4 Pork-crop
- 5 Beef
- 6 Dairy
- 2 Broiler



Panel member home counties are shaded

FIGURE 5. Location of active representative farms in 2006

TABLE 1. Overview of Missouri rep farms database, 2006

Farm Type	Number of Farms	Total Receipts ($1000)		Operator Assets ($1000)	
		Min.	Max.	Min.	Max.
Feedgrain-soy	8	$281	$1,011	$1,005	$6,963
Cotton and rice	3	$553	$1,676	$1,026	$8,962
Crop-beef	8	$162	$850	$698	$4,724
Pork-crop	4	$299	$4,276	$1,495	$6,862
Beef	5	$121	$274	$1,234	$3,373
Dairy	6	$254	$1,305	$1,215	$4,120
Broiler-beef	2	$147	$208	$992	$1,011
All farms	36	$121	$4,276	$698	$8,962

suggested by USDA with less than $250,000 in agricultural product sales. All of these smaller rep farms have beef cattle.

A summary of the eight farms with row crops and cow-calf enterprises is presented as an example of economic analysis commonly drawn from the rep farm process. Figure 6 data are from the baseline report released May 1, 2006. Average annual costs and returns for the group indicate narrowing margins from about $40 per productive acre (crop + forage acres) in 2006 to $14 per acre in 2010. Operating expenses, averaged across all crop-beef farms, increased $21 per acre from 2003 to 2006. The largest changes occurred in fuel, fertilizer, and interest expenses.

Returns, costs, and cash margins differ across the set

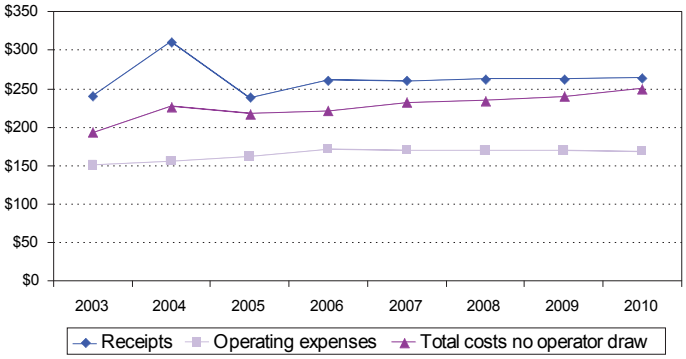


FIGURE 6. Projected farm receipts and costs

of rep farms. Figure 7 shows projected whole farm receipts and costs on a per acre basis, averaged over the five-year projection period. Cash margins for this set of farms range from $5 to $45, with an average of $27 per acre.

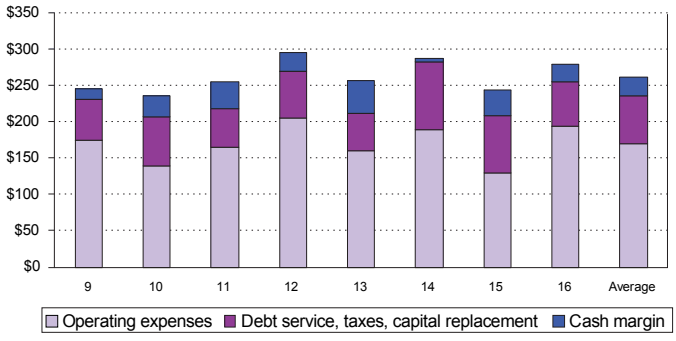


FIGURE 7. Projected per-acre costs and returns by farm, averaged over 5 years

In the near term, six of the crop-beef farms are expected to cash flow, while two will more than likely not meet all cash demands.

To evaluate the economic and environmental impacts of the agricultural practices at the farm level, the Farm Environmental Policy System (FEPS) was developed by integrating the information on the economic and environmental parameters to determine the agricultural practices that minimize environmental impact from farms yet maintain the farmer's economic viability. Economic and environmental input data were acquired from representative farm panels. The initial financial and environmental characteristics of the representative farm were developed and used as the baseline to the alternative agricultural practices.

The FLIPSIM model was updated to connect to FAPRI's stochastically generated 10-year price projections. Stochastically generated prices were used in the pork and poultry representative farm assessments. Stochastic prices for the 10-year FLIPSIM simulations are linked to the FAPRI national econometric model. As changes were made in the FAPRI econometric models, FLIPSIM was updated.

FAPRI developed an annual publication, "Outlook for Missouri Agriculture," that provides a venue for passing projected price and farm level risk assessment on to farmers while they are in the process of determining the coming year's cropping strategy.

Regional economic assessment

Regional decision makers use different measures of economic well-being to react to environmental policies. This project worked with the Community Policy Analysis Center (CPAC) to conduct input/output assessments of community economic response to alternative environmental practices. We use the Upper White River Basin assessment to illustrate regional economic analyses.

There are two basic ways in which an economic sector (like agriculture and its related industries) contributes to the economic well-being of a community or region. First, it produces and sells goods and services (business sales), employs people that are paid wages and salaries (jobs and income), and increases the overall wealth of the community (gross regional or state

TABLE 2. Net value added by and the number employed in agricultural economic sectors for the Arkansas portion of the Upper White River Basin counties, Missouri portion of the Upper White River Basin counties, and entire Upper White River Basin area

	Gross regional product generated by agricultural sectors		
	AR Counties	MO Counties	Total Region
	($ millions)	($ millions)	($ millions)
Cattle & Hog Farming	$59	$16	$75
Cattle & Hog Processing	$3	$7	$10
Poultry Farming	$35	$2	$38
Poultry Processing	$102	$472	$574
Crop Farming	$22	$39	$62
Crop Processing	$737	$620	$1,357
Other Agriculture-Related	$23	$12	$35
Total	$982	$1,169	$2,151
	Employment by agricultural sectors		
	AR Counties	MO Counties	Total Region
	(no. of jobs)	(no. of jobs)	(no. of jobs)
Cattle & Hog Farming	4,519	2,344	6,862
Cattle & Hog Processing	469	320	789
Poultry Farming	2,873	3,506	6,378
Poultry Processing	113	388	501
Crop Farming	532	1,250	1,782
Crop Processing	2,184	10,228	12,412
Other Agriculture-Related	1,016	1,868	2,884
Total	11,706	19,902	31,608

product)[2]. Gross state product is considered the most comprehensive income measure (i.e., from earned and unearned sources). These effects are called the sector's direct contributions to the state's economy. Gross regional product is another way to express value added within the region.

Secondly, the sector generates indirect economic contributions. For example, the firms in the sector provide a source of demand for other local firms' products. In addition, the sector's firms sell their goods to other local firms. The indirect economic contributions are measured in the same manner as are the direct economic contributions (i.e., sales, jobs, income, and gross state product). It is reasonable to assume that the indirect economic contributions depend on the direct contributions because they would not occur if the agriculture and related firms did not exist.

Missouri's economy is a diverse mix of sectors. However, for much of the rural portions of the state, agriculture is a vital component in the lives and well being of its residents. We examined the economic importance of agricultural related economic sectors in the Upper White River Basin Watershed. All counties in and immediately adjacent to the watershed were examined.

Table 2 shows the net value added by and the number employed in agricultural economic sectors for the Arkansas portion of the Upper White River Basin counties, Missouri portion of the Upper White River Basin counties, and entire Upper White River Basin area. Crop processing is very large because this is an area where foods are processed and a major food distribution center.

[2] Gross state product measures the contributions of business activities to the state's well being net of sales to other local businesses. It is important to note that the different measures of economic contribution should not be added together. Business sales includes gross state product and gross state product includes labor income.

However, when we look at numbers of jobs shown, we find that many of the jobs are at the farm level. If we then look a little further, we see that agricultural jobs create more regional economic output than the average jobs in the area (Figure 8). Business sales from jobs in agriculture account for 12 percent of the total sales in the region, but only 5 percent of the jobs in the region are in agriculture. Thus, a job created in the agricultural sector has more than twice the business sales impact than the average job in the region.

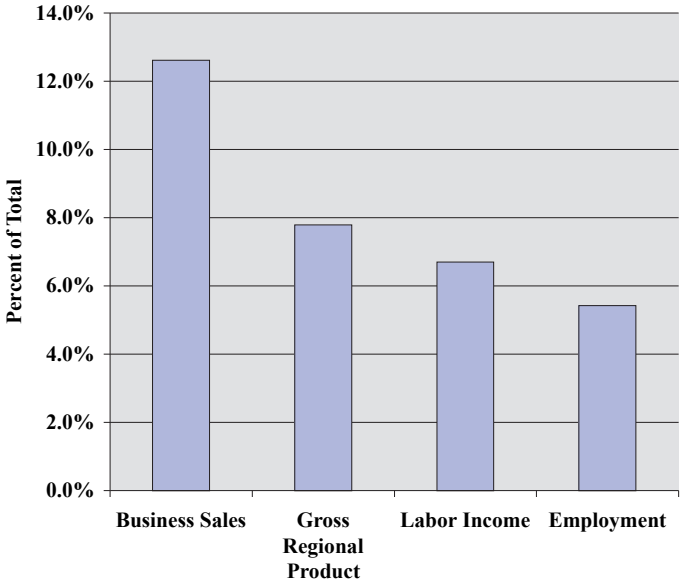


FIGURE 8. Summary of the agricultural related sectors as a percentage of all economic sectors in the Upper White River Basin

Monitoring

Water quality monitoring is an essential part of any effort to determine cause and effect and source of pollutants. Monitoring needs to be extensive enough over time and across the landscape to sort out variability due to weather, soil types, land use, topography, and land management. A study on the relationship of landscape characteristics and nutrient concentrations in Missouri reservoirs was partially funded by the EPA. Missouri reservoirs are believed to be greatly influenced by external nutrient loading from the landscape modified by morphology and hydrology. Limnological research in Missouri demonstrated that nutrient levels in streams feeding into lakes are related to land cover in the watershed. Nutrient levels increase in streams as the proportion of cropland within the watershed increases and decline as forest cover increases. The study attempted to determine whether land cover in the watershed, and measures of morphology and/or hydrology, could account for variation in Missouri reservoir nutrient levels and determine the trophic state of a lake.

Limnology data used in the analysis came from 135 Missouri reservoirs. Reservoirs were sampled seasonally on three or four occasions. The results suggested that, statewide, cropland accounts for the majority of the nutrient loadings to reservoirs and streams. Undoubtedly, cropland is a greater relative source of nutrients than grass and forest, which were the other dominant crops in Missouri Figure 9 (Jones et al. 2004).

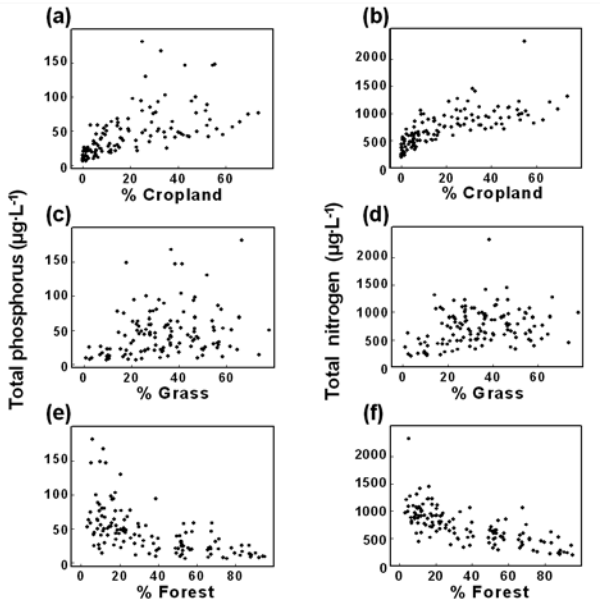


FIGURE 9. Linear plots of total phosphorus and total nitrogen against the proportions of cropland, grass, and forest in the catchments.

The statewide regression analysis suggested that a reservoir in urban catchments would have twice the nutrient level of a reservoir in a non-cropland (forest and grass) basin. Variation in rates and timing of fertilizer application and tillage practices affect nutrient losses from cropland and pastures. The impact of riparian zones on nutrient export from a watershed was not quantified in this study.

The analysis suggested that efforts to improve reservoir water quality in the state should focus on minimizing non-point nutrient export from cropland. Best management practices (BMPs) could reduce nutrients

in runoff from cropland; however, BMP effects on the importance of cropland to nutrient levels in Missouri reservoirs will vary by watershed.

Point sources of phosphorus also impact Missouri reservoirs. The most enriched region of Table Rock Lake has historically been the upper James River Arm, as a consequence of point source inputs from the Springfield Southwest Wastewater Treatment Plant (SWTP). Increased eutrophication in Table Rock Lake led to regulated reductions in point source phosphorus loads by the Missouri Clean Water Commission. The SWTP upgraded its phosphorus treatment and began to meet the regulated discharge phosphorus concentration of 0.5 mg/l in March 2001.

Data were collected by the USGS in Wilson's Creek immediate downstream from SWTP during 1993-2003. Estimated monthly phosphorus releases from SWTP during 1992 through September 2003 were supplied by City Utilities of Springfield. Lake water quality data were generated through two UMC programs; Table Rock Lake Long-Term Monitoring (TRM) and the Lakes of Missouri Volunteer Program (LMVP). Prior to the upgrade, the SWTP accounted for an estimated 64 percent of the P load to the upper James River and 27 percent of the total P load to the lake (Missouri Department of Natural Resource 2001). The 89 percent decrease in monthly P discharge from the SWTP reduced longitudinal gradient in P levels along the James River Arm. Declining P levels as rivers flow into reservoirs are characteristic of many large reservoirs in Missouri. Based on water clarity, the benefits of the SWTP upgrade will be obvious in the lower reaches of the James River Arm.

Overall this study supported the theory that large-scale reductions in P load can reverse eutrophication. Additional data will be collected to further document in-lake benefits of this management application. The monitoring data from the Table Rock Lake project is being used by the Upper White River watershed project.

Bacterial source tracking

Prior to this study, part of Shoal Creek was cited on the 303d list as impaired by fecal coliform from unknown agricultural sources in excess of the whole body contact standard. The fecal coliform and *E. coli* standards for fishable/swimable stream use are a geometric average of 200 colonies/100 ml and 126 colonies/100 ml of water, respectively. The standard is focused on the swimming season of the year (April-October). Stakeholders perceived the source of the fecal coliform was likely poultry because there are many poultry house in the watershed.

A number of methods have been developed to identify the human and animal hosts responsible for fecal pollution of water resources. The basic process is known as bacterial source tracking (BST) or microbial source tracking. Because direct isolation and identification of pathogenic microbes in stream water is difficult and expensive, available methods are based on indirect estimation of the potential presence of waterborne disease-producing organisms (pathogens) by measuring the numbers of harmless indicator organisms of fecal origin. The advantage of using "indicators" is that they are present in feces in large numbers and are easily found in the environment. Relatively scarce pathogens, however, represent a direct measure of public health risk. The methods which employ indicators are based on either specific genetic or functional characteristics of the target bacteria for association with human or animal hosts. These procedures require the assembly of a reference library of bacterial isolates from known host species, the patterns/profiles of which are stored in analytical software programs. Patterns of bacteria isolated from environmental water samples are then compared to library patterns for host association.

This study used DNA source tracking to determine the sources of fecal coliform and *E. coli* in the Upper Shoal Creek watershed. Dr. J. Jones, professor of fisheries and wildlife sciences, led a team to monitor water quality in Shoal Creek and its tributaries. Dr. C. Andy Carson, Professor of Veterinary Pathobiology affiliated with the World Health Organization Collaborating Center for Enteric Zoonoses at UMC, directed laboratory analysis of the fecal and water samples using the Repetitive Extragenic Palindromic-Polymerase Chain Reaction (RepPCR) technique to identify the likely human or animal source by analyzing the deoxyribonucleic acid (DNA) of the fecal coliform, also known as DNA source tracking.

Fecal coliform and *E. coli* concentrations were measured for the weekly samples collected beginning May 18, 2001, when monitoring was initiated by

FAPRI. The geometric mean of *E.coli* concentrations in the samples collected from May 18 until October 31 was 187 colonies/100 ml, just above the water quality standard for whole body contact. The arithmetic average was much higher (1,396 colonies/100 ml) and there was a large variation between the samples. DNA source tracking techniques were used to obtain patterns of the *E.coli* colonies found in the water and compare them to patterns of known species including humans, cattle, poultry, dogs, horses, hogs, and wildlife. DNA analyses of the samples determined what proportions of *E.coli* came from each potential source considered. The results shown in Figure 10 indicate that the contamination came from many sources including cattle, wildlife, and humans. A small amount originated from poultry.

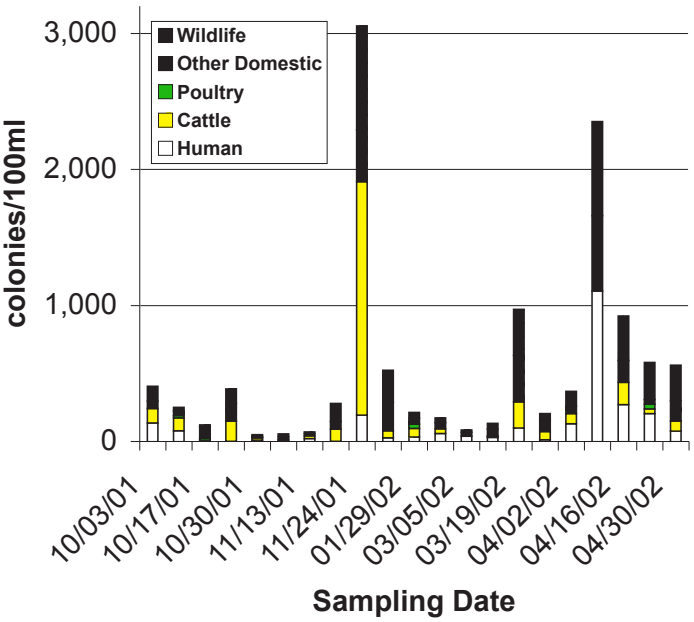


FIGURE 10. Shoal Creek fecal coliform concentrations by sources and by week at USGS gauge at highway 97

Stakeholders have come to realize that DNA source tracking may make it possible to better identify and target the most important human health concerns. The research initially focused on Shoal Creek. A second 319 funded study and a different grant from EPA focused on the Little Sac River, another southwest Missouri stream impaired by bacteria and listed on the 303(d) list.

Human health risk varies with the source of the bacteria. Accurate identification of bacterial sources can make health risk assessment, versus measurement indicator assessment, possible.

During the period of study in Shoal Creek, the RepPCR procedure was used. More recently, a library independent procedure based on a bacterial indicator shown to be largely human feces specific was developed. This bacteria, known as *Bacteroides thetaiotaomicron*, is one of the most numerous organisms in the human intestinal tract but much less common in nonhuman hosts. The Little Sac River study used the Rep-PCR and tested the *Bacteroides thetaiotaomicron* method (Carson, et al., 2005). Part of the study purpose was to compare the results of both tests.

The *Bacteroides thetaiotaomicron* method can be done rapidly and is less expensive than the rep-PCR method. Since it has been widely recommended that BST be done using more than a single test method, the new method may prove to be a very efficient, complementary procedure. More reliable BST data will result. Since the *Bacteroides* test was developed during the study period, and applied experimentally only in the latter stages, only preliminary comparison of the two BST tests was reported. Shortly after the Bacteroides method was published in 2005 personnel at the EPA laboratory in Cincinnati expressed interest in evaluating the method at various locations nationwide.

Soil assessment and analyses

Knowledge of soil properties is an essential component of any assessment of potential agricultural pollution. Soil characteristics such as permeability, texture, structure, and chemical properties determine the interaction of soil and potential pollutants such as nutrients, pesticides, bacteria, and sediment. The rates of infiltration and storage availability for water determine pollutant movement in solution or suspended in water. Soil chemical properties determine the potential adsorption of nutrient, pesticides, and other potential chemical pollutants. One of the applications of soil assessment and analyses conducted as part of this project follows.

Poultry production in Missouri is a large and expanding industry. Most of Missouri's poultry production occurs in CAFOs located within the southwestern

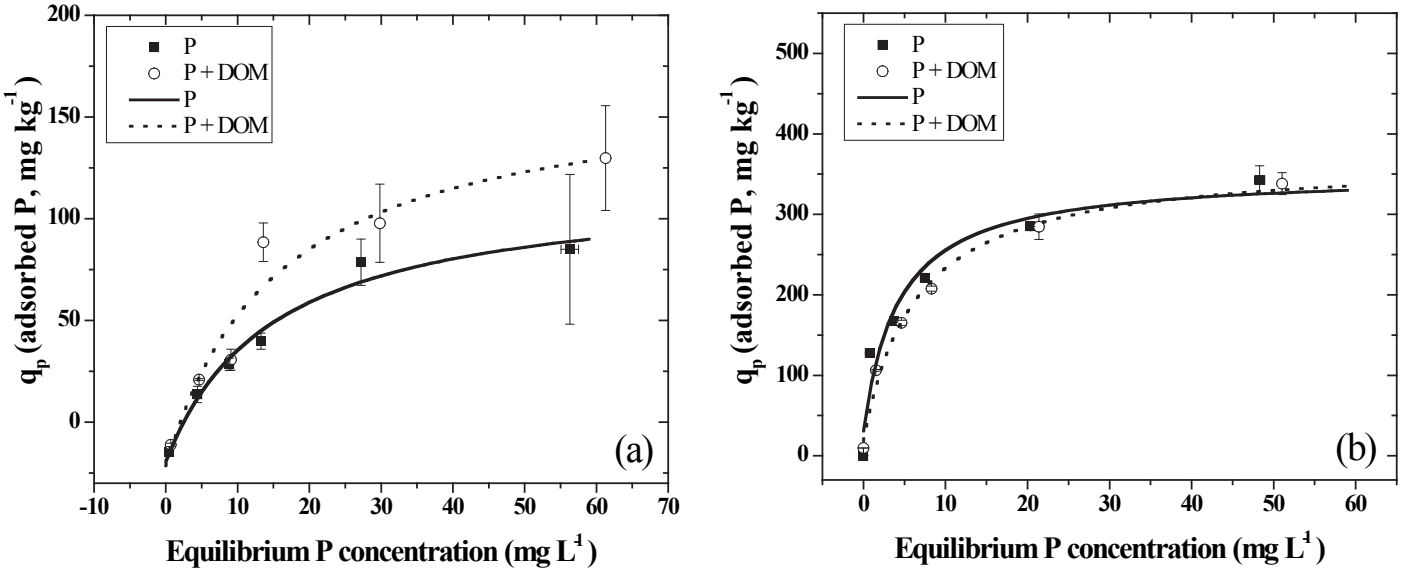


FIGURE 11. Soil P for Goss soil: A (a) and B (b) horizons

counties of the state. Most of the litter produced is land applied on the poultry producers' or neighboring farms.

The experimental design for this project was developed by Dr. Keith W. Goyne, UMC. The research focused on understanding the effects and interactions of poultry litter-derived dissolved organic compounds upon reaction with the highly weathered soils found in southwest Missouri. The study determined the extent that dissolved organic matter (DOM) derived from poultry litter competes with inorganic phosphorus (P) for adsorption sites in soil, and investigated whether dissolved organic nitrogen is retained more or less strongly to soil surfaces than inorganic N.

Six soils were identified for use in the experiments based on their prevalence in southwest Missouri. The characterized and archived samples were requested from the Missouri Cooperative Soil Survey. The poultry litter samples were collected from two different poultry operations near Neosho, Missouri. These litter samples were used to investigate sorption of organic and inorganic nutrients present in water-soluble poultry litter extract to the six benchmark soils.

The results of this study indicate that dissolved organic compounds released from poultry litter do not compete with P for adsorption sites in the highly weathered ultisols found in southwest Missouri. In fact, the data indicate that dissolved organic matter extracted from poultry litter may, in some instances, enhance P adsorption to soil surfaces. For example, the P adsorption for the A (upper layer) and B (the second layer) horizons of Goss soil is shown in Figure 11. Dissolved organic matter released from poultry litter during or after rainfall events is not likely to enhance P transport in surface runoff or deeper into the soil profile in fields receiving poultry litter application. However, this should not be interpreted as an indicator that land application of poultry litter is without environmental challenges. Indeed, long-term and/or excessive application of poultry litter can increase soil pH, soil P content, and organic matter content, all of which are factors that diminish P adsorption in soil. The data collected also indicate that dissolved organic nitrogen is preferentially adsorbed to soil relative to NO_3^-N. Nevertheless, dissolved organic nitrogen represented slightly more than 50 percent of the total dissolved nitrogen concentration in poultry litter extract. Due to the potential of these compounds to mineralize either in soils or surface waters, water quality and nitrogen cycling studies should not neglect to investigate the importance of dissolved organic nitrogen in areas where poultry litter is land applied. (Goyne and Motavalli 2006).

Model calibration, validation, and enhancement

The process models used in this project, EPIC, APEX, and SWAT, each contain 300 to 400 equations working

recursively at a daily time step. They embody hundreds of staff years of development and validation, and are upgraded and updated as new scientific relationships are discovered and as new policy directions require the addition of sub-models that address these new directions; i.e., renewable energy crop production and associated environmental impacts.

FAPRI used the SWAT model to estimate flow, sediment, and water quality parameters as a function of weather variables and other model input parameters. When data are available, one strategy to estimate the input parameters is to compare the simulated values obtained during a time period to measured data and to adjust the model parameters so that measured and simulated values match. This process is known as calibration. Simulated values and measured data are then compared for a period of time not used for the model calibration. This is called model validation. Ideally, several years of measured data on flow, sediment, and water quality are required for model calibration and validation. However, in practice, the data do not always exist, and the model is calibrated, validated, or simply verified with what is available.

The base flow separation program described in Arnold et al.1995, Arnold and Allen 1999 is used to estimate what part of the stream flow is base flow and what part is from surface runoff. Since the model estimates surface runoff separately from lateral and base flow, the calibration and the validation can be done on each fraction of the flow to ensure that the ratios between each of them are well respected.

Several calibration indicators are used to quantify how well the model reproduces the measured data. Correct representation of the crop yields ensures that the correct amounts of moisture and nutrients are taken up by the vegetation and removed from the hydrologic system. Annual crop yields are usually available from the National Agricultural Statistics Service. The percent deviation between simulated and measured quantities and the Nash-Sutcliffe coefficient are commonly used indicators. The Nash-Sutcliffe coefficient compares the difference between predicted and observed values relative to the difference between observed values and the median of the observed values. The correlation coefficient (R^2) indicates how well the measured and predicted values are correlated. The Nash-Sutcliffe and the R^2 can be estimated on an annual, monthly, or daily basis. For flow, the percent deviation should be less than 10 and the Nash-Sutcliffe and the R^2 daily coefficients should be more than 0.5 for the model to be acceptable and more than 0.7 to be satisfactory. For water quality data, the threshold values are usually higher for the percent deviations and lower for the Nash Sutcliffe coefficient. Alternatively, the model can be calibrated on the basis of concentration frequency curves for water quality constituents.

Data sets suitable for use in model calibration are extremely limited due to the short time steps necessary to carry out realistic simulations of nutrient transport. This is especially true for phosphorus, which tends to be transported from agricultural watersheds during very brief periods of overland flow resulting from individual storms.

As a part of the long-term effort to reduce nutrient inputs into Chesapeake Bay, edge-of-field studies were conducted in the Maryland Coastal Plain region of the Bay watershed. The region has both intensive grain and poultry production, and surface waters exhibit many of the eutrophication problems that are prevalent in other agricultural regions throughout the country.

FAPRI entered into a cooperative study with the University of Maryland entitled “Model Calibration Support for Maryland Coastal Plain Agricultural Watersheds” to calibrate and validate the APEX model, particularly the phosphorus sub-models. The project provided input data for the APEX model including meteorological, soils, and agronomic data. Initially, phosphorus transport from the Maryland watersheds was only provided for 1993 and 1994 for comparison with model output as part of the overall calibration process. Edge-of-field runoff from two adjacent watersheds (5.9 and 8.9 ha) continues to be monitored on an event basis. The watersheds are located at the Wye Research and Education Center (WREC) located in Queen Anne’s county Maryland. All fields at WREC drain into the Wye River, a mesohaline sub-estuary of Chesapeake Bay. Both watersheds are equipped with flumes, flow meters, and automated samplers. Sampling is triggered on a flow volume basis, making it possible to calculate the total load of contaminants transported in each runoff event. Surface runoff from these watersheds has been monitored since 1984. The timing and volume of runoff, and thus the number

TABLE 3. Seasonal simulated and measured water and soluble phosphorus runnoff from two Maryland watersheds

	Event #	No till		Event #	Tillled	
		Simulated	Measured		Simulated	Measured
Runoff		(mm)			(mm)	
Winter 93	1-13	104.2	102.7	1-14	117.9	135.3
Spring 93	14-25	22.6	30.3	15-26	23.7	27.4
Summer 93	26	0.7	0.3	27	0.9	20.6
Fall 93	27-31	1.6	11.3	28-32	1.8	7.6
Annual 93	1-31	129.2	144.7	1-32	144.4	191.0
Winter 94	32-45	268.4	240.5	33-46	275.4	244.3
Spring 94	46-50	10.8	30.6	47-51	9.2	10.8
Summer 94	51-55	1.4	19.5	52-60	2.0	31.4
Fall 94	None	0.0	0.0	None	0.0	0.0
Annual 94	32-55	280.6	290.7	33-60	286.6	286.5
Winter 95	56-64	10.2	29.8	61-68	13.7	32.1
Spring 95	65-72	12.0	19.0	69-76	12.7	13.6
Summer 95	73	0.0	0.2	77-79	0.0	4.2
Fall 95	74-87	30.0	47.1	80-92	46.4	43.8
Annual 95	56-87	52.2	96.0	61-92	72.8	93.7
Soluble P in runoff		(gr/ha)			(gr/ha)	
Winter 93	1-13	382.7	466.2	1-14	313.1	273.9
Spring 93	14-25	111.9	164.1	15-26	85.1	93.5
Summer 93	26	3.2	139.6	27	4.1	80.7
Fall 93	27-31	9.2	288.2	28-32	12.4	69.3
Annual 93	1-31	507.1	1,058.0	Jan-32	414.7	517.4
Winter 94	32-45	1,396.0	1,231.8	33-46	1,673.8	790.8
Spring 94	46-50	42.1	41.9	47-51	58.3	26.3
Summer 94	51-55	0.9	209.8	52-60	9.7	160.2
Fall 94	None	0.0	0.0	None	0.0	0.0
Annual 94	32-55	1,439.0	1,483.5	33-60	1,741.8	977.3
Winter 95	56-64	32.5	383.6	61-68	104.7	157.9
Spring 95	65-72	49.3	175.3	69-76	51.1	41.5
Summer 95	73	0.0	3.9	77-79	0.0	18.0
Fall 95	74-87	36.0	561.4	80-92	338.2	238.6
Annual 95	56-87	117.7	1,124.2	61-92	494.0	456.0

Note: the number of runoff events for no-till and tilled watersheds are slightly different because the tilled watershed had runoff on more days than the no-till watershed had runoff, likely due to increased infiltration in the no-till watershed.

of samples generated, varies widely depending on precipitation patterns. Runoff typically ceases within 24 hours of the cessation of precipitation. Annual runoff volume ranges from approximately 10 to 20 percent of annual precipitation volume. At the end of each runoff event, samples are removed immediately and transported to the analytical lab at WREC. All samples are analyzed for total particulate phosphorus, total dissolved phosphorus, and ortho-phosphate.

Only three years of the 22 years in this series have been analyzed by this project. The remaining years of data are expected to be used in future cooperative projects to enhance APEX and other process models. The amount of data used for calibration is minimized to preserve data for validation. The results were summarized by quarter of the year to allow differences to be categorized according dominant processes which might affect runoff and phosphorus in runoff (Table 3). Process models always have the potential to be enhanced, but the interaction of all of the processes makes it difficult to determine which sub-model modifications are most likely to result in improved estimates. The year used to calibrate the model was 1994. Measured data from 1995 were not received from the Maryland Agro-Ecology Center until the model was calibrated. Runoff estimates for all years compare quite well with the no-till watershed estimates deviating more from measured data in absolute and percentage differences than the tilled watershed. The soluble phosphorus measured values are subject to greater deviation. The no-till soluble phosphorus runoff tends to be underestimated.

The event-by-event measured versus simulated water flow and phosphorus in runoff are shown in Figure 12. Two possible areas of model improvement are to enhance the snow melt sub-model and to the soluble phosphorus model as it relates to initial soluble phosphorus release from dead plant material. The snow model appears to be accounting for the snow melt in fewer large events than were measured. The concentration of phosphorus in runoff events following crop harvest and frost appear to be understated, particularly for no-till.

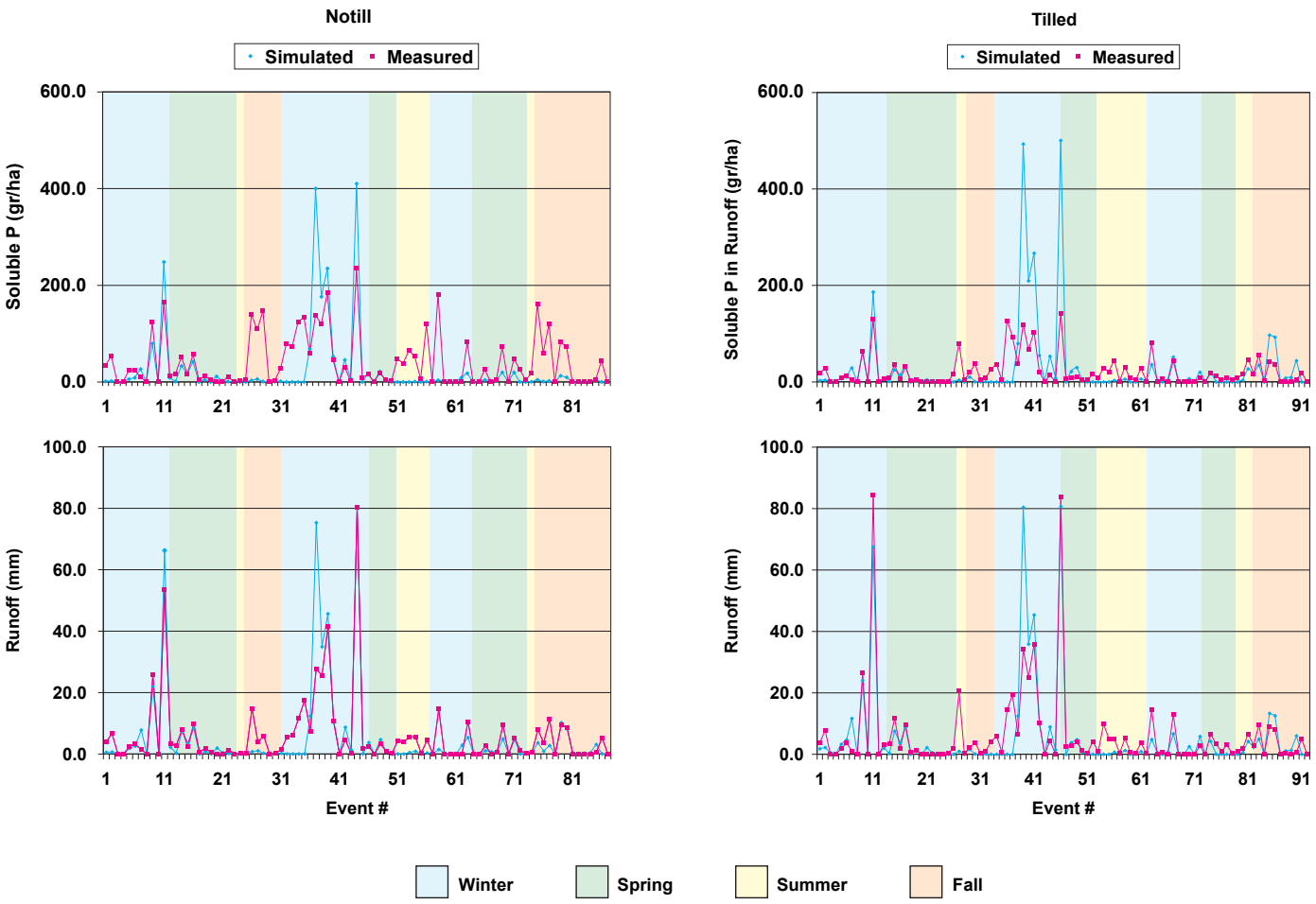


FIGURE 12. Maryland P and water runoff comparison

Over time, further cooperative efforts that use the 20 years of measured information will bring scientists together to make adjustments in sub-models that will likely result in improved estimates. However, the inherent variability of soils, management, crop cover, and hydrology as well as weather will prevent modeling from producing precise event-by-event estimates. However, models allow environmental strategies to be assessed across the landscape and across time, including stochastic estimates for the future. The cost of monitoring prohibits extensive assessment across the landscape and over long periods of time.

Some of the monitoring data were used in the simulation model calibration to validate the relative average nutrient levels versus event or seasonal calibration (Table 4). Monitoring and analysis found that nutrient levels in Missouri reservoirs and streams highly correlated with the proportion of cropland within the watershed, a surrogate for non-point source loadings (Jones et al. 2004).

The key to the value of environmental modeling is the ability to take information that is practically available and to create quantitative estimates that scientists and policy makers can use to better allocate limited public and private resources to maintain and to enhance the environment. However, modeling is not effective without strategic monitoring to validate and enhance the models. This project brought together, perhaps, the best of both methods for nutrient assessment at the watershed level.

Technology transfer and implementation

The list of publications and presentations show that this effort stimulated knowledge development and transfer across many disciplines, geographic areas, and decision makers. The efforts were designed to determine the quantitative relationships and then transfer the knowledge in such a way that facts can change perceptions. From the beginning, with the knowledge

TABLE 4. Summary statistics for liminological data, land cover, and watershed-morphology data for 135 Missouri Reservoirs

	Median	Mean	Minimum	25%	75%	Maximum
Nutrient Data						
Total Phosphorus ($\mu g \cdot L^{-1}$)	39	45	6	21	58	182
Total Nitrogen ($\mu g \cdot L^{-1}$)	705	725	200	500	920	2330
Land Cover (%)						
Forest	4	35	0	12	54	95
Grass	31	32	0	19	46	78
Cropland	13	19	0	5	32	74
Urban area	0	7	0	0	3	96
Water	5	6	0	3	8	25
Watershed-morphology data						
Reservoir area (ha)	42	750	2	17	114	21787
Dam height (m)	14	16	5	10	19	77
Volume ($m^3 \times 10^4$)	208	7787	6	67	509	333319
Watershed area (ha)	1028	37781	33	393	3857	1875178
Ratio of watershed to reservoir area	21	48	4	15	39	592
Flushing index (year -1)	1.1	3.7	0.1	0.5	2.5	87.1

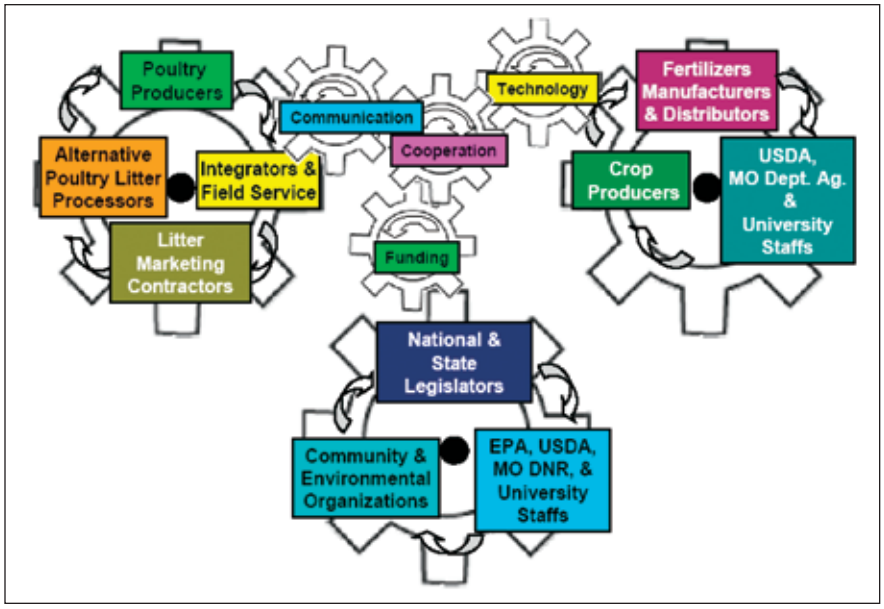


FIGURE 13. Potential cooperators for implementing poultry litter application innovations

that they would ultimately become the decision makers, considerable effort was devoted to making stakeholders a part of the process. The effort was to provide the information and analyses they need to make their own choices subject to environmental standards and economic feasibility.

In addition to environmental and economic analyses, multiple efforts were started that were designed to help stakeholders develop their own decision making groups, and to implement programs and practices. One example is the poultry litter team formed at the 2001 meeting in Neosho, which conducted two litter application demonstrations.

The description of cooperative effort to improve marketing of poultry litter nutrient was presented to the meeting attendees. Figure 13 describes the many cooperators that could contribute to creating and marketing a poultry litter byproduct. Not all of the potential

players took part in the team effort, but many did. The team stimulated new cooperators and the process continues.

The established team included poultry growers, poultry integrators, fertilizer distributors, value-added litter product producers, fertilizer inspectors, university researchers, and state and federal agencies. All poultry litter and value-added products were donated. The Missouri fertilizer inspection service determined the nutrient content of litter and fertilizer products. The USDA Natural Resource and Conservation Service (NRCS) collected soil samples before planting and after harvest. The UMC soils laboratory analyzed the samples and determined the soil nutrient data. The poultry litter and commercial fertilizer rates for nitrogen, phosphorus, and potassium for each demonstration field strip are show in Figure 14b.

Crop yield data was collected for corn the first year and soybeans the second year (Figure 14a). Local farmers and extension and NRCS staff observed both litter application and crop harvest. If we compare the returns per acre above fertilizer cost (Figure 25), we find that based on 2001 local prices only the layer manure had more returns than commercial fertilizer. However, assuming litter costs stayed the same and commercial fertilizer costs were based on March 2006 local prices, nearly half of the poultry litter strips had higher returns.

The farmer who made his field available for the demonstration fertilized a 70 acre field with layer manure following the first year of the test. Farmers in the area say poultry litter use has increased in the last two to three years.

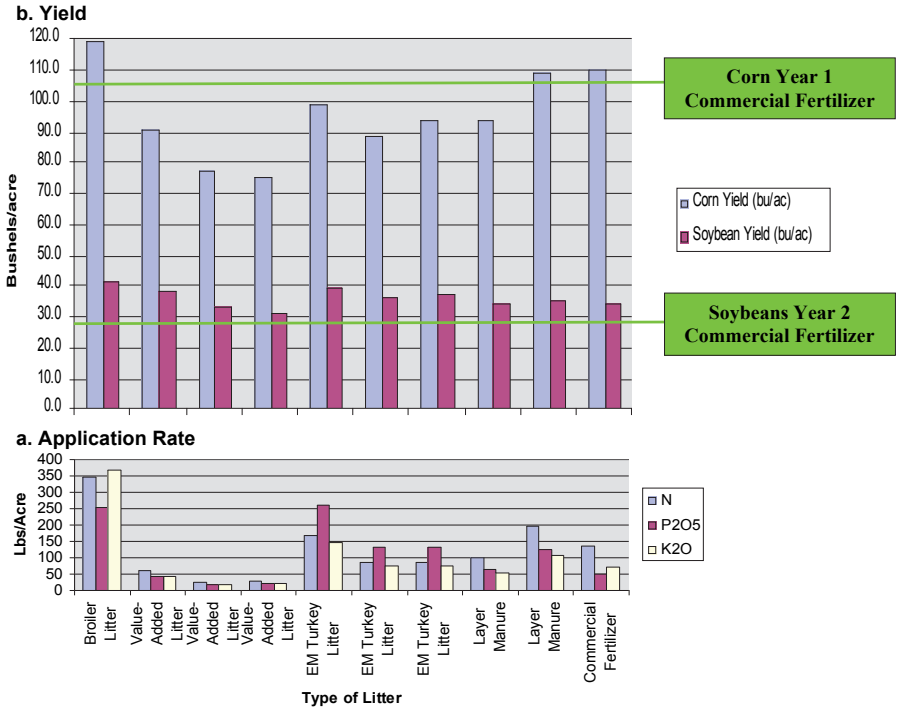


FIGURE 14. Poultry litter demonstration: (a) application rates and (b) resulting yields

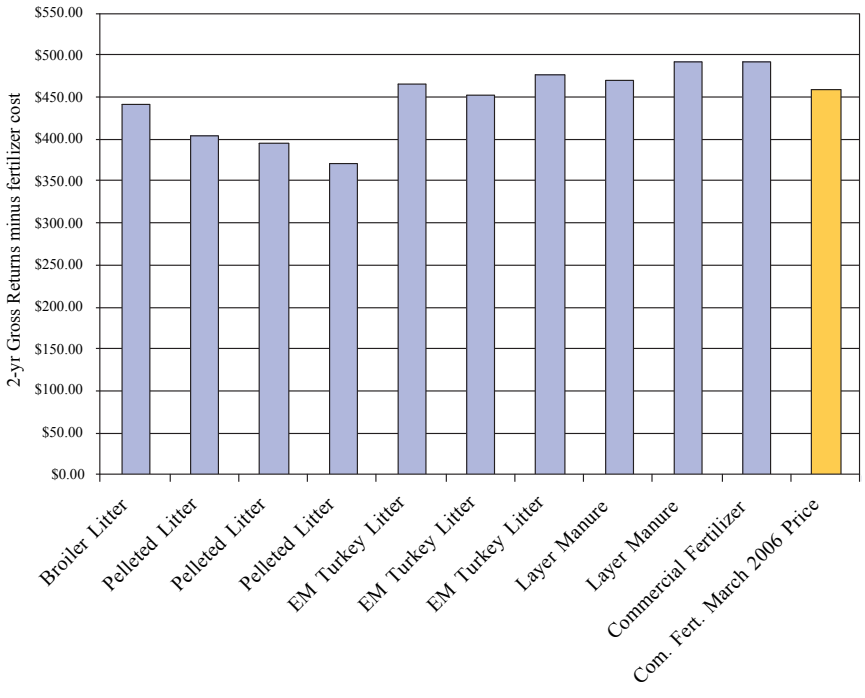


FIGURE 15. 2001 gross returns less fertililzer cost and estimated returns compared to commercial fertilizer based on March 2006 local prices

Summary of Objectives and Accomplishments

The project was funded by an EPA grant in 1997 and five annual amendments from 1998 through 2002. The 1997 grant had three objectives:

1. to extend three existing Missouri Department of Natural Resources watershed projects (Cameron, Bates County, & Monroe City) by a) developing next generation farm level models to link financial and environmental performance, and b) developing a set of predictors that can be used to identify potential hot spots for future analyses,
2. to monitor water quality in the Cameron, Missouri, drinking water supply watersheds, and
3. to do a pilot process test that allows the full weight of the University to bear on local agricultural/environmental issues, the University of Missouri Water Quality Initiative.

The five amendments contained a total of 33 objectives. These objectives are summarized into the following categories:

1. cover alternative issues,
2. address more and larger geographic areas,
3. enhance the economic and environmental models,
4. provide education and assistance to other scientists and conservation program directors,
5. incorporate regional economic analyses into assessments,
6. develop new biological assessment tools, and
7. build all of these tools into comprehensive assessments for TMDL analyses and environmental policy development and assessment.

1997 grant objective 1

The original three watersheds were the focus of model development and enhancement efforts, continued interaction with local stakeholders at farm and watershed levels, multiple reports and presentations, and, most importantly, stakeholder adoption of practices that led to water quality improvement throughout the 1997 grant and the first three grant amendments.

The Cameron, Monroe City Route J, and Miami Creek projects focused on the reduction of the atrazine in drinking water sources. Watershed modeling was used to help communities and producers within a watershed deal with the overall issues of agricultural non-point source pollutants. The watershed modeling was combined with farm-level economic and environmental modeling to estimate field runoff and the farm-level economic impacts of stakeholder proposed alternatives designed to reduce nutrient and pesticide loads at the edge of a field, outlet of a farm, and in the streams.

The models were used to establish water quality baseline characteristics resulting from current management practices. Then daily, monthly, and annual water quality impacts of the current and proposed management practices were estimated. Finally, the Cameron, Monroe City Route J, and Miami Creek watershed projects evaluated alternate agricultural practices designed to reduce agricultural non-point source pollutants in untreated water. The economic viability of the alternatives was assessed by FAPRI with input from local representative farm panels.

Farmers in the Cameron and Grindstone watersheds modified cropping patterns and practices and reduced atrazine loadings. The Monroe City Route J watershed analyses showed that the atrazine runoff was greatly affected by soil type, atrazine application rates, and timing of application (Figure 16). Farmers in the Monroe City watershed changed both the timing and the rates of atrazine application, resulting in reduced atrazine loadings.

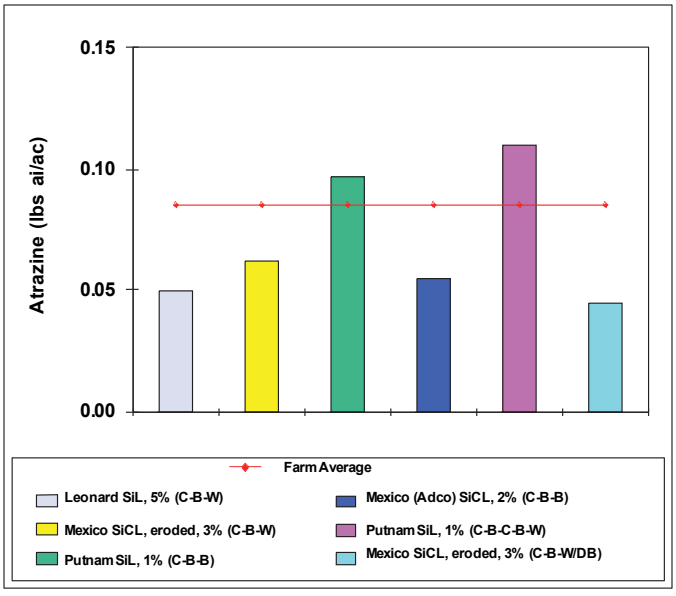


FIGURE 16. Atrazine runoff by soil, Monroe City

The Miami Creek study of atrazine loadings in the stream also identified timing of application as a critical management practice (Figure 17). Model simulations estimated the probability distribution of days per month the atrazine standard most likely would be exceeded. This allowed stakeholders to examine the tradeoffs between water treatment to remove atrazine in spring months versus alternative atrazine application levels and application timing. Weather variability prevents precise control of atrazine in runoff.

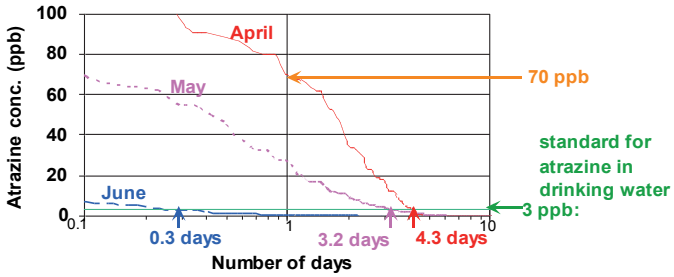


FIGURE 17. Atrazine runoff distribution in the Miami Creek watershed, by month

1997 grant objective 2

The second objective was to monitor water quality in the drinking water supply watershed that serves Cameron, Missouri. The City of Cameron reservoirs (reservoirs 1, 2, 3, and Grindstone) are located in northwest Missouri (Figure 18).

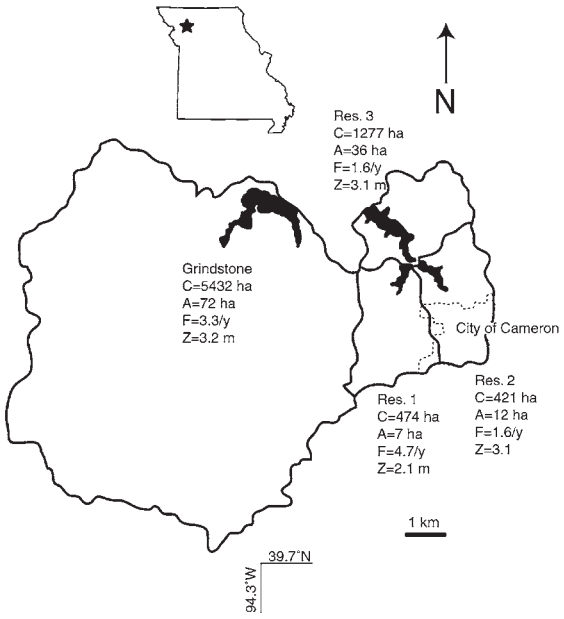


FIGURE 18. City of Cameron Reservoirs and catchments, C=catchment area, A=reservoir surface area, F=nominal flushing rate, Z=mean depth

These reservoirs are near the upper end of the trophic continuum among all Missouri reservoirs. Among the 137 Missouri reservoirs with extensive data, Grindstone and Reservoir 1, respectively, have the second and fourth highest mean summer total phosphorus (TP) and the seventh and third highest mean summer chlorophyll *a* (Chl) (Jones and Knowlton 2005). Time series showed close correspondence in the timing and magnitude of peak concentrations of TP and Chl (Figure 19).

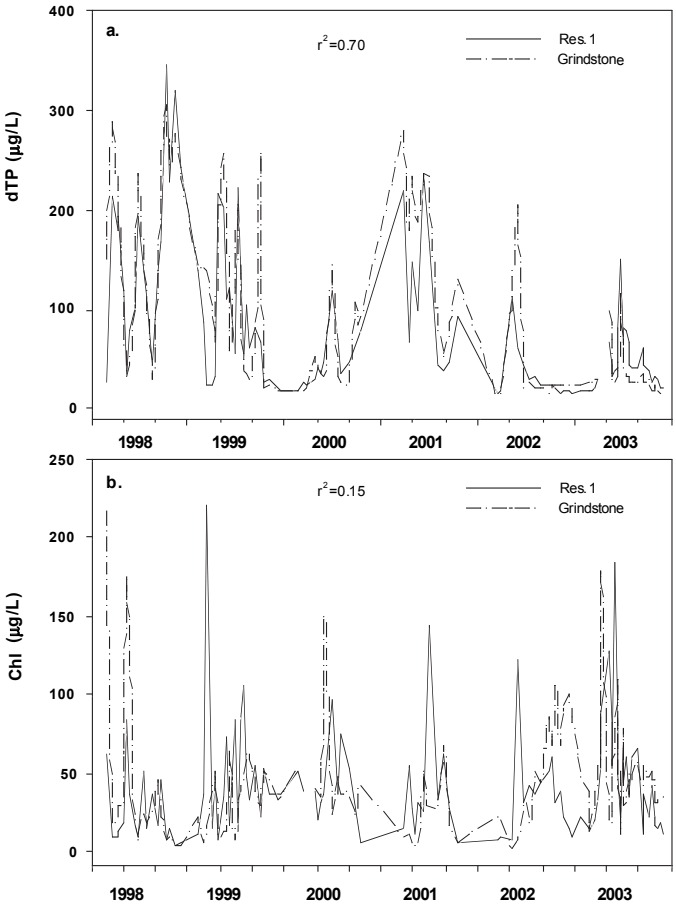


FIGURE 19. Cameron reservoirs summer total phosphorus and chlorophyll a results 1998-2003

1997 grant objective 3

The third objective was to perform a pilot holistic process test that would allow multiple groups of UMC scientists to simultaneously address local agricultural and environmental issues. The holistic process test was entitled the "Missouri Water Quality Initiative" in the Long Branch watershed. The Long Branch watershed was selected by the Missouri Watershed Water Quality Initiative leaders because it has diverse purposes. It

serves as the drinking water source for a large portion of north central Missouri and a significant recreation source for water sports and fishing. Based on a 1999 survey of visitors and their expenditure patterns conducted by the Department of Parks, Recreation and Tourism at UMC for the Missouri Division of State Parks, CPAC determined that tourism in the area contributes total economic activities of $5.3 million. It contributes $3.2 million in retail sales, $1.7 million in services, and $0.5 in taxable goods (due to indirect and induced effects) and 180 jobs have been created.

Several hundred residential septic tanks and two municipal sewage treatment facilities are located within the watershed. The lake has been identified in studies by the US Army Corps of Engineers as having various pollutants that negatively impact water quality. The most effective approach to pollutant control was preventive measures designed to reduce nutrient and pesticide application rates and to use strategic pesticide application timing.

Managing pollutants associated with agricultural practices requires cooperative efforts by agricultural producers and may require incentives to maintain their economic viability. The cooperative efforts among local stakeholders on the watershed steering committee and the interdisciplinary research team facilitated the study of the Long Branch watershed. Long-term agricultural and economic goals were established. Farm panels were created to provide management, asset, and financial data that were used to develop farm financial assessments of management alternatives. Field-scale environmental simulations and representative farms were developed. The representative farms were used to simulate past, present, and future economic/environmental performance under alternative economic and environmental conditions.

A watershed-level environmental baseline was established from which to gauge the levels of reduction in pollutants entering Long Branch Lake from future conservation activities affecting improvements in water quality. Following the first phase of the Long Branch watershed initiative, 3,168 acres of private farmland were enrolled in the Missouri Enhanced Conservation Reserve Program and converted to grassland and trees. FAPRI used the SWAT model to assess the project's impacts.

The results showed that the proportions of pollutant reductions are directly related to the acreages of specific crops removed: sediment production reflects soybean acreage and atrazine production related to corn acreage. Incorporation of atrazine into soil instead of surface application will decrease the percent loss of atrazine; however, incorporation may lead to higher erosion. With respect to rainfall events, atrazine loss is sensitive to application timing. Regarding sediment, row crop acreage accounted for most of the soil erosion and sediment yield. Thus, selection of crop rotations and management practices can significantly reduce erosion, sediment yield, and atrazine from cropland (Figures 20 and 21).

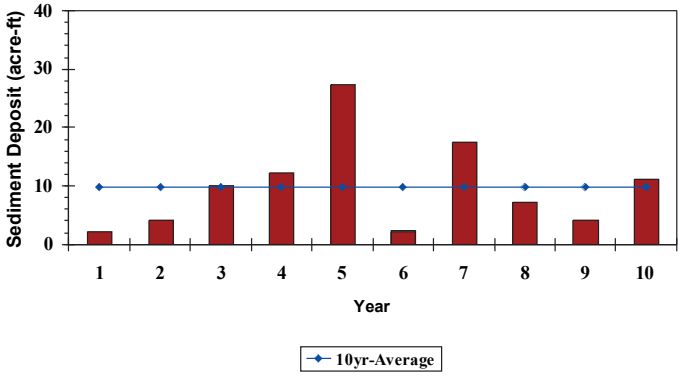


FIGURE 20. Long Branch Lake estimated annual sediment deposits

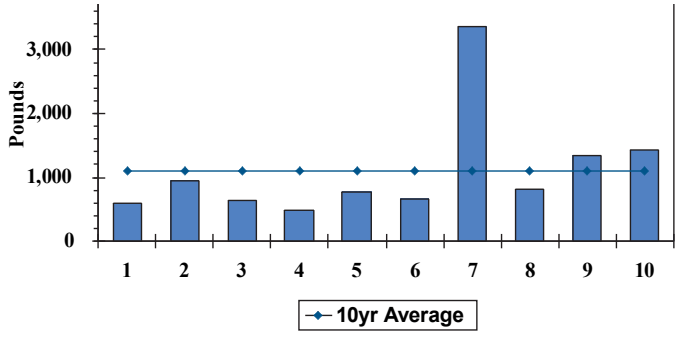


FIGURE 21. Long Branch Lake estimated annual atrazine loading

Other Long Branch watershed findings. A number of interdisciplinary data gathering efforts provided a comprehensive overview: data gathering/GIS; water quality/nutrients and chemicals; groundwater quality; sediment analysis; farmer surveys; farmer economics; fish populations; macro invertebrate sampling; and Extension outreach.

It was determined that the summer 1998 values of biological characteristics of Long Branch Lake were not significantly different from those for the period from 1978 to 86. While water quality data shows a great deal of interannual variation, it has not changed consistently over time. Long Branch Lake is similar to many reservoirs in the glacial plains of north Missouri in that it is moderately fertile with high levels of suspended solids. River-borne sediments entering the lake are deposited in the upper arms with little material reaching the southern end at this time. An inventory of benthic invertebrates indicated that Long Branch Creek is in "fair" condition, compared to similar streams in the Prairie Region. Fish species collected in Long Branch Creek were tolerant of highly variable conditions: low dissolved oxygen, high temperature, and high turbidity and sediment loads. Based on a survey of farms, 59 percent grow crops, with the predominate crop being soybeans, followed by corn and wheat. Cattle were raised on 72 percent of the farms. All farms utilize an on-site sewage system, with the most common system being a septic tank with an open pipe to a receiving area; few use a sewage lagoon. Long Branch Watershed modeling and sedimentation studies were expanded to include wooded slopes. Cooperative efforts between model developers and FAPRI modelers added new land uses to the watershed model.

1998 and 1999 Amendments

These two amendments expanded the work in using new versions of the SWAT and EPIC models to enhance assessment of alternative BMPs. Monitoring was expanded to include additional pollutants. Farm and financial modeling were enhanced to assess the stochastic nature of weather, crop production, and market prices. Reports for local stakeholder use were developed. Market information from FAPRI econometric models were linked to farm level financial analyses and the information was used to create local agricultural forecasts.

For example, the Miami Creek watershed study assessed the effects of no-till practices and reduced applications of atrazine in the watershed. A model-based analysis of the impact increased precipitation on flow, pollutant loadings to the stream, and loadings at the watershed outlet was conducted. A consequence of this work was the request by MDNR to install a flow gauge on Miami Creek in 2001. In 2004, the model was updated to SWAT2003/2005, improved to take into account pasture management, and calibrated using three years of flow data. It was then utilized to estimate the impact of the watershed-based, cost-share conservation project (agricultural non point source special area land treatment project) funded by MDNR.

The Miami Creek conclusions were: no-till practices reduce sediment contributions to the stream; no-till practices do not reduce significantly the sediment leaving the watershed; nitrates in solution are not significantly reduced; organic nitrogen is attached to sediment; soluble P loads increase; organic phosphorous decreases; atrazine loadings are proportional to application rates; and precipitation patterns are reproduced and amplified in flow, sediment, and nutrient loadings. In terms of sediment yields, the impact of the increased precipitation was offset by the impact of switching to a no-till crop production system. In terms of organic nitrogen adsorbed to soil particles, the impact of the changes in management practices more than offset the impact of the precipitation.

The 1999 amendment also expanded the coverage of the representative farm financial modeling to include new swine and poultry farms. These farms were modeled environmentally using the APEX model. Phosphorus concerns in southwest Missouri led to the beginning of some additional soil analyses. The soil analyses were delayed for a few years due to changes in soil chemistry staff.

Soil is one of the major factors influencing environmental outcomes, i.e., sediment, nutrient, and chemical runoff. Soil properties were studied to better understand the effects and interaction of poultry litter-derived dissolved organic compounds upon reaction with highly weathered soils. The study results indicated that dissolved organic compounds released from poultry litter do not compete with P for adsorption sites in the highly weathered soils found in southwest Missouri. However, long-term and/or excessive application of poultry litter can increase soil pH, soil P content, and organic matter content, all factors that diminish P adsorption in soil and may lead to additional P in runoff.

2000 Amendment

The 2000 amendment objectives and accomplishments completed the Miami Creek, Monroe City, and Long Branch assessments. Farm level modeling was expanded to include more farms. Stochastic analysis was added to farm level economic assessment. The 2000 amendment continued development of linkages of Missouri representative farms to the national system of farms and to national methodology and analyses. Monitoring continued and expansion to the Upper Shoal Creek watershed was planned to study a karst/southwest Missouri watershed to determine contamination sources and production alternatives.

This amendment led to the development of holistic approaches to both research methodologies and stakeholder participation. A regional meeting was planned to bring farmers, state and federal agency staff, legislators, and environmental interest groups to identify alternative approaches to handling animal manures, particularly, the embodied phosphorus.

2001 Amendment

The 2001 amendment began developing the framework for holistic assessment and local stakeholder use of multi-faceted assessment results. To understand the multi-faceted linkages between the environmental and economic aspects, FAPRI conducted a holistic research effort in the Upper Shoal Creek watershed. The holistic approach combined computer simulation modeling, analytical facts, interdisciplinary perspectives, and multi decision-making levels that allow stakeholders to simultaneously evaluate many different economic and environmental perspectives. Combinations of environmental and economic models were used to quantify the impacts of alternative management practices at farm, watershed, and regional levels.

The FAPRI team, Dr. Jones' monitoring team, and Dr. Carson's DNA tracking team collected fecal coliform, *E. coli*, and nutrient data in the Upper Shoal Creek watershed, compiled other sources of fecal coliform and *E. coli* data, including EPA developed data, and conducted many different levels of DNA analysis including participation in a national study of 19 laboratories. FAPRI modified and calibrated fecal coliform equations in the SWAT model and cooperated with the USDA, Agricultural Research Service (ARS) and Texas A&M Experiment Station modelers in Temple, Texas.

The Upper Shoal Creek holistic assessment developed many products. The main ones are listed below.

1. A working SWAT model for the Upper Shoal Creek calibrated for flow, bacteria, nitrogen, and phosphorus.
2. Test and validation of the bacteria fate and transport equations in the SWAT model. These equations are now integrated in the SWAT2005. This model has now been used in the Little Sac River, and in Kansas (Parajuli et al. 2006). More remains to be done in the field of survival of bacteria in stream sediment, fate and movement of bacteria in groundwater, better estimation of bacteria loading in animal manure, and representation of the different factors that affect bacteria survival. However, these equations produce reasonable estimates of bacteria concentrations.
3. Working APEX models to evaluate different management strategies at the farm level.
4. A 2 ½ year long data set of fecal coliform, *E. coli*, nutrient, and suspended solids. Samples were collected weekly from March to October and monthly during the rest of the year. The data set contains data points that characterize base flow and storm flow conditions and has been made available to the Missouri DNR.
5. A 5-month-long data set of weekly fecal coliform concentrations measured at one spring located near the US Geological Survey (USGS) flow gauge and the stream sampling point.
6. Chlorophyll *a* concentrations in Shoal Creek measurements 100 meters upstream of the USGS flow gauge at Highway 97.
7. A DNA landscape database for the Shoal Creek watershed. The database includes composite samples of beef manure, poultry litter (chicken and turkey), humans and wastewater, domestic animals (dogs and horses), and wildlife (wild turkeys, deer, and geese).
8. Bacterial source tracking data based on rep PCR technology for the 2½ years of fecal coliform bacteria found in the water.
9. An analysis about what can be expected if poultry litter is removed from the watershed.

10. A report about the watershed scale analysis. This report includes the results from the bacterial source tracking, nutrient analyses, and model result analyses.
11. An approved TMDL for Shoal Creek.
12. Numerous presentations at regional, national, and international meetings.

In addition to these products, the study established a dynamic local watershed group that is actively addressing bacteria and nutrient issues in Shoal Creek. Modeling, monitoring, and bacterial source tracking provided data to demonstrate the validity of all three methods. Although the highest fecal loads came from cattle, human fecal loads are unusually high and other sources, including wildlife, were present.

Nutrient levels were high. Nitrogen levels appeared to be largely caused by elevated concentrations in the groundwater, and phosphorus loadings were derived from surface runoff from pasture and hay land where poultry litter was applied. Removing poultry litter from the watershed could bring significant water quality improvement within 10 years; however, goals such as Oklahoma's standard of 37 ppb of phosphorus will not likely be met in 10 years.

CPAC used the IMPLAN model to estimate the regional economic contributions of recreation and the poultry industries in 10 southwest Missouri counties to be $1.4 and $1.8 billion, respectively. Marketing poultry litter outside the southwest Missouri region was estimated to create 182 jobs and $15.9 million of economic growth.

The bacterial source tracking efforts stimulated Dr. Carson's laboratory to develop a new human/nonhuman source identification method called *Bacteroides thetaiotaomicron*. The *Bacteroides thetaiotaomicron* method is currently being used in a project with the St. Louis Metropolitan Sewer District and the USGS.

In addition to the Shoal Creek study, FAPRI built models of watersheds monitored by the Agroforestry Center to validate the potential use of the APEX model in forested watersheds. FAPRI also continued to add, replace, and update representative farms in Missouri. In 2003, FAPRI had 42 farms that were used in FAPRI analyses for the U.S. House and Senate agricultural committees analyses.

FAPRI helped set up a Southwest Missouri Animal Manure Phosphorus Recycling Initiative workshop to find positive approaches to balancing phosphorus in Missouri. The workshop was held at Crowder College in Neosho. Approximately 90 people representing varied interests participated in a process of identifying promising approaches. The entire group agreed on two thrusts and established two volunteer teams. The teams include members of the major interest groups in southwest Missouri. The two thrusts were:

- Use of poultry litter for bioenergy production and
- Litter hauling and adding value.

2002 Amendment

FAPRI continued field, farm, and watershed modeling efforts, including cooperative efforts with model developers, to add analytical features such as fecal coliform, enterococcus, and *E. coli* to existing models and to enhance model interfaces and data bases to facilitate use by all stakeholders.

FAPRI initiated five proposals that contained cooperatives efforts with Center for Agricultural Resource and Environmental Systems, CPAC, and other organizations. Three have been funded:

- Upper White River Integrated Economic and Environmental Management Project,
- Utilizing Small-diameter Trees in Natural and Planted forest Stands for the Production of Renewable Energy and other Value-added Wood products, and
- Evaluating Economic Benefits of soil and Water Conservation in Missouri.

Each of these efforts will use the tools, techniques, and cooperative stakeholder participation approach to holistic assessment developed by this grant to provide quantitative information to local, state, and regional decision makers.

FAPRI is currently conducting analyses in nine watershed projects with joint funding from other sources in Missouri, Arkansas, and Maryland. FAPRI maintains about 40 representative farms in Missouri with joint funding from the USDA. FAPRI completed the Upper Shoal Creek TMDL with this project and was requested to prepare the Little Sac River TMDL. The Little Sac river TMDL was funded separately and has

been completed. FAPRI brought stakeholder groups together to develop three cooperative assessments in the Upper White River basin:

a) a 319 study led by FAPRI,
b) a 319 study in Arkansas led by the Arkansas Water Resources Center, and
c) the Watershed Initiative led by the Upper White River Basin Foundation.

FAPRI recently completed jointly funded efforts that examine the use of CRP buffers to trap sediment and nutrients. Preliminary analyses of the potential value of CRP fields and buffers for wildlife nesting areas were presented at the "Managing Agricultural Landscapes for Environmental Quality Workshop" held in Kansas City, Missouri, October 11-13, 2006. FAPRI is working cooperatively with the Missouri Agroforestry Center, CPAC, and CARES to complete a small-diameter tree harvesting agroforestry assessment for the Missouri Forest Products Association. This effort expands forestry analyses pioneered by this grant.

Dr. Carson's laboratory and FAPRI's efforts have led to national recognition of work partially funded by this grant. FAPRI is helping establish the Scientific Assessment of Fecal Effluent in Water Center (SAFE Water Center). The approaches developed during this project are being used to assess the sources of bacteria in the St. Louis area.

Further study and analyses of the Maryland watershed will likely occur as time and resources permit.

FAPRI efforts include steering committees made up of local stakeholders, state and federal agency staff, and environmental organizations. These relationships have led to invitations to be members of committees such as the Missouri Poultry Industry Committee and to present results at many different meetings and conferences addressing environmental issues.

Concluding Comments

Today's world is more closely connected by transportation, electronic communication, and trade than every before, but within our local communities social connectivity often seems to have weakened. The sense of interdependence at the community level has diminished, leading to diverging groups and expectations. The study has identified many of the environmental, economic, and education and technology transfer issues that can best be addressed jointly.

Quantitative assessment of joint issues is the beginning of the process to find community-based solutions. The process can be adopted in watersheds and regions across states and nations. The authors hope the readers have found this report and all the efforts of the Missouri Watershed Water Quality Initiative useful as they address environmental, economic, and education and technology transfer issues.

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Benson, V.W. Holistic Assessment of the Shoal Creek Watershed. Soil and Water Conservation Society Annual Conference. Indianapolis, IN. 2002.

Benson, V.W. Invited presentation at Heartland Region Phosphorus Best Management Practices Workshop, Arbor Day Farm Lied Lodge and Convention Center, Nebraska City, NE, June 9, 2004.

Benson, V.W. Presentation to The Missouri Bio-Energy Nutrient Management Commission, requested by Senator Doyle Childers. January 31, 2002.

Benson, V.W. Combining electric power generation and water quality enhancement to grow the southwest Missouri economy. Project report for Missouri Department of Natural Resources, November 2003.

Benson, V.W. Water Quality Modeling. Resource Tools and Techniques Supporting Successful Watersheds: A Workshop Conference, Jefferson City, MO. March 24, 2004.

Benson, V.W. Water Quality and Nutrient Modeling, EPA Region 7 Administrator Briefing, Kansas City, KS March 30, 2004.

Benson, V.W. Presentation to Southwest Missouri legislators, Jefferson City, March 30, 2004.

Benson, V.W. Presentation at the Quad States Poultry conference, Fayetteville, AR. May 6, 2004

Benson, V.W. Presentation at the Planting for the Future Conference, Ft. Collins, CO, June 7, 2004.

Benson, V.W. Globalization and Its Impact on the Environment. North Dakota State U, Globalization Impacts on Agriculture Conference, Fargo, October 12, 2004.

Benson, V.W. Report of the Missouri Poultry Industry Committee submitted to the Missouri Legislature. Dec. 9, 2003.

Benson, V.W. The Value of Recycled Poultry Litter. Missouri Farm Financial Outlook 2004, University Outreach and Extension and Dept. of Agricultural Economics, University of MissouriColumbia. November 2003.

Benson, V.W. Synchronizing Agricultural Management and Environmental Regulations. Agri-Dealer Policy Forum, Washington, DC. Feb. 26, 2003.

Benson, V.W. Decision-Making Information for Watershed Stakeholder Groups. Farm Journal Meeting April 1, 2003 Columbia, MO

Benson, V.W. Synchronizing Agricultural and Environmental Policy. Governors Conference on Agriculture, Osage Beach, MO. November 23, 2003.

Benson, V.W. Developing Cost and Benefit Decision-Making Information for Watershed Stakeholder Groups. Water and the Future of Kansas Conference, Manhattan. March 11, 2003

Benson, V.W. Water Quality and Nutrient Modeling. EPA Region 7 Administrator Briefing, Kansas City. April 18, 2003.

Benson, V.W. Bioenergy and Agriculture, Growing the Rural Economy with Renewable Energy: Windfarming and Bioenergy–New Crops for Missouri Farms Conference, Columbia. March 6, 2003.

Benson, V.W. Poultry Industry Updates: Poultry Litter Demonstration Lamar, Poultry Litter Burning On-farm System and Power Plants, Shoal Creek TMDL, and Upper White River Project. Poultry Industry Committee Meeting, July 9, 2003. Southwest Center, Mount Vernon, MO.

Benson, V.W. Nutrient Modeling and Development of Management Solutions. Missouri Poultry Industry Committee, Jefferson City. January 27, 2003,

Benson, V.W. FAPRI Analyses of Agricultural & Environmental Policy. FAPRI Review, Washington, DC. Dec. 18, 2003.

Benson, V.W. FAPRI Holistic Assessment, Presentation to Atlanta Regional DOE Staff, Atlanta, GA. Jan. 22, 2003.

Benson, V.W. FAPRI Holistic Assessment. Presentation to National Chicken Council Environmental Committee, Atlanta, GA. Jan. 23, 2003.

Benson, V.W. Agricultural Enterprises, Energy, and Carbon Credits. Annual Conference of Missouri Extension Agricultural Engineers, Columbia, MO. Oct. 11, 2005

Benson, V.W. Missouri Phosphorus Issues as Viewed by an Economist in the Space Shuttle. Soil and Water Conservation Society Show-Me Chapter of Missouri Fall Forum. Jefferson City, Oct. 20, 2005.

Benson, V.W. Fapri Enivornmental Aanalytics. Presentation to a group of Albanian scientists, Columbia, MO.

Benson, V.W. Integrating Energy, Environmental, and Economic Issues. Presented to Missouri Special Senate Committee on Fuel, Waste and the Environment, Jefferson City. March 30, 2006.

Benson, V.W. Bio-engery Brainstorm. Presented to the Southwest Missouri Bio-energy Commitee, Crowder College, Neosho, Feb. 27, 2006,

Benson, V.W. and D.Robinson. North Central Missouri County Economic Indicators. Macon. Feb. 8, 2006.

Benson, V.W. and D. Robinson. Missouri County Business Sales and Property Tax Revenues from All Agricultural and Concentrated Livestock Production Economic Sectors. Presentation to Missouri House agriculture committee members, Jefferson City, March 7, 2006.

Benson, V.W. and D.Robinson. Missouri County Business Sales and Property Tax Revenues from All Agricultural and Concentrated Livestock Production Economic Sectors-revised. Presentation to Missouri House agricultural committee members, Jefferson City, MO. March 29, 2006.

Benson, V.W., C. Baffaut, and D. Robinson. Missouri CAFO Economic and Environmental Assessment. Presentation to Missouri House agricultural committee, Jefferson City. Jan. 10, 2006.

Carson, C.A., B.L. Shear, M.R. Ellersiek,.and A. Asfaw. Identification of fecal coliforms from humans, animals and birds by ribotyping. Conference of Research Workers in Animal Diseases, Chicago, IL. Nov. 2000.

Carson, C.A. Identification of fecal *Escherichia coli* from humans and animals. Invited Seminar, Communicable Disease Surveillance Centre, London, England. Oct. 29, 2001.

Benson, V.W. Conservation Reserve Program (CRP) Assessment. Missouri Water Quality Committee Meeting. Columbia. April 19, 2005.

Carson, C.A. Microbial Source Tracking. Missouri Milk, Food and Environmental Health Association/ Annual Educational Conference. Columbia. April 3, 2002.

Carson, C.A. Fecal Pollution/Water Quality. Annual US Department of Agriculture Water Quality Short Course. Columbia, MO. 2002-present.

Carson, C.A. Comparison of ribotyping and rep-PCR for identification of host sources of fecal *E. coli*. Invited Speaker at Colloquium: Tracking Sources and Sinks of Microorganisms. Amer. Soc. for Microbiology 102nd General Meeting. Salt Lake City, UT. May 19-23, 2002.

Carson, C.A. Host sources of fecal *E. coli* in Missouri waterways. Keynote Speaker at Missouri Regional Watershed Conference. Kirksville. July 30, 2002.

Carson, C.A. Tracking sources of fecal pollution in Missouri waterways. Livestock

Symposium. Kirksville. Dec. 7, 2002.

Carson, C A. W.V. Benson, H. Yampara, J. Christiansen. Two-year Association of Seasonal Sources of Fecal *E. coli* with Rain Events and Storm Flows in Southwest Missouri. Presented to the Soil and Water Conservation Society, St Paul, MN. July 24-28 2004.

FAPRI Display project results at "It's the Water Workshop," Hannibal, MO. Sept. 15, 2005.

Farrand, D.T. Balancing phosphorus in the quad-state region. Missouri Geographic Information Systems Conference. Columbia. 2001.

Farrand, D.T. Impacts of exporting poultry litter outside the Shoal Creek Watershed in southwest Missouri." Soil and Water Conservation Society Annual Conference, Spokane, WA. 2003.

Farrand, D.T. Water quality impacts of the CREP program in the Long Branch Watershed. Soil and Water Conservation Society Annual Conference, Spokane, WA. 2003.

Farrand, D.T. Water quality impacts of CREP in the Long Branch Lake Watershed. Missouri Natural Resources Conference, Osage Beach. Jan. 2003.

Farrand, D.T. Evaluating wildlife effects of herbaceous riparian filter strips in northeast Missouri: summary of 2003 field surveys. Buffer project progress report to cooperating landowners and agency staff. October 2003.

Farrand D.T. Evaluating wildlife effects of herbaceous riparian filter strips in northeast Missouri. Poster presented to the Unit Leaders Meeting of the University of Missouri Cooperative Wildlife Research Unit. Sept. 2003.

Farrand, D.T. Effects of scale and land cover map resolution on estimating quail habitat quality in Missouri. 2002 Annual Conference of The Wildlife Society, Bismarck, ND. 2002.

Farrand, D.T. Predicting environmental benefits of agroforestry practices in northern Missouri using APEX. 2003 Soil and Water Conservation Society Annual Conference, Spokane, WA. 2003.

Farrand, D.T. Avian response to herbaceous riparian filter strips in northeast Missouri. Grassland Birds in North America: Current and Future Currencies Symposium, The Wildlife Society 11th Annual Conference. Calgary, AB. 21, Sept. 2004.

Farrand, D.T. Water quality impacts of CREP & Wildlife response to CCRP. Presented to EPA Region VII staff. Kansas City, KS. March 30, 2004.

Farrand, D.T. Wildlife and water quality impacts of CCRP and CREP. FAPRI Annual Environmental Review, Washington. Dec. 2003.

Farrand, D.T. Avian response to herbaceous riparian filter strips in northeast Missouri. 65th Annual Midwest Fish and Wildlife Conference. Indianapolis, IN. Dec. 12-15, 2004.

Lory, J.A. and V.W. Benson. Distribution of Fertilizer Use and Manure in Missouri. Crop Advisors Conference, Columbia. Dec. 18, 2003.

Womack, Abner. The FAPRI Environmental Process– SW Missouri Example. Missouri State Capitol, Jefferson City. March 29, 2006.

Long Branch Water Quality Initiative Meeting Papers

At the completion of the Long Branch Water Quality Initiative Dr. Kurtz and his group hosted a Watershed Initiative Advisory Council meeting April 16, 1999. The minutes of that meeting as well as the short reports listed below are available from Dr. Kurtz at kurtzw@missouri.edu.

"Groundwater Resources and Groundwater Quality Assessment for the Long Branch Watershed." J.D. Rockaway, J.D. Cawlfield, K. Bowen.

"Quantifying the Role of Riparian Corridor Condition in Decreasing Inputs from Non-point Sources in Agricultural Watershed." R.P. Udawatta, G.S. Henderson, J.R. Jones and R.D. Hammer.

"Assessing Relationship Between Species Occurrences and Water Quality Parameters in Long Branch Creek." D.B. Noltie and C.M. Riggert.

"A survey of Benthic Invertebrates of Long Branch Creek." C.F. Rabeni.

"Economic Baseline for Long Branch Watershed — 1999-2000, Macon and Adair Counties." A.M. Cox and S. Haynes.

"Data Development for Biophysical and Socioeconomic Analysis, Long Branch Watershed." D. Connett and T. Prato.

"Long Branch Lake Geology of Water Quality, 1998 Results." J.R. Jones and B.D. Perkins.

"Groundwater Resources and Groundwater Quality Assessment for the Long Branch Watershed." J.D. Rockaway, J.D. Cawlfield, and Kendra Bowen.

"Erosion and Sedimentation Report for Long Branch Watershed." R. Cheshier.

"Assessment of Sediment Deposition in Long Branch Lake." P.L. Osborne and M.C. Crenshaw.

"Assessment of Metal Content and Sediments in Long Branch Lake." S.E. Hasan.

"Water Quality and Sediment Composition in the Long Branch Reservoirs." S.E. Hasan and P. Osborne.

"Survey of Farm Operators: Long Branch Lake Watershed." R. Gronski and Sandy Rikoon.

"Summary of Assessing Relationships Between Species Occurrences and Water Quality Parameters in Long Branch Creek." D. Noltie and C. Riggert.