doi:10.2489/jswc.67.5.442

Case study comparison between litigated and voluntary nutrient management strategies

A. Sharpley, P. Richards, S. Herron, and D. Baker

Abstract: The impairment of surface water quality in the United States has been well documented, as has the potential for agriculture to contribute nutrients that accelerate this impairment. In response, widespread implementation of conservation strategies to reduce nutrient losses and mitigate impairment has occurred. This study reports and compares the outcomes of voluntary and litigated conservation and nutrient management strategies in watersheds of Lake Erie and northwest Arkansas, respectively. In the Maumee (MRW) and Sandusky River Watersheds (SRW) that drain into Lake Erie, voluntary strategies to reduce total phosphorus (P) loading from cropland were implemented in the mid-1980s. The strategies focused on reducing particulate P loading through erosion control programs, utilizing no-till and reduced-till management. As various subsidies became available, as well as improved planters and better herbicides, farmers rapidly adopted conservation tillage. Between 1975 and 1995, this led to a decline in fertilizer and manure application and increased conservation tillage acreage, which contributed to a reduction in total and dissolved P export. In the last 10 years, however, increased no-till acres with surface soil P stratification, fall and winter broadcasting of P fertilizer, and more extreme rainfall-runoff events have contributed to an increase in dissolved P export. In the Eucha-Spavinaw Watershed (ESW), northwest Arkansas, litigation required a minimum of 33% of the poultry litter produced be exported out of ESW and the remaining land applications to be based on the risk of P runoff. Use of the Eucha-Spavinaw P Index (ESPI) has decreased the land application of poultry litter from an average 5.6 t ha^{-1} (2.5 tn ac^{-1}) before litigation to 2.5 t ha^{-1} (1.12 tn ac^{-1}) in 2009. This, combined with the fact that 70% to 80% of the produced litter was being transported out of ESW, has greatly reduced the risk of P loss in agricultural runoff. At 2009 fertilizer prices, the loss of P and nitrogen (N) from cropped acres in MRW and SRW was US\$13 ha^{-1} (US\$5 ac^{-1}), and the value of P and N exported in litter from ESW was US\$40 ha^{-1} (US\$16 ac^{-1}). While voluntary implementation of BMPs in Lake Erie watersheds decreased total P export, continued monitoring is needed to adaptively manage these BMPs to ensure their long-term effectiveness. Litigated BMP adoption in northwest Arkansas did reduce land application of litter but at a cost to beef grazing operations, which are symbiotic to poultry operations and had been using litter as a low-cost source of N and P.

Key words: best management practices—conservation adoption—Lake Erie phosphorus—nutrient management—phosphorus runoff—water quality

Farmers continue to wrestle with pressures to increase production, remain profitable, and feed an increasing world population, while at the same time minimize nutrient export to surface and ground waters. This paper describes two examples of the challenges and outcomes of meeting production and environmental goals in terms of phosphorus (P) management. First, in response to deteriorating water quality in Lake Erie in the 1960s and early 1970s, a coordinated but voluntary program was set in place to reduce point and nonpoint agricultural P loads to the lake, while maintaining farm productivity (Baker and Richards 2002). Phosphorus loads have been monitored since 1975 to determine the effect of adopting best management practices (BMPs), such as conservation tillage and nutrient management planning, in predominantly row crop agriculture in two Ohio watersheds ((Maumee [MRW] and Sandusky [SRW] River Watersheds) with major tributaries to Lake Erie (Richards and Baker 2002). These conservation measures centered on the reduction of particulate P loading to Lake Erie through adoption of conservation tillage systems, including no-till and reduced-till. Substantial governmental subsidies became available to help farmers make this transition, along with better equipment and new herbicides for no-till production. The conservation paradigm was adopted because it provided a good "return on investment" for farmers.

Second, we describe the impacts of legislation governing the land application of P in the Eucha-Spavinaw Watershed (ESW) in northeast Oklahoma and northwest Arkansas, United States. The ESW is the main source of water for Tulsa, Oklahoma, in which legislation now governs the land application of poultry litter. In 2003, the City of Tulsa and Tulsa Metropolitan Utility Authority agreed to a settlement with several poultry companies and the City of Decatur wastewater treatment plant in Arkansas. The agreement provided measures to reduce P discharge from the Decatur wastewater treatment plant and in runoff from pastures fertilized with poultry litter, which were contributing to accelerated algae growth, causing taste and odor problems in downstream drinking water sources for several municipalities in northeast Oklahoma. The settlement required poultry farmers to have a nutrient management plan (NMP) that determined appropriate rates of poultry litter application based on the potential for P loss in runoff (i.e., P-based management) using the Eucha-Spavinaw P Index (ESPI), developed specifically for land use (pastures), topography, and climate of ESW (DeLaune et al. 2006). Similar Indices have been adopted by 47 of 50 states in the

Andrew Sharpley is a professor in the Department of Crop, Soil, and Environmental Sciences, Division of Agriculture, University of Arkansas, Fayetteville, Arkansas. **Peter Richards** is a senior research scientist with the National Center for Water Quality Research, Heidelberg University, Tiffin, Ohio. **Sheri Herron** is executive director of BMPs Inc., Farmington, Arkansas. **David Baker** is director emeritus with the National Center for Water Quality Research, Heidelberg University, Tiffin, Ohio.

United States as a component of required NMP strategies (Sharpley et al. 2003b). The settlement further stipulated that no litter could be applied to soils which exceeded a 300 mg kg^{-1} (300 ppm) Mehlich-3 soil test P (STP) concentration and that no more than two-thirds of the litter produced in ESW could be land applied within ESW. As a result of ESPI and the STP threshold, this watershed is subject to stricter P-based manure management than most states (Osmond et al. 2006).

These two sets of watersheds offer some contrasts. While both are dominated by agricultural land use, the MRW and SRW have mostly cropland, whereas ESW has primarily pasture and animal agriculture. In the MRW and SRW, implementation of agricultural BMPs relies largely on voluntary measures, while measures are litigated in the ESW. This paper presents information on the impacts of implementing voluntary-based BMPs in the MRW and SRW and litigation-based BMPs in the ESW on nutrient management, water quality, and the economic viability of farming systems in these watersheds.

Figure 1

The Maumee and Sandusky River Watersheds.

The Maumee and Sandusky River Watersheds Experience

The MRW (16,395 km^2 [40,497 ac]) and SRW (3,240 km^2 [8,003 ac]) are located in the southwest portion of the Lake Erie drainage basin (figure 1). Agriculture, mainly corn (*Zea mays* L.), soybean (*Glycine max* [L.] Merr.), and wheat (*Triticum aestivum* L.), is the dominant land use in both watersheds (i.e., 74% to 78%), with similar areas in forest and urban land (i.e., 15% to 16%; table 1). Animal agriculture in the watersheds is limited, and although manure was used as a nutrient source for crops, most nutrients were applied as mineral fertilizer (i.e., 85%) (USDA NRCS 2009a, 2009b).

Table 1

Land use in the Maumee and Sandusky River Watersheds based on 2001 National Land Cover Database (as summarized on a watershed basis by Dan Button, US Geological Survey, Columbus, Ohio) and in the Eucha-Spavinaw Watershed based on 2004 planning information (DeLaune et al. 2006).

	Maumee River		Sandusky River		Eucha-Spavinaw	
Land use	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)	Area (km^2)	Percent (%)
Forest	984	6	291	9	55,200	51
Pasture	984	6	130	4	46,400	43
Row crop	12,132	74	2,527	78	2,800	3
Water/wetland	656	4	65	2	1,800	2
Urban	1,475	9	227	7	1,400	1
Total	16,395	—	3,240	—	107,600	—

Water Quality Trends: Pre-1995. In the mid 1980's, return-on-investment considerations led extension agents and farmers to move from build-up to maintenance fertilizer applications. This is reflected in fertilizer P use decreasing 22% in MRW and 17% in SRW, with land-applied manure decreasing 17% and 34%, respectively, between 1971 and 1995 (Richards et al. 2002a). As a result, overall P inputs to MRW decreased from 40,000 to 29,000 Mg (44,080 and 31,985 tn) P between 1975 and 1995, while P outputs from the watershed in produce and river loads increased slightly from 19,000 to 22,000 Mg (20,938 and 24,244 tn) P. These shifts amounted to a decrease in P surplus over the MRW from 12 to 4 kg ha^{-1} (10.7 to 3.6 lb ac^{-1}). Over the same period, inputs to SRW decreased from 6,500 to 5,800 Mg (7,163 to 6,392 tn) P, while outputs increased from 3,800 to 4,200 Mg (4,188 to 4,628 tn) P; this amounts to a reduction in P surplus from 8 to 5 kg P ha^{-1} (7.1 to 4.5 lb P ac^{-1}) (Baker and Richards 2002). Current information shows these watersheds to be close to being P-balanced (USDA NRCS 2009a, 2009b). At the same time, no-till corn and soybean increased from 0% to 50%, while 5% of agricultural land was taken out of production (i.e., set aside in the Conservation Reserve Program) (Richards et al. 2002a).

Reductions in P inputs to MRW and SRW and implementation of voluntary BMPs translated into a decrease in dissolved, particulate, and total P and sediment export to Lake Erie in both watershed tributaries, although only Sandusky River is shown in figure 2. Nitrate-nitrogen and total nitrogen (N) export increased (figures 2k, 2l, 2o, and 2p). Richards and Baker (2002), analyzing daily flow-adjusted concentrations, reported changes between 1975 and 1995 of –27% for sediment, –46% for total P, –88% for dissolved P, +12% for nitrate-N, and –21% total Kjeldahl N, all highly significant trends ($p < 0.01$). Figure 2 shows trends based on annual loads and annual flow-weighted mean concentrations (FWMCs). These trends mirror those of Richards and Baker (2002) in terms of trend direction, but because of the much smaller sample size and considerable scatter in annual values, only the pre-1995 trends in dissolved P loads and FWMCs are statistically significant ($p < 0.05$).

These changes were attributed to adoption of erosion control measures, conservation tillage, and lower fertilizer and manure applications (19% to 30% between 1975 and 1995 in SRW and MRW, respectively). For example, 85% of highly erodible land in MRW and 97% in SRW had been treated (Richards et al. 2002b). Lower fertilizer P application was a result of farmers adopting a maintenance fertilization approach, fewer fall and winter applications, and more incorporation and subsurface application of P. Total N is dominated by nitrate-N, which moves primarily through tile systems and is more susceptible to leaching as a consequence of adoption of conservation tillage (Sharpley and Smith 1994).

Post-1995 Trends. As mentioned earlier, there was a dramatic reduction in P transport between 1975 and 1995, following implementation of voluntary BMPs in MRW and SRW. However, it is clear from figure 2 that since 1995 trends for nearly all parameters are different. A slight but not significant increase ($p > 0.05$) in precipitation is accompanied by a marginally significant increase in discharge. Sediment and dissolved and total P concentrations and loads either show increases or slower decreases than in the earlier period. In contrast, trends for N forms have either gone from increasing to decreasing or have increased more slowly, with the exception of total Kjeldahl N loads. Based on the annual data, trends in discharge, total Kjeldahl N loads and FWMCs, and total P loads are marginally significant ($0.10 < p < 0.05$), and trends in FWMCs of dissolved P, nitrate-N, and total N are highly significant ($p < 0.01$). Increasing trends in total P and total Kjeldahl N loads are statistically significant, but trends in their FWMCs are decreasing, though not significantly. This indicates that these load trends are driven by increases in discharge and are not a consequence of changes in land management. Similarly, decreases in nitrate-N (and consequently total N; figures 2l and 2p) likely reflect a dilution of the nitrate pool in soil by increasing total runoff on an annual basis (figure 2a), along with a potentially greater biological uptake of nitrate in the aquatic ecosystem, taking advantage of the greater supplies of dissolved P.

Annual flow-weighted mean concentrations of dissolved P have increased sharply, while particulate P concentrations continue to decline (figures 2h and 2j). The trend of increasing dissolved P and decreasing particulate P FWMCs may be attributed to a combination of several factors: a buildup of P in soil, generally due to excess of P applied over that removed in crops and river loads; a buildup of surface soil P with conversion to no-till cropping; and increased application of fertilizer and manure, without incorporation, in the fall and winter. In the winter of 2006 to 2007, widespread fall application of fertilizer and a warmer and wetter than normal winter (175% of average annual rainfall occurred between October and January), coupled with a three-fold greater rainfall than normal in August of 2007 (i.e., 25 cm [10 in]), exacerbated dissolved P concentrations in runoff (figure 2b) (Richards et al. 2010). Similar patterns produced high dissolved P loadings in water year 2008.

While dissolved P loads declined in 2009 and 2010, spring (April to June) loads in 2010 were the highest in 35 years of monitoring and coincided with a period when Lake Erie was more biologically responsive to inputs (Krieger et al. 2010). Preliminary analysis of the data for 2011 indicates that the spring 2011 loads of dissolved P were even larger (Baker and Richards unpublished), and western Lake Erie responded with the largest cyanobacteria bloom observed to date (Tom Bridgeman, personal communication).

With rising fertilizer prices, it is instructive to estimate the cost of replacing nutrients in discharge from MRW and SRW. Using fertilizer prices at of the end of 2007, the value of the P lost in 2007 from the MRW and SRW combined is estimated to be US$5,800,000, and the value of the N lost in 2007 is US$62,800,000. No data are available to estimate losses of potassium (K). The combined loss amounts to US$34.9 ha^{-1} (US$14.1 ac^{-1}) in these watersheds. Allocating the loss to crop acres only and assuming that each crop acre only receives fertilizer every other year, a loss of US$93.2 ha^{-1} (US$37.7 ac^{-1}) of fertilizer N and P is estimated.

Adaptive Best Management Practice Management. The dramatic increase in dissolved P loads between 1995 and 2006 highlights the need for an iterative process of BMP assessment and adaptation to meet production and environmental goals. Extreme loads of dissolved P observed in 2007 illustrate the environmental impact and the economic loss that can occur when weather interacts with agricultural practices that are less than optimal. Lessons learned are that practices, such as incorporation of applied P in no-till crops, use of winter cover crops on conventionally tilled fields, and a transition from fall to spring application of P, could have reduced the potential for P loss from MRW and SRW. In addition, more extensive soil testing would allow reductions in P applications to fields or parts of fields in which soil P is already above agronomic needs.

The Eucha-Spavinaw Watershed Experience

The ESW drains 1,076 km^2 (2,658 ac) of the Ozark Plateau in northeast Oklahoma and northwest Arkansas, feeding Lakes Eucha and Spavinaw, which serve as the water supply for the cities of Jay, Tulsa, and several surrounding rural communities in Oklahoma (figure 3). Land use is forest (51%) and pasture (43%) with little row crop (3%) and urban land (1%; table 1). The watershed is home to an intensive and highly productive synergistic poultry/beef cattle operations, which use poultry litter as a fertilizer source for pastures dominated by bermudagrass (*Cynodon dactylon*) and tall fescue (*Lolium arundinaceum*). In fact, the portion of northwest Arkansas in which ESW is located is the top producing area for beef cattle in Arkansas and second in the nation for broiler production behind Georgia (USDA ERS 2011a).

Nutrient Management Planning. As part of the ESW settlement agreement between the City of Tulsa, Tulsa Metropolitan Utility Authority, several poultry companies, and the City of Decatur wastewater treatment plant, Arkansas, to minimize the potential for P runoff, four nutrient management special-

Figure 2

Annual discharge, loads, and flow weighted mean concentrations (FWMCs) for the Sandusky River near Fremont, Ohio (USGS Station #04198000), for the 1975 to 2011 water years. (a) Annual discharge, (b) northwest Ohio precipitation, (c) sediment loads, (d) FWMCs of suspended solids, (e) total phosphorus (P) loads, (f) FWMCs of total P, (g) particulate P loads, (h) FWMCs of particulate P, (i) dissolved P loads, (j) FWMCs of dissolved P, (k) nitrate-nitrogen loads, (l) FWMCs of nitrate-nitrogen, (m) total Kjeldahl nitrogen (N) loads, (n) FWMCs of total Kjeldahl N, (o) total N loads, and (p) FWMCs of total N. Squares are pre-1995. Circles are post-1995. Black filled are significant at $p \leq 0.05$, grey filled significant at $0.10 < p < 0.05$, and white filled not significant. Data based on 16,952 total samples averaging 458 samples per year.

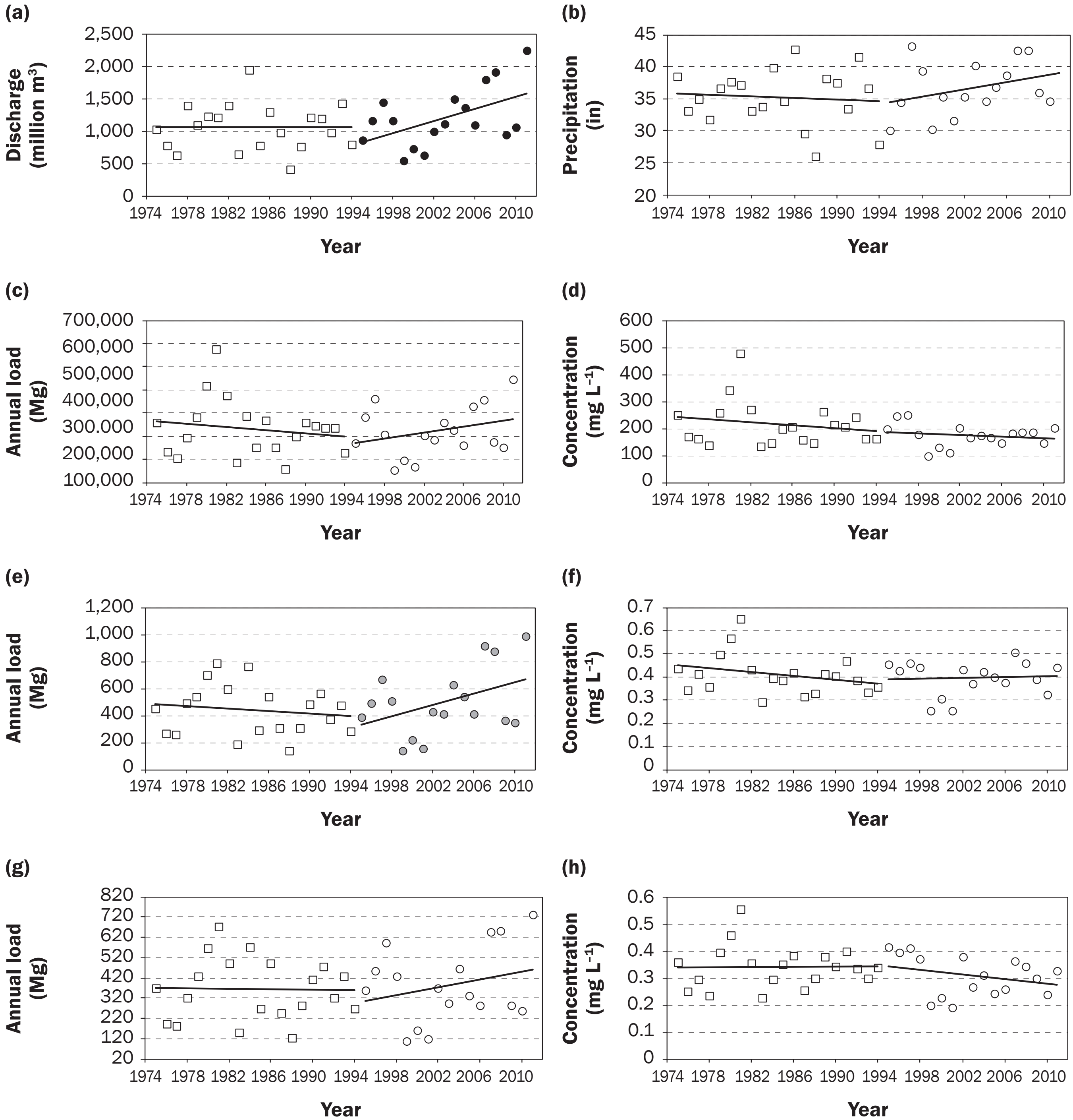

Figure 2 continued ⟶

Figure 2 Continued

Annual discharge, loads, and flow weighted mean concentrations (FWMCs) for the Sandusky River near Fremont, Ohio (USGS Station #04198000), for the 1975 to 2011 water years. (a) Annual discharge, (b) northwest Ohio precipitation, (c) sediment loads, (d) FWMCs of suspended solids, (e) total phosphorus (P) loads, (f) FWMCs of total P, (g) particulate P loads, (h) FWMCs of particulate P, (i) dissolved P loads, (j) FWMCs of dissolved P, (k) nitrate-nitrogen loads, (l) FWMCs of nitrate-nitrogen, (m) total Kjeldahl nitrogen (N) loads, (n) FWMCs of total Kjeldahl N, (o) total N loads, and (p) FWMCs of total N. Squares are pre-1995. Circles are post-1995. Black filled are significant at $p \leq 0.05$, grey filled significant at $0.10 < p < 0.05$, and white filled not significant. Data based on 16,952 total samples averaging 458 samples per year.

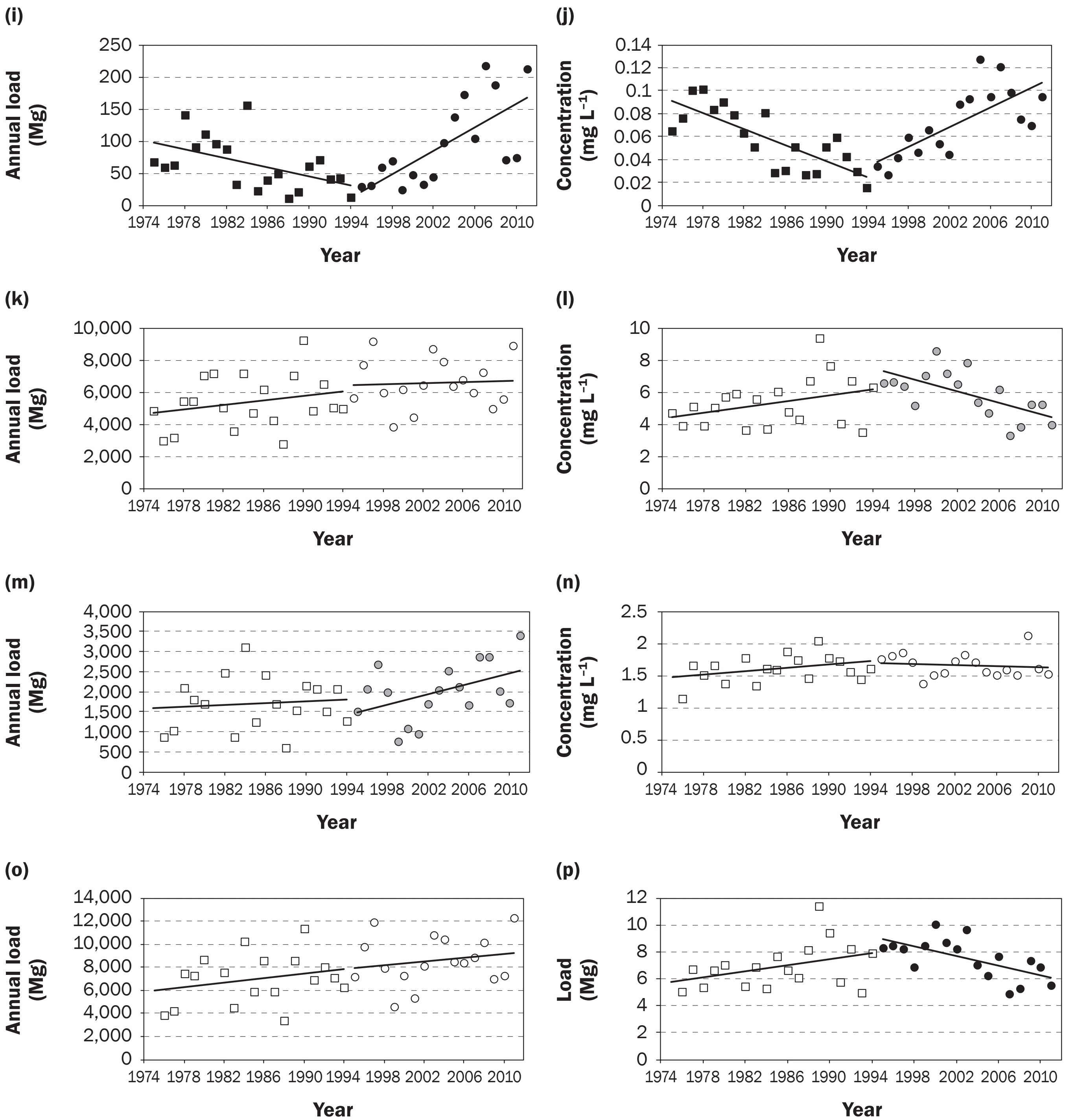

Figure 3
The Eucha-Spavinaw Watershed.

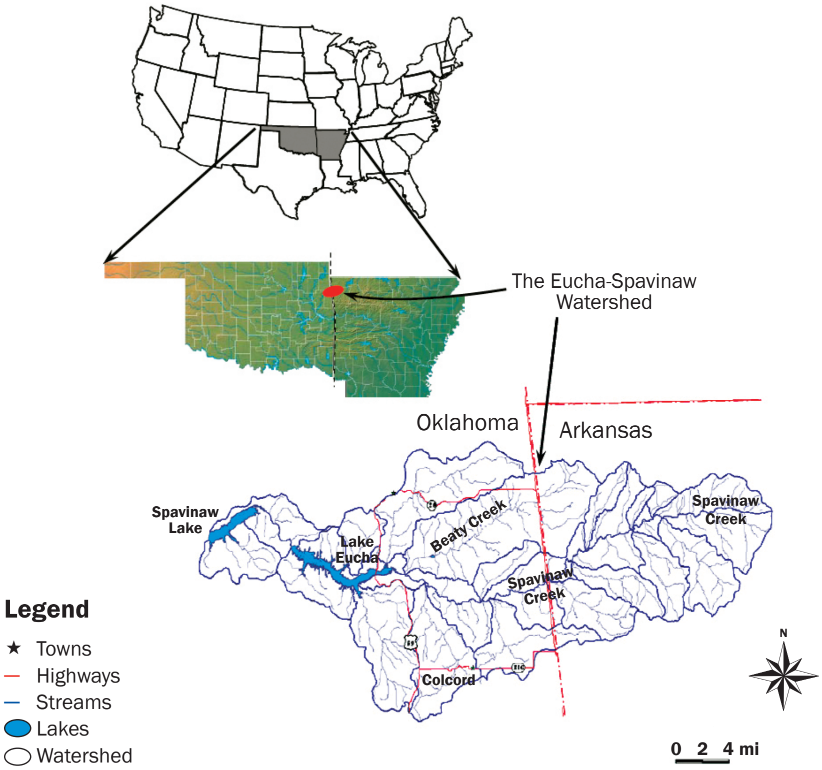

Table 2
Summary findings of P-based nutrient management planning in the Eucha-Spavinaw Watershed from 2004 to 2007 (updated from Sharpley et al. 2009a).

Parameter	2004	2005	2006	2007	2008	2009
Average soil test P (mg kg^{-1})	165	186	178	170	175	196
Fields with <300 mg kg^{-1} (%)	95	91	90	95	95	89
Average poultry litter rate (t ha^{-1})	3.3	3.2	2.9	2.6	2.5	2.5
Area of watershed receiving litter (%)	7	6	7	6	7	6
Litter exported (%)	69	75	74	77	80	82

ists were hired. These specialists worked with poultry and beef cattle farmers to develop annually updated NMPs to manage their poultry litter and determine application rates based on the risk assessment tool ESPI. The court-mandated version of ESPI is compliant with the Natural Resources Conservation Service (NRCS) Conservation Practice (CP) 590 Standard for managing the land application of P, in terms of source and transport factors that determine the risk of P loss, and is described in more detail by DeLaune et al. (2007). Essentially, ESPI follows the basic source and transport factor framework of multiplicative indices used in many other states (Sharpley et al. 2003b), along with the court-mandated STP threshold of 300 mg kg^{-1} (300 ppm) (as Mehlich-3 P), limiting application of P in any form.

Information used in the current assessment was obtained from NMPs written between 2004 and 2009 in ESW as part of the settlement agreement. Available data included STP concentration (as Mehlich-3 P; 0 to 10 cm [0 to 4 in] soil sampling depth), nutrient content of litter (total N, P, and K, and water extractable P) (Self-Davis and Moore 2000), number and area of fields for which a plan was written, timing and rate of litter application, and presence of NRCS-approved BMPs. These BMPs included riparian buffers (CP 390), stream bank protection (CP 395), and fencing (CP 382) (USDA NRCS 2003).

Impacts on Poultry Litter Management. While there has been no consistent change in STP concentrations measured since 2004, averaging 177 mg kg^{-1} (177 ppm), the majority of the soils tested were below the 300 mg kg^{-1} (300 ppm) threshold (89% to 95%; table 2). The percentage of ESW for which STP concentrations are below 50 mg kg^{-1} (50 ppm), the threshold above which no plant response to applied P is generally seen, was about 10%.

Each year since 2004, ESPI-based plan writing has had a direct impact on nutrient management and has decreased land application of poultry litter from 3.3 to 2.5 t ha^{-1} (1.5 to 1.1 tn ac^{-1}), a 20% decrease in four years (table 2). The rates of poultry litter application in 2009 are 40% to 60% less than N-based rates prior to the settlement agreement, which were 4.5 t ha^{-1} y^{-1} (2.0 tn ac^{-1} yr^{-1}) for cool and 6.7 t ha^{-1} y^{-1} (3.0 tn ac^{-1} yr^{-1}) for warm season grasses (Slaton et al. 2004).

Even though litter application rates have decreased about 50% since 2004, this has not been translated into a consistent decline in STP concentrations (table 2). For example, the average STP concentration of soils sampled during the NMP process was 165 mg kg^{-1} (165 ppm) in 2004 and 196 mg kg^{-1} (196 ppm) in 2009. This is not unexpected given the slow decline in STP even when no P is applied due to the slow release of sorbed P and offtake with harvested forage (Sharpley et al. 2007). The lag time between management change and STP response will likely exceed 5 years (McCollum 1991; Sharpley et al. 2009b). However, based on data collected by the planning team, the number of fields receiving poultry litter declined from 900 in 2004 to 700 in 2009, which cover only 7% to 6% of the whole ESW (table 2).

Approximately 82,000 t (90,364 tn) of poultry litter are produced within ESW annually. From amounts of litter applied determined by NMPs, it was calculated that 69% to 82% of the litter produced in ESW was exported (table 2). Thus, ESPI–based NMPs more than met guidelines set forth in the settlement agreement (i.e., at least one-third the litter produced be exported out of ESW) each year since its enactment.

Economic Impacts of Beef Cattle Production. Estimates of the economic

Table 3

Economic impact of nitrogen (N), phosphorus (P), and potassium (K) removed in poultry litter in terms of replacement fertilizer N, P, and K values in the Eucha-Spavinaw Watershed (ESW) in 2004 and 2009 (updated from Sharpley et al. 2009a).

Parameter	2004			2009		
Litter applied (t)	25,640			15,090		
Litter removed (t)	55,990			66,540		
	N	P	K	N	P	K
Average litter total (mg kg^{-1})	29,530	15,960	22,800	30,440	15,450	24,570
Nutrients exported in litter (t)	1,650	900	1,280	2,110	1,070	1,700
Fertilizer cost (US$ t^{-1}) *	304	293	200	536	694	1,102
Fertilizer nutrient value (US$ t^{-1})	662	637	333	1,165	1,509	1,837
Litter nutrient value (US$ t litter^{-1})	20	10	8	35	23	45
Total N, P, and K value (US$ t litter^{-1})	**38**			**103**		
ESW replacement cost (US$1,000) †	**1,094**	**570**	**425**	**2,458**	**1,615**	**3,123**
Total ESW cost (US$)	**2,088,150**			**7,196,000**		

* Based on April 2004 and 2008 prices for N as urea (46% N), P as triple superphosphate (46% P), and K as potash (60% K). Data from USDA Economic Research Service (2011a).

† Total cost to poultry growers in the Eucha-Spavinaw Watershed.

impacts of the court-mandated ESPI on ESW farmers were obtained from NMP information and the average annual cost of mineral fertilizer (table 3). The export of N, P, and K exported in poultry litter was calculated as the product of the average nutrient content of poultry litter and the amount exported from ESW. Between 2004 and 2009, there was a dramatic increase in fertilizer prices. Based on elemental analysis, N from urea increased from US$662 to US$1,165 t^{-1} (US$600 to US$1,057 tn^{-1}), P from triple superphosphate increased from US$637 to US$1,509 t^{-1} (US$578 to US$1,369 tn^{-1}), and K from potash increased from US$333 to US$1,837 t^{-1} (US$302 to US$1,667 tn^{-1}) (table 3; USDA ERS 2011b). This translated to an increase in the nutrient value of litter based on fertilizer replacement cost, which in 2009 was US$35 t^{-1} (US$32 tn^{-1}) for N, US$23 t^{-1} (US$20 tn^{-1}) for P, and US$45 t^{-1} (US$40 tn^{-1}) for K. The nutrient value of litter exported from ESW amounted to US$103 t^{-1} (US$93 tn^{-1}) in 2009 (table 3). Over the study period (2004 to 2009), fertilizer prices peaked in 2008 at US$552 and US$800 t^{-1} (US$500 and US$726 tn^{-1}) for N and P, respectively. Assuming soil P and K were sufficiently high to warrant no P or K application, the cost to ESW farmers of buying replacement fertilizer N was appreciably greater than the US$6 to US$10 t^{-1} (US$5 and US$9 tn^{-1}) farmers received from the sale of poultry litter.

A poultry litter application of 6.7 t ha^{-1} (3.0 tn ac^{-1}) could be recommended to meet the N requirements of bermudagrass pasture. However, a farmer would have to spend US$140 ha^{-1} (US$57 ac^{-1}) on replacement fertilizer N to maintain yields, based on the average 2009 litter application rate of 2.6 t ha^{-1} (1.2 tn ac^{-1}) in ESW. Based on ESW as a whole, the value of nutrients exported in litter in 2009 was US$2,458,000 for N, US$1,615,000 for P, and US$3,123,000 for K; for a total of US$7,196,000. Clearly, there is a large negative economic impact on beef cattle grazing farmers of replacing needed N exported in litter with mineral fertilizer.

Discussion

Nutrient management and watershed planning efforts in MRW, SRW, and ESW to ameliorate water quality concerns yielded some direct benefits and a few indirect consequences. This analysis gives insight into how future watershed management strategies could be more effective. For instance, in ESW, producers who want to land-apply poultry litter must have a NMP with ESPI used to determine application rates that do not put fields at a high risk for P loss. In MRW and SRW, NMPs are required for producers of a certain size, and a comparable P index is used in plan development (Sharpley et al. 2003a; USDA NRCS 2002). However, because most P is imported into the watersheds as mineral fertilizer, the P index is not used to manage most of the agricultural land in MRW and SRW.

Because fertilizer must now be purchased at relatively high prices and because of a shift from build-up to maintenance applications, the majority of SRW soils (>80%) are at or below the agronomic optimum Mehlich-3 STP concentration of 60 mg kg^{-1} (60 ppm). This contrasts with the ESW, where litter-based P is in excess of pasture needs in the watershed (Slaton et al. 2004). Further, poultry litter has historically been applied at rates to meet plant N requirements, thereby overapplying P (Beegle 2000; Lanyon 2000; Sims et al. 2005). This contrast is common between row-crop and animal production–dominated watersheds. For instance, localized accumulations of P have occurred in other areas such as the Delmarva Peninsula (Delaware and Maryland), Neuse River (North Carolina), and North Bosque River (Texas), which are dominated by animal production (Maguire et al. 2005; Sharpley et al. 2003a).

One might expect that the improved management approaches suggested for MRW and SRW would be easier to implement than those for ESW, in spite of being voluntary, because they all would save the farmer money. But other factors, including the following, intervene:

- As crop planting equipment has become larger, it no longer includes tools to incorporate fertilizer in the subsurface adjacent to the seed. Thus, fertilizer applications in MRW and SRW are of necessity separated from planting, and broadcast applications on the surface, with or without incorporation, are commonplace. In the rocky soils dominating pastures of the Ozark Plateau in ESW, incorporation of litter in the soil remains impractical.

- In row-crop dominated watersheds, the drive to maximize yield can discourage waiting until spring to fertilize. Planting must be done as early as possible, at least for corn. If the weather in the fall permits preparing fields for next year's planting, it will be done. Similarly, in watersheds dominated by poultry operations, farmers only have a short window of opportunity for broiler-house cleanout and, thus, poultry litter application, with few choosing to store or stack litter.
- Fertilizer dealers have relatively little to do in winter as compared to fall and spring, creating an incentive to spread fertilizer in winter if the fields can be driven on, i.e., frozen ground.
- Farmers tend to be risk-averse and are reluctant to make changes that cost the farm enterprise money if they are not required to do so. This makes the voluntary adoption of costly conservation measures more difficult unless there is some financial incentive or cost-share mechanism for the farmer.

Implications of the court-mandated nutrient management planning in ESW have resulted in a decrease in poultry litter application rates and less than a quarter of the litter produced is applied in ESW, with the remainder being exported out of the watershed. These changes in litter management have affected the beef cattle farmers, to whom litter is an inexpensive source of N (and to an increasing extent P and K), most. In order to maintain the economic viability of all farming enterprises, the NMP process must go beyond addressing poultry litter application rates and environmental risk and include educational efforts to help farmers develop sustainable whole-farm operations. In particular, the economic and environmental sustainability of beef cattle farmers would benefit from educational information and training on exclusion of livestock from streams, incorporation of N_2-fixing legumes into pastures, rotational grazing, introduction of tall fescue containing a nontoxic endophyte, forage harvest and feed management, and forage species diversification.

Conclusions

As fertilizer N and P prices have tripled in the last decade, meeting production and environmental goals can have a greater impact on farming. At the end of 2009, N as urea was US$1,165 t^{-1} (US$1,057 tn^{-1}), and P as triple superphosphate P was US$1,509 t^{-1} (US$1,369 tn^{-1}) (USDA ERS 2011b). Based on these prices, the cost of N and P loss from MRW and SRW in 2007 was US$93 ha^{-1} (US$38 ac^{-1}) of agricultural land. In the ESW, the cost of replacing N and P exported in litter amounted to US$140 ha^{-1} (US$57 ac^{-1}) based on 2009 fertilizer prices. As the farmer only gets US$5 to US$10 t^{-1} (US$4 to US$9 tn^{-1}) for litter due to high transportation costs related to volatile fuel prices and distance moved, income from the sale of litter is minimal compared to the cost of buying replacement fertilizer N and P.

Information from coordinated nutrient management planning in ESW demonstrates the beneficial impacts of using the P-based risk assessment tool, ESPI, on the land application of P in the watershed. Application rates of P-containing poultry litter have declined 50% to 75%, with over 80% of the litter now exported out of ESW. Given the additional fact that no P is applied to soils with a Mehlich-3 STP greater than 300 mg kg^{-1} (300 ppm), it is clear that the risk of P runoff from land-applied poultry litter has been reduced since 2004. Although this study did not monitor water quality in the watershed, it is likely that P-based NMPs and use of ESPI in ESW will lead to decreased P export from agricultural nonpoint sources.

These two examples highlight that production and environmental goals can coexist under certain conditions. While voluntary adoption of BMPs in MRW and SRW decreased P export, a continued robust, adequately supported and transparent monitoring and assessment program is needed to insure their long-term effectiveness. However, litigated nutrient management based on environmental risk in ESW did negatively impact the economic viability of beef cattle production, which synergistically benefits from poultry production. In combination, these two examples suggest that conservation management should be flexible and BMPs adapted to site-specific conditions. As important, some cost-share process should exist to help farmers address some of the costs of decreased productivity with environmentally based management, as long as predetermined and agreed minimum environmental stewardship standards are maintained.

References

Baker, D.B., and R.P. Richards.2002. Phosphorus budgets and riverine phosphorus export in northwest Ohio. Journal of Environmental Quality 31:96-108.

Beegle, D.B. 2000. Integrating phosphorus and nitrogen management at the farm level. *In* Agriculture and Phosphorus Management: The Chesapeake Bay, ed. A.N. Sharpley, 159-168. Boca Raton, FL: Lewis Publishers.

DeLaune, P.B., B.E. Haggard, T.C. Daniel, I. Chaubey, and M.J. Cochran. 2006. The Eucha/Spavinaw Phosphorus Index: A court mandated index for litter management. Journal of Soil and Water Conservation 61(2):96-105.

Krieger K., D.B. Baker, R.P. Richards, and J. Kramer. 2010. Record amounts of dissolved phosphorus hit Lake Erie. Water Quality News and Notes, July 10, 2010. Tiffin, OH: Heidelberg College, National Center for Water Quality Research. http://www.heidelberg.edu/sites/herald.heidelberg.edu/files/NCWQR%20News%20and%20Supplement_072210.pdf.

Lanyon, L.E. 2000. Nutrient management: Regional issues affecting the Bay. *In* Agriculture and Phosphorus Management: The Chesapeake Bay, ed. A.N. Sharpley, 145-158. Boca Raton, FL: Lewis Publishers.

Maguire, R.O., W.J. Chardon, and R. Simard. 2005. Assessing potential environmental impacts of soil phosphorus by soil testing. *In* Phosphorus: Agriculture and the Environment, eds. J.T. Sims and A.N. Sharpley, 145–108. Agronomy Monograph 46. Madison, WI: American Society of Agronomy.

McCollum, R.E. 1991. Buildup and decline in soil phosphorus: 30-year trends on a Typic Umprabuult. Agronomy Journal 83:77-85.

Osmond, D.L., M.L. Cabrera, S.E. Feagley, G.E. Hardee, C.C. Mitchell, P.A. Moore, Jr., R.S. Mylavarapu, J.L. Oldham, J.C. Stevens, W.O. Thom, F. Walker, and H. Zhang. 2006. Comparing ratings of the southern phosphorus indices. Journal of Soil and Water Conservation 61(6):325-337.

Richards, R.P., and D.B. Baker. 2002. Trends in water quality in LEASEQ rivers and streams (Northwestern Ohio), 1975-1995. Journal of Environmental Quality 31:90-96.

Richards, R.P., D.B. Baker, and D.J. Eckert. 2002a. Trends in agriculture in the LEASEQ watersheds, 1975-1995. Journal of Environmental Quality 31:17-24.

Richards, R.P., F.G. Calhoun, and G. Matisoff. 2002b. The Lake Erie agricultural systems for environmental quality project: An introduction. Journal of Environmental Quality 31:6-16.

Richards, R.P., D.B. Baker, J.P. Crumrine, and A.M. Sterns. 2010. Unusually large loads in 2007 from the Maumee and Sandusky Rivers, tributaries to Lake Erie. Journal of Soil and Water Conservation 65(6):450-462, doi:10.2489/jswc.65.6.450.

Self-Davis, M.L., and P.A. Moore, Jr. 2000. Determining water-soluble phosphorus in animal manure. *In* Methods of phosphorus analysis for soils, sediments, residuals, and waters, ed. G.M. Pierzynski, 74–76. Southern Cooperative Series Bulletin #396. Raleigh, NC: North Carolina State University.

Sharpley, A.N., T.C. Daniel, J.T. Sims, J. Lemunyon, R.A. Stevens, and R. Parry. 2003a. Agricultural Phosphorus and Eutrophication. Second Edition. USDA-ARS Report 149. Washington, DC: US Government Printing Office.

Sharpley, A.N., S. Herron, and T.C. Daniel. 2007. Overcoming the challenges of phosphorus-based management in poultry farming. Journal of Soil and Water Conservation 62(6):375-389.

Sharpley, A.N., S. Herron, C. West, and T.C. Daniel. 2009a. Outcomes of phosphorus-based nutrient management in the Eucha-Spavinaw watershed. *In* Farming with Grass: Achieving Sustainable Mixed Agricultural Landscapes, ed. A. Franzluebbers, 192-204. Ankeny, IA: Soil and Water Conservation Society.

Sharpley, A. N., P.J.A. Kleinman, P. Jordan, L. Bergström, and A.L. Allen. 2009b. Evaluating the success of phosphorus management from field to watershed. Journal of Environmental Quality 38:1981-1988.

Sharpley, A.N., and S.J. Smith. 1994. Wheat tillage and water quality in the Southern Plains. Soil Tillage Research 30:33-48.

Sharpley, A.N., J.L. Weld, D.B. Beegle, P.J.A. Kleinman, W.J. Gburek, P.A. Moore, and G. Mullins. 2003b. Development of Phosphorus Indices for nutrient management planning strategies in the US. Journal of Soil and Water Conservation 58(3):137-152.

Sims, J.T., L. Bergstrom, B.T. Bowman, and O. Oenema. 2005. Nutrient management for intensive animal agriculture: Policies and practices for sustainability. Soil Use Management 21:141-151.

Slaton, N.A., K.R. Brye, M.B. Daniels, T.C. Daniel, R.J. Norman, and D.M. Miller. 2004. Nutrient input and removal trends for agricultural soils in nine geographic regions in Arkansas. Journal of Environmental Quality 33:1606-1615.

USDA ERS (Economic Research Service). 2011a. Quick Stats - Agricultural Statistics database. Washington, DC: USDA. http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/index.asp.

USDA ERS. 2011b. US fertilizer use and prices. http://www.ers.usda.gov/Data/FertilizerUse/.

USDA NRCS (Natural Resources Conservation Service). 2002. Phosphorus index risk assessment procedure worksheet. USDA-NRCS Ohio Field Office Technical Guide Section 1. Columbus, OH: USDA Natural Resources Conservation Service.

USDA NRCS. 2003. National Conservation Practices Standard Codes. http://www.nrcs.usda.gov/technical/Standards/nhcp.html.

USDA NRCS. 2009a. Lower Maumee rapid watershed assessment. Washington, DC: USDA. ftp://ftp-fc.sc.egov.usda.gov/OH/pub/Rapid_Assessments/Lower_Maumee_FINAL_4-27-09.pdf.

USDA NRCS. 2009b. Sandusky rapid watershed assessment. Washington, DC: USDA. ftp://ftp-fc.sc.egov.usda.gov/OH/pub/Rapid_Assessments/Sandusky%20RWSA%207-31-08.pdf.