Outcomes of phosphorus-based nutrient management in the Eucha-Spavinaw Watershed

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The role of phosphorus (P) in accelerating eutrophication of fresh waters is well documented (Carpenter et al. 1998), as are more recent findings that P can seasonally limit the productivity of coastal waters (Howarth et al. 2002). However, P is an essential dietary input for poultry production and is used as a fertilizer nutrient to achieve maximum pasture production in beef-cattle grazing systems, predominant in northwest Arkansas and northeast Oklahoma.

In many areas of the United States, regulatory and nonregulatory agencies have changed their strategic approach to nutrient management planning with respect to water quality impacts because it has become cheaper to control nutrient sources than treat the symptoms of nutrient enrichment. Such a strategy was put in place to target and remediate sources of P in the Eucha-Spavinaw Watershed (ESW) in northwest Arkansas and northeast Oklahoma, which collects and supplies water to the metropolitan area of Tulsa, Oklahoma.

In 2003, the City of Tulsa and Tulsa Metropolitan Utility Authority (Plaintiffs) agreed to a settlement with several poultry integrators (including Tyson Foods, Cargill, Cobb–Vantress, George's, Peterson Farms, and Simmons Foods) and the City of Decatur, Arkansas (Defendants), wastewater treatment plant. The settlement addressed concerns that P in runoff from pastures fertilized with poultry litter and in wastewater discharge from Decatur accelerated algal growth, which caused subsequent taste and odor problems in drinking water. The settlement required nutrient management plans (NMPs) for poultry producers to determine land application rates of poultry litter based on the risk of P loss from fields to streams. Use of a P Index developed for ESW, the Eucha-Spavinaw P Index (ESPI), was required. It was also stipulated that no more than 67% of the poultry litter produced in ESW could be land applied, and that no litter could be applied to fields with a soil test P (STP) concentration (as Mehlich-3 extractable soil P) greater than 300 mg kg^{-1}.

Nutrient flows on a typical poultry production–beef-cattle grazing farm, prevalent in ESW, are presented in figure 1, illustrating the challenges facing nutrient budgeting of these integrated farming systems. In general, N and P inputs far exceed outputs at a farm level. Estimates of annual flows and balance of N and P for pathways shown in figure 1 are presented in table 1 for a representative poultry–beef operation in northwest Arkansas (West and Waller 2007). For this example, only 14% of the imported N and 12% of the imported P were exported in animal produce (table 1). Thirty-two percent of the N and 17% of P were recycled back to the pasture through ungrazed vegetation and cattle excreta. The remaining N and P (about 54% and 74%, respectively) were unaccounted for within the farm system. This scenario illustrates the potential for N and P to accumulate within poultry production–beef-grazing systems. While litter N can be used to maintain forage production, adoption of P-based NMPs, as in ESW, can limit on-farm use of litter as a source of N. Because of increasing fertilizer costs, the purchase of fertilizer as a replacement for litter N, P, and K is no longer an economically viable option for graziers.

This chapter documents the outcomes of legislated NMP in terms of litter management, soil P levels, land affected, and most critically the impacts on beef-cattle grazing in ESW. Information given in this paper is from NMPs written in ESW by the team of trained planners assigned to this watershed since the 2004 settlement.

Table 1. Annual N and P balance and flow through components of a poultry production–beef grazing system in northwest Arkansas (adapted from West and Waller 2007).

Farm component*	Nitrogen ($kg\ ha^{-1}\ y^{-1}$)	Phosphorus ($kg\ ha^{-1}\ y^{-1}$)
Poultry N and P balance†		
N & P import in feed	370	100
N & P export in poultry	40	10
N & P recovered in litter and applied to pastures	100	52
Cattle / forage N and P balance‡		
N & P uptake into top growth§	127	19
Forage N & P consumed by cattle at 0.7 grazing utilization	88	13
Ungrazed forage N & P returned to soil	38	6
Supplement N & P consumed by cattle	1	<1
N & P excreted by cattle on pasture	81	11
N & P exported in cattle live weight: weaned cows and cull cows	10	2
Whole-farm N and P balance		
Total N & P import in feed and supplement	371	101
Total N & P export in poultry and beef	50	12
Excess N & P (import – export)	321	89
N & P returned to pasture as ungrazed forage and cattle excreta	119	17
Unaccounted for N & P (e.g., litter, N volatilization)	202	72

* 80 ha farm in forage (bermudagrass, tall fescue, white clover, and some annuals) assuming 5.8 Mg ha^{-1} yr^{-1} forage dry matter produced.

† 3 poultry houses with 5 broiler flocks per year, producing 1.6 Tg of bird live weight, assuming 3.8 Mg ha^{-1} yr^{-1} litter produced.

‡ 80 beef cows, 72 calves, 12 heifers, and 3 bulls. Farm is self-sufficient in feed production for the cattle except winter energy supplement for cows and heifers and mineral supplement. No hay is imported or exported, and no phosphatic fertilizer is imported.

§ Top-growth concentration is 2.20% N and 0.32% P.

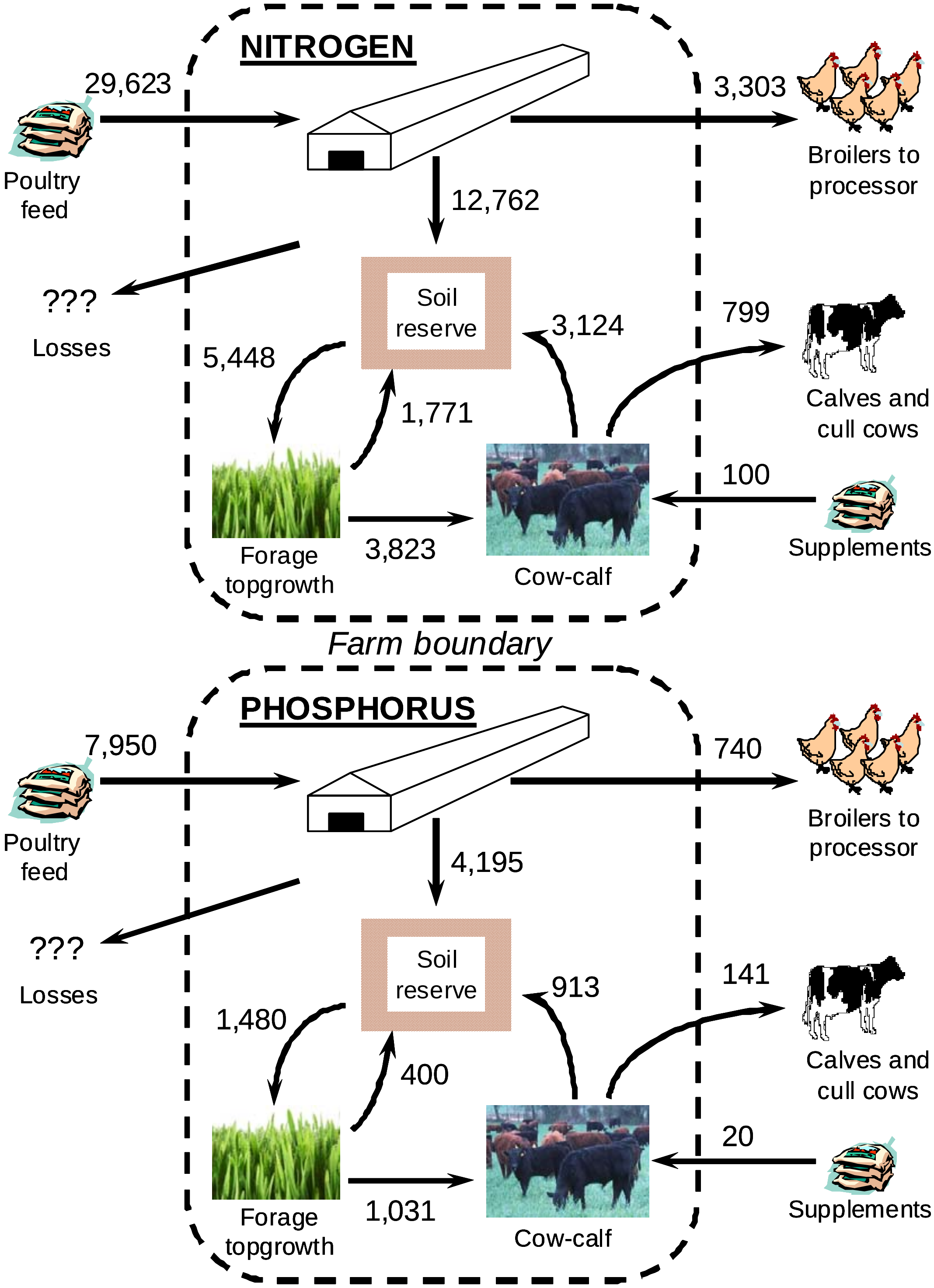

Figure 1. Farm-scale N and P budget for a theoretical 80 ha farm in northwest Arkansas with three broiler houses and 80 beef cows, 72 calves, 12 heifers, and 3 bulls. Values are total N and P in kg yr^{-1} (adapted from West and Waller 2007).

Experimental Design

Eucha-Spavinaw Watershed. The ESW is a 107,600 ha drainage basin in the southwest portion of the Ozark Plateau in northwest Arkansas and northeast Oklahoma (figure 2). The ESW drains into Lakes Eucha and Spavinaw, which serve as the municipal drinking water supply to the cities of Jay and Tulsa, Oklahoma, as well as some surrounding rural communities. Land use in ESW is mostly forest (51%) and pasture (43%), with lesser amounts of row crops and urban land use (table 2). The drainage area is densely populated with poultry–beef-cattle operations that use poultry litter as a fertilizer source for pastures dominated by bermudagrass (*Cynodon dactylon*) and tall fescue (*Lolium arundinaceum*). The area in which ESW is located is the top producing area for both poultry and beef cattle in Arkansas (USDA 2008).

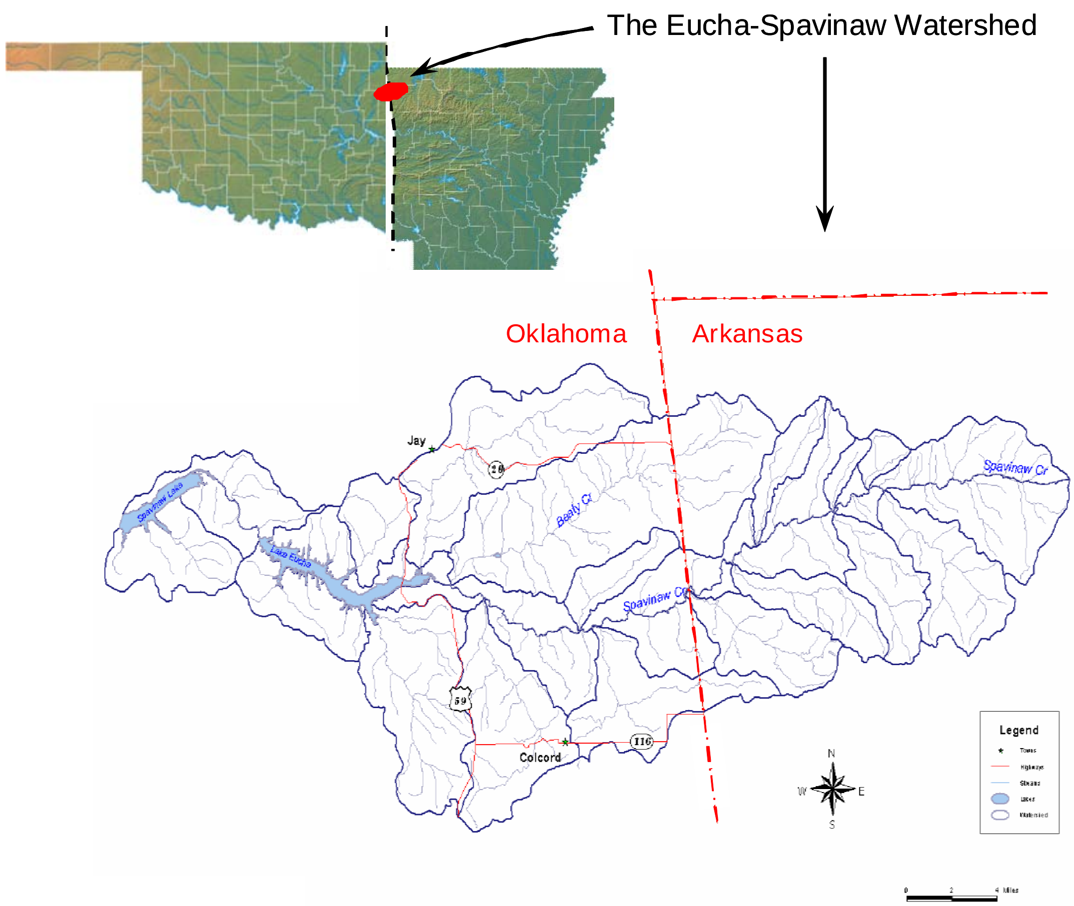

Figure 2. Eucha-Spavinaw Watershed.

Table 2. Land use in the Eucha-Spavinaw Watershed, based on 2004 information.

Land use	Area (ha)	Percent
Forest	55,200	51.3%
Pasture	46,400	43.0%
Row crop	2,800	2.6%
Water	1,800	1.7%
Urban	1,400	1.3%
Total	107,600	

Eucha-Spavinaw Phosphorus Index. The current version of ESPI used in NMP writing within the ESW is given in tables 3 and 4; this represents a nationally recognized approach to managing land application of P in terms of source and transport factors that influence environmental risk (Sharpley et al. 2003; DeLaune et al. 2007). Phosphorus source characteristics in ESPI are soil test P (STP), water-extractable P (WEP) (Self-Davis and Moore 2000) in applied litter, and an estimate of particulate P loss. Phosphorus transport characteristics were used to estimate the potential for P sources to be mobilized during rainfall and runoff. Surface runoff class for each site was a function of field slope and runoff curve number and reflected the potential for runoff to occur from a given site. Soils classified as frequently flooded had a much greater potential for P transport than occasionally and nonflooded soils. Greater loss ratings in ESPI were assigned to litter applied at times of the year when the occurrence of runoff was greatest. Finally, credit was given to reducing the potential for P loss when best management practices (BMPs) approved by the Natural Resources Conservation Service (NRCS) were implemented at a site. These BMPs included stream fencing, setback or buffer areas next to a stream where no litter was applied, and stream-side vegetative or riparian buffers, which have been shown to filter particulate P loss and decrease dissolved P loss in runoff entering a stream. Further rationale for including these factors and calculations in site risk assessment was given by DeLaune et al. (2007).

Table 3. The Eucha-Spavinaw P Index, site characteristics, and calculation methodology.

Characteristic	P loss category	Loss rating value
	P source characteristics	
Soil test P	Continuous variable	0.0007 * STP† (lb ac^{-1})
Water-extractable manure P rate	Continuous variable	0.4 * WEP‡ applied (lb ac^{-1})
Particulate P soil erosion factor	Continuous variable	RUSLE2 value * STP/667
P source rating value = ∑source characteristics ratings		
	P transport characteristics	
Soil runoff class	Negligible	0.1
	Low	0.2
	Moderate	0.3
	High	0.5
	Very High	1.0
Flooding frequency	None	0
	Occasional	0.1
	Frequently	2.0
Application method	Incorporated	0.1
	Surface applied	0.2
	Surface applied on frozen ground or snow	0.5
Application timing	July to October	0.1
	April to June	0.4
	November to March	0.5
Harvest management	Hayed only	0.1
	Hayed and grazed	0.2
	Grazed only	0.3
P transport rating value = ∑transport characteristics ratings		
	Other site characteristics	
Best management practices	Approved BMPs	0.9
	ESPI site factor calculation	
	ESPI = P source rating value * P transport rating value * BMP factor	

† Mehlich-3 soil test P concentration for a 0 to 10 cm sample and a factor of 1.33 to convert from mg kg^{-1} (as measured) to lbs acre^{-1} (used by plan writers).

‡ Water extractable P concentration of manure applied.

Table 4. Eucha-Spavinaw P Index (ESPI) interpretations and nutrient application recommendations.

ESPI scale	Site interpretations and recommendations
< 33	Low potential for P movement from site. Apply nutrients based on ESPI calculation. Caution against long-term buildup.
34 to 55	Medium potential for P movement from site. Evaluate the Index and determine any areas that could cause long-term concerns. Consider adding conservation practices or reduced P application to maintain the risk at 55 or less. Apply nutrients based on ESPI calculation.
56 to 100	High potential for P movement from site. Evaluate the Index and determine elevation cause. Add appropriate conservation practices and/or reduce P application. The immediate planning target is a PI value of 55 or less. If this cannot be achieved with realistic conservation practices and/or reduced P rates in the short term, then a progressive plan needs to be developed with a long-term goal of a PI less than 55. Apply nutrients to meet crop phosphorus needs according to NRCS Nutrient Management standard (590). Application rates based on phosphorus needs generally equate to <1 ton/ac. Since accurate, uniform applications at these low rates are rarely obtained, no litter application is recommended.
>100	Very High potential for P movement from site. No litter application. Add conservation practices to decrease this value below 100 in the short term and develop a progressive conservation plan that would reduce the PI to a lower risk category, with long-tem goal of a PI less than 55.

Nutrient Management Planning. Information used in this assessment was obtained from NMPs written between 2004 and 2007 in ESW as part of the settlement agreement. Available data included STP concentration (as Mehlich-3 P; 0 to 10 cm soil sampling depth), nutrient content of litter (total N, P, K, and WEP), 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).

Results and Discussion

Poultry Litter Management. There was no consistent change in STP since 2004, averaging 175 mg kg^{-1} (table 5). While maximum STP concentration was >750 mg kg^{-1} for each of the four years of study, 92% of the soils were below the 300 mg kg^{-1} STP threshold in 2004, 86% in 2005, 89% in 2006, and 89% in 2007 (figure 3).

Table 5. Annual mean, minimum, and maximum and 4-year mean soil test P, water-extractable P, and total P and mean total N and total K concentration in poultry litter sampled as part of nutrient management plan development in the Eucha-Spavinaw Watershed.

Parameter	2004	2005	2006	2007	4-year mean
Soil test P (mg kg^{-1})					
Mean	165	186	178	170	175
Minimum	14	5	1	10	8
Maximum	893	972	811	766	861
	Poultry litter				
Water-extractable P (mg kg^{-1})					
Mean	907	829	947	988	918
Minimum	116	238	300	191	211
Maximum	2,188	1,532	1,842	1,906	1,867
Total P (mg kg^{-1})					
Mean	15,960	14,460	14,540	15,450	15,100
Minimum	8,000	6,200	7,200	7,300	7,170
Maximum	25,330	20,700	25,600	22,400	23,510
Total N (mg kg^{-1})	29,530	30,440	32,910	28,860	30,440
Total K (mg kg^{-1})	22,880	23,910	26,110	25,450	24,590

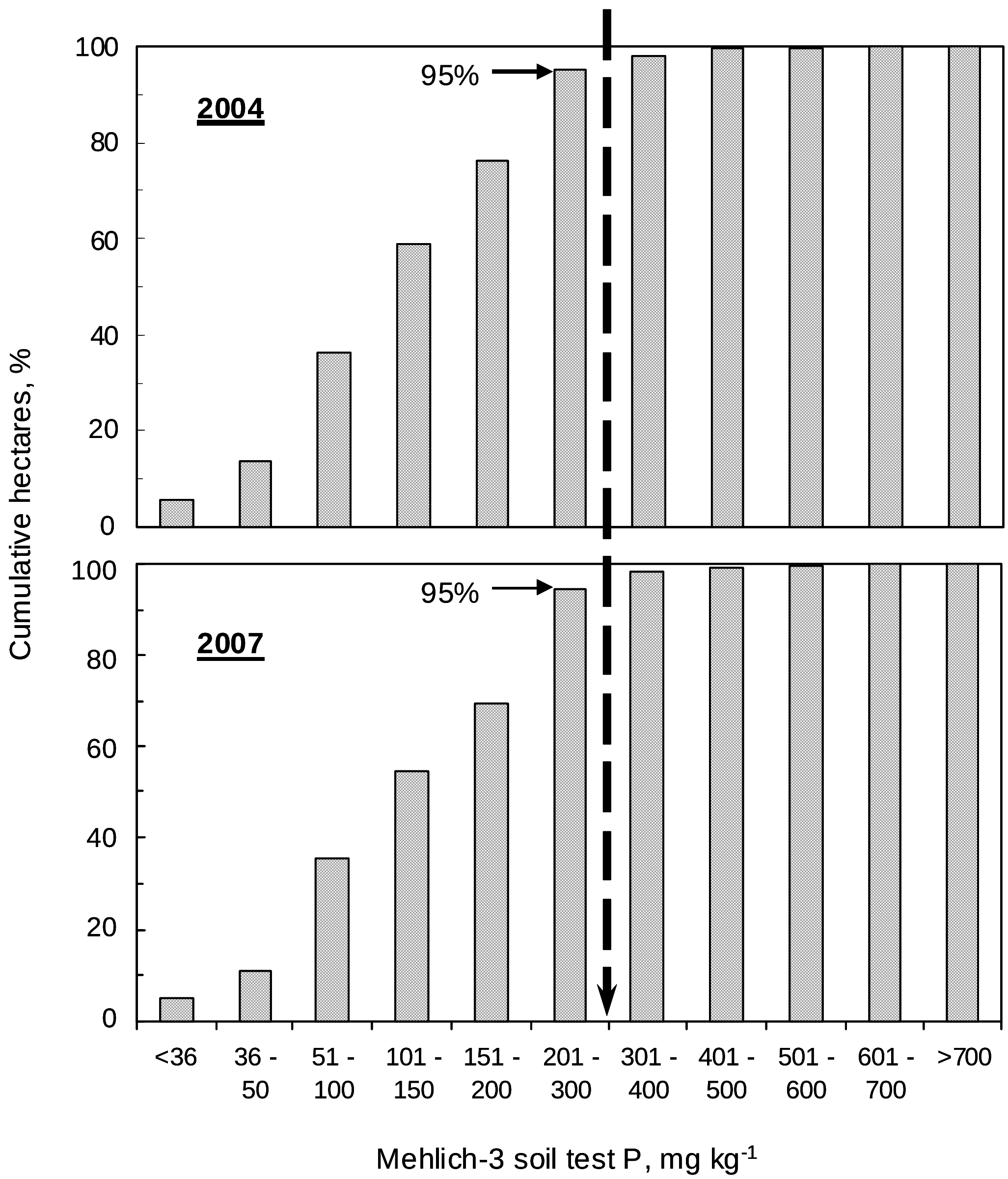

Figure 3. Cumulative hectares within the Eucha-Spavinaw Watershed with soil samples testing below 300 mg kg^{-1} Mehlich-3 soil test P from nutrient management plans written in 2004 and 2007.

Nutrient content of poultry litter was fairly consistent among years, averaging 30.4 g N kg^{-1}, 15.1 g P kg^{-1}, and 24.6 g K kg^{-1} (table 5). Mean annual WEP concentration of litter, which was used in ESPI as an estimate of the potential for P to be released from litter to rainfall-runoff water, ranged from 829 to 988 mg kg^{-1} and was an average of 6.0% of total P (table 5). Poultry litter WEP was fairly constant from year to year, averaging 918 mg kg^{-1} from 2004 to 2007. However, there was a nine-fold variation between the four-year mean minimum and maximum values (table 5). This shows how important it was to measure WEP for consideration in ESPI rather than using a book value of 500 mg kg^{-1} prior to 2004.

Since 2004, ESPI-based plan writing has continued to have a direct impact on nutrient management and has decreased land application of poultry litter. The number of fields and land area for which NMPs were written in ESW are given in table 6. In 2007, NMPs were written for 839 fields, totaling approximately 6,650 ha, with an average recommended litter application rate of 2.6 Mg ha^{-1} yr^{-1} (table 6). These application rates are 40% to 60% less than historic recommendations of county conservation districts in the Arkansas portion of the watershed, which were 4.5 Mg ha^{-1} yr^{-1} for cool-season grasses and 6.7 Mg ha^{-1} yr^{-1} for warm-season grasses. Each year since 2004, average poultry application rate decreased, and in 2007 it was 2.6 Mg ha^{-1} yr^{-1}. This represented a 20% decline in poultry litter application each year from 2004 to 2007.

Table 6. Number of fields for which a plan was written, acres planned, number of fields receiving litter, area receiving litter, and litter application rates recommended by Eucha-Spavinaw P Index in the Eucha-Spavinaw Watershed.

Parameter	2004	2005	2006	2007
Number of fields	970	860	993	839
Hectares planned	8016	6999	8023	6655
Number of fields receiving litter	902	738	797	696
Hectares receiving litter	7642	6280	7243	6274
Percent of watershed receiving litter	7	6	7	6
Percent of planned area receiving litter	95	90	90	94
Litter application (Mg ha^{-1})				
Mean	3.34	3.18	2.91	2.62
Minimum	0	0	0	0
Maximum	9.52	6.16	6.72	5.82

Based on data collected by the planning team, the percentage of fields receiving poultry litter declined from 93% in 2004 to 83% in 2007, which amounted to only 6% to 7% of the whole ESW area that received poultry litter each year since 2004 (table 6). The lack of change in STP values since 2004, even though litter application rates decreased by about 50%, was, therefore, not unexpected. Research has shown that STP levels increase much more rapidly with added P than the rate of decline with forage uptake and harvest (McCollum 1991; Sharpley et al. 2007).

Approximately 82 Gg of poultry litter is produced within ESW annually. Export of litter from ESW was 69%, 75%, 74%, and 78% in 2004, 2005, 2006, and 2007, respectively (table 7). Thus, ESPI-based NMPs exceeded the guidelines (i.e., at least 33% of the litter produced be exported out of ESW) set forth in the settlement agreement each year since its enactment.

Table 7. Impact / cost of N, P, and K removed in poultry litter in terms of replacement fertilizer N, P, and K values in the Eucha-Spavinaw Watershed.

	2004			2005			2006			2007		
Litter applied (Mg)	25,640			20,760			20,940			17,980		
Litter removed (Mg)	55,990			60,870			60,690			63,650		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
Average litter total N, P, and K (mg kg^{-1})	29,530	15,960	22,800	30,440	15,620	23,910	32,910	14,540	26,110	28,860	15,670	25,450
Nutrients exported in litter (Mg)	1,650	900	1,280	1,850	950	1,460	2,000	880	1,590	1,840	1,000	1,620
Fertilizer cost ($ Mg^{-1})†	304	293	200	366	330	270	399	357	301	499	577	388
Fertilizer nutrient value ($ Mg^{-1})	662	637	333	796	717	450	868	776	502	1,086	1,254	647
Litter nutrient value ($ Mg litter^{-1})	20	10	8	24	11	11	29	11	13	31	20	17
Total N, P, and K value ($ Mg litter^{-1})		**38**			**46**			**53**			**68**	
ESW replacement cost ($1,000)‡	1,094	570	425		681	655	1,733	685	795	1,995	1,233	1,048
Total ESW cost ($)	**2,088,150**			**2,810,927**			**3,213,210**			**4,292,742**		

† Based on prices in April of each year for N as urea (46% N), P as triple superphosphate (46% P), and K as potash (60% K). Data from USDA Economic Research Service, http://www.ers.usda.gov/Data/FertilizerUse.
‡ Total cost to poultry growers in the Eucha-Spavinaw Watershed.

Economic Impacts on Beef-Cattle Graziers. Using information from the NMPs, estimates were obtained for nutrient content of poultry litter from each farm, average annual cost of mineral fertilizer, and economic impact of the NMP process on ESW farmers (table 7). The amount of N, P, and K exported in litter was calculated as the product of litter exported and nutrient concentration of litter. During this period, fertilizer prices increased dramatically. Based on elemental analysis, N from urea increased from \$662 to \$1086 Mg^{-1}, triple superphosphate increased from \$637 to \$1254 Mg^{-1}, and K as potash increased from \$333 to \$647 Mg^{-1} (table 7) (USDA ERS 2008). This translated to an increase in the nutrient value of litter based on fertilizer replacement cost, which in 2007 was \$31 Mg^{-1} for N, \$20 Mg^{-1} for P, and \$17 Mg^{-1} for K. The nutrient value of litter exported from ESW amounted to \$68 Mg^{-1} in 2007 (table 7). With continued increase in fertilizer prices, the value of exported litter rose to \$134 Mg^{-1} in 2008. As the farmer would receive only \$6 to \$9 Mg^{-1} for litter, due to high transportation costs, income from the sale of litter was minimal compared to the cost of buying replacement fertilizer N, assuming soil P and K were sufficiently high to warrant no P or K application.

For a bermudagrass pasture, a poultry litter application of 6.7 Mg ha^{-1} could be recommended. However, with the average 2007 litter application rate of 2.6 Mg ha^{-1} in ESW, a farmer would have to spend \$128 ha^{-1} on replacement fertilizer N to maintain yields. Based on ESW as a whole, the value of nutrients exported in litter in 2007 was \$1,995,000 for N, \$1,250,000 for P, and \$1,048,000 for K – a total of \$4,292,742. The economic impact of replacing nutrients exported in litter to beef-cattle grazing farmers is clear.

Management Implications

Nutrient management planning in ESW since the settlement agreement has led to an overall reduction in poultry litter application rates, and twice as much litter being exported as applied in the watershed. As poultry litter has been an inexpensive source of N (and to a lesser extent P and K) to maximize forage production and quality for beef-cattle graziers, changes in litter management have impacted these farmers most. Thus, the NMP process must go beyond addressing poultry litter application rates and environmental risk assessment by including an educational effort to help farmers develop sustainable whole-farm operations. Some management practices that can contribute to the economic and environmental sustainability of beef-cattle grazing operations include incorporation of N_2-fixing legumes into pastures; rotational grazing; exclusion of livestock from streams, forage harvest, and feed management; forage species diversification; and introduction of tall fescue containing a nontoxic endophyte.

Legumes. Established stands of legumes (e.g., white clover [*Trifolium repens* L.]) can fix 90 to 280 kg N ha^{-1} yr^{-1} in perennial grass pastures, with values increasing as percentage legume increases (Mallarino et al. 1990a; West and Mallarino 1996). A portion of the N fixed by legumes is transferred to associated grass via decomposition of nodules, roots, leaves, and stems and excreted forage consumed by cattle. Mallarino et al. (1990b) determined that an average of 41 kg ha^{-1} yr^{-1} of fixed N was transferred from white clover and recovered in tall fescue forage using ^{15}N-tracer technique. However, successful use of legumes as an alternative N source depends on fine-tuned management practices, such as maintaining favorable soil pH, replenishment of the soil seed bank to promote continual recruitment of new legume seedlings, preventing overgrazing to maintain legume plant vigor and N_2 fixation rate, and avoiding insufficient grazing of the grass component to prevent excessive shading of the legumes by grass.

Rotational Grazing. Rotational grazing can more uniformly redistribute excreted N and P within pastures, decreasing the potential for accumulation and subsequent loss in frequented (e.g., camping) sites, such as at water and shade. In fact, rotational grazing consistently increases pasture carrying capacity and animal weight gain over continuous grazing. For instance, Aiken (1998) reported a 39% increase in carrying capacity and 44% increase in weight gain ha^{-1} with steers grazing wheat (*Triticum aestivum* L.) and annual ryegrass (*Lolium multiflorum* Lam.) during spring in an 11-paddock rotation. Hoveland et al. (1997) observed a 37% increase in weight gain ha^{-1} in rotational over continuous stocking with tall fescue–bermudagrass, which was explained entirely by an increase in carrying capacity.

Livestock Exclusion from Streams. Livestock that defecate and urinate in and near streams can potentially contribute significant amounts of N and P over time. By observing four pastures where cattle had access to streams over four intervals during the spring and summer of 2003 in the Cannonsville Watershed in south central, New York, James et al. (2007) were able to estimate fecal P contributions to streams. On average, approximately 30% of all fecal deposits expected from a herd were observed to fall on land within 130 feet of a stream, and 7% fell directly into streams. Approximated to all grazed pastures in the watershed, cattle excreta contributed 12% of the agriculturally-derived P loading (Scott et al. 1998). While some programs may subsidize streambank fencing, farmer participation is mixed. These programs often include stipulations concerning reimbursement, maintenance, and upkeep that are simply too restrictive and time-consuming to farmers. In addition, riparian exclusion may result in various secondary effects that are not subsidized, such as the loss of productive pasture land. Because riparian areas serve as watering sources for cattle as well as shade, alternative amenities away from the stream or controlled access should be considered.

Harvest and Feed Management. Another challenge facing those farming high-P soils in watersheds such as ESW is to draw down soil P to levels considered low risk for P loss in runoff. As grazing beef excrete >90% of the P they consume, forage management may shift from all-grazing to harvesting and removing some or all the herbage as hay or silage. For example, Coblentz et al. (2004) reported 45 kg N ha^{-1} yr^{-1} was removed by bermudagrass that received 112 kg N ha^{-1} yr^{-1} as fertilizer in western Arkansas. Mehlich-3 extractable soil P declined 48 mg kg^{-1} during two years. Forage harvested from high-P sites can be fed back to animals in identifiable low-P, low-runoff risk areas on the same farm; however, that does not mitigate the farm-scale P accumulation problem. Export of the harvested forage from the watershed as a cash hay crop to buyers demanding feed of high nutritional quality, such as dairy and horse producers, offers the best opportunity to draw down soil P to sustainable levels while making a profit.

Forage Species Diversification. Diversifying the type of forage on a farm can more thoroughly exploit changing growing conditions throughout the year to maximize nutrient uptake and recycling. For instance, bermudagrass has a five- to seven-month production lapse during which temperature is too cold for growth (West and Waller 2007). Annual grasses and legumes can be autumn-planted and grazed during the winter and early spring and/or allowed to accumulate growth in spring for a harvest of hay or silage. Winter crops would take up N and P during a time of year when nutrients are most subject to leaching and runoff losses.

Nontoxic Endophyte-Free Tall Fescue. Tall fescue is the predominant perennial forage grass in ESW and the surrounding region, owing to its high yield and adaptation to widely variable soil and climatic conditions and grazing management systems (West and Waller 2007). However, infection of tall fescue by its wild fungal endophyte (*Neotyphodium coenophialum*) generally reduces animal productivity and health (Nihsen et al. 2004). Endophyte toxins exacerbate heat stress in cattle during hot, humid conditions, causing animals to seek shade or stand in ponds for relief; they also reduce blood flow to body extremities in cold weather. Endophyte-free cultivars of tall fescue, which lack such toxins, do not persist well under the combined stresses of drought and heavy grazing pressure. New cultivars contain endophytes specifically selected for lack of ergot alkaloid production, but they retain the benefits of drought and grazing tolerance for host grass persistence. Parish et al. (2003) reported that steers grazing tall fescue with a nontoxic endophyte spent less time idling and standing, consumed less water, and consumed more forage than steers grazing toxic fescue, indicating the potential for better redistribution of excreted nutrients when using nontoxic endophytes. Steer-calf weaning weight increased 15% when cow–calf pairs grazed tall fescue infected with a nontoxic endophyte compared with grazing on wild-type toxic endophyte. Greater live-weight gain may increase farm revenues, while minimizing environmental impacts.

Conclusions

Even when large amounts (>70%) of poultry litter are exported out of ESW and BMPs are implemented, this will not translate into an immediate decrease in P inputs into Lakes Eucha and Spavinaw because of elevated P storage in soils and river sediments. This stored P is expected to be released to river water for a period of time (i.e., years). Thus, it is critical to acknowledge that a lack of significant decrease in P concentrations in Lakes Eucha and Spavinaw does not mean that improved nutrient management planning, lower litter applications, and adopted BMPs have not been successful in decreasing P loss from pastures in ESW.

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