The Eucha/Spavinaw phosphorus index: A court mandated index for litter management

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ABSTRACT: Phosphorus (P)-based management strategies have been adopted in state planning standards nationwide, as most states have modified and adapted the original P index approach to better assess local landscape characteristics and management practices. However, P-based management strategies and environmental issues have become the focus of legal action within and between the states of Arkansas and Oklahoma due to differing management strategies in trans-boundary watersheds. A court settlement agreement was reached between parties in July 2003 requiring the development of a new P index by January 1, 2004 for use in writing nutrient management plans throughout the entire Eucha/Spavinaw watershed. The University of Arkansas found it most appropriate to modify the existing P index already in use in Arkansas to meet terms of the settlement agreement and to better reflect landscape characteristics and management practices specific to the Eucha/Spavinaw watershed. Hence, the Eucha/Spavinaw P index was developed and submitted to the court. By court decree, nutrient management plans in the watershed were written using the Eucha/Spavinaw P index beginning in February 2004. The Court issued further modifications to the Eucha/Spavinaw P index prior to release because the court felt that the specific P index did not fully comply with the settlement agreement. Through 2004, it was reported that the implementation of the Eucha/Spavinaw P index resulted in recommended litter application rates that were approximately one-third the rates that were common before the implementation of the Eucha/Spavinaw P index. Litter application rates recommended by the Eucha/Spavinaw P index were as much as 60 percent lower than application rates that would be recommended with the Arkansas phosphorus index for pastures as currently used.

Keywords: Court settlement, Eucha/Spavinaw watershed, lawsuit, phosphorus index, poultry, water quality

Agriculture is a leading source of pollution in rivers and streams, contributing to 48 percent of reported water quality problems in impaired streams and rivers (USEPA, 2000). Attention toward phosphorus (P) management has escalated in recent years since P, although an essential nutrient for crop and animal production, can accelerate eutrophication of freshwater systems (Carpenter et al., 1998; Sharpley, 2000). Pastures and agriculture involving intensive livestock production systems are an important source of P delivered to surface waters (USGS, 1999; Haggard et al., 2003). In particular, fields receiving nutrients via manure applications based upon nitrogen (N) requirements can lead to an over-application and long-term buildup of P (Gburek et al., 2000). Hence, policies regarding nutrient management now address P as well as N (USDA and USEPA, 1999; Sharpley et al., 2003).

The P index is a simple tool provided to field staff, watershed planners, and farmers to rank the vulnerability of fields as sources of P loss in runoff (Lemunyon and Gilbert, 1993). The original P index consisted of an additive matrix that accounted for and ranked transport and source factors affecting P loss in surface runoff from a given site. Source factors (soil test P, applied P) and transport factors (soil erosion, surface runoff, subsurface flow, channel processes) are used in conjunction to identify critical source areas, which are specific, identifiable areas within a watershed that are most vulnerable to P loss (Gburek et al., 2000). A field is ranked as highly vulnerable to P loss when high P availability due to soil test P and/or P applications coincides with high surface runoff or soil erosion (Sharpley et al., 2001). As recommended by the authors of the original P index, individual states have modified and adapted the original P index to reflect local physiographic conditions and management practices. Sharpley et al. (2003) conducted a survey of 50 states and found that 47 have adopted the P index approach. This survey also found a wide variation in P indices and their approach, reflecting both regional differences in P movement and philosophical differences as to how P risk from a site should be assessed using a P indexing approach.

Phosphorus based management strategies in conjunction with degrading water resources from land application of poultry litter are the focus of political debate within and between the states of Arkansas and Oklahoma. The Eucha/Spavinaw watershed is a 1076 km^2 (415 mi^2) drainage basin in northeast Oklahoma and northwest Arkansas encompassing Lake Eucha and Lake Spavinaw, which collect, store, and supply water to users in the Tulsa, Oklahoma metropolitan area (Figure 1). 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 (*Festuca arundinacea*) (Table 1). In July 2003, the City of Tulsa, Oklahoma and the Tulsa Metropolitan Utility Authority reached a settlement agreement with Tyson Foods, Cobb-Vantress, Peterson Farms, Simmons Foods, Cargill, George's and the City of Decatur, Arkansas as a result of a December

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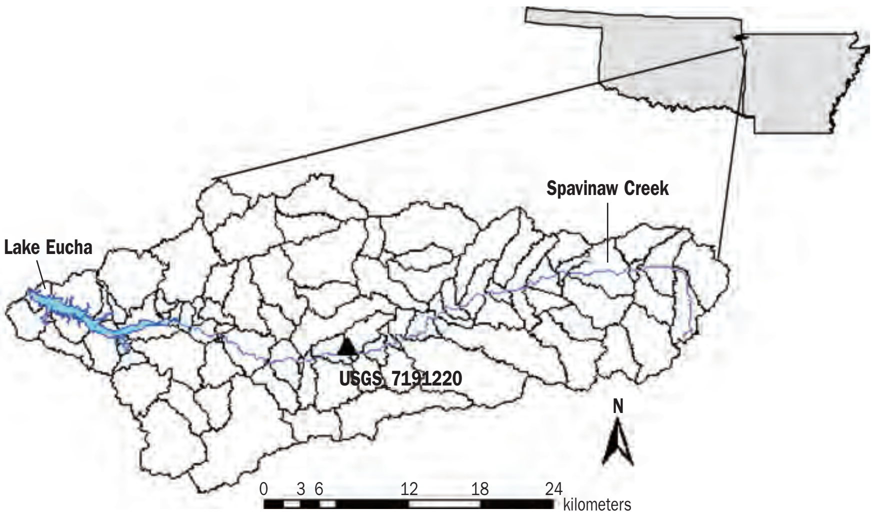
Figure 1
The Eucha/Spavinaw watershed located in northwest Arkansas and northeast Oklahoma.



2001 suit filed for damage to the water supply in the Eucha/Spavinaw watershed (U.S. District Court Case No. 01-CV-0900-EA (C)). The City of Tulsa alleged that excess agricultural P runoff from pastures as well as discharge from the City of Decatur, Arkansas wastewater treatment plant caused prolific algae growth and subsequent taste and odor problems in finished drinking water from the Lake Eucha-Spavinaw complex.

Prior to the lawsuit, poultry litter application rates in the Eucha/Spavinaw watershed had been recommended by various means. For much of the 1990s, recommended litter application rates were determined throughout the watershed using a method that combined soil runoff potential and soil test P (NRCS Conservation Practice Standard Code 633; DeLaune et al., 2004b). Although there are no records of compliance, P applications were not allowed to sites having Mehlich III soil test P concentrations greater than 150 mg kg^{-1} (0 to 15 cm; 300 lb ac^{-1}, 0 to 6 in depth). In 2001, Arkansas adopted the P index for pastures (DeLaune et al., 2004b) to write nutrient management plans in the Arkansas portion of the Eucha/Spavinaw watershed.

The Tulsa-poultry integrator case was scheduled for trial in March of 2003 but a settlement agreement was reached and differences between the parties delayed the final agreement until July 16, 2003. The agreement specified that contract poultry growers in the Eucha/Spavinaw watershed were forbidden from land application of poultry litter until a new P risk-based index was developed for use throughout the entire watershed. The new P index was intended to be jointly developed and agreed upon by a "P index Team", consisting of equal number of representatives, from Oklahoma State University and the University of Arkansas. The agreement required the new P index

> *"to achieve the least amount of total P loading reasonably attainable from each application site to the water supply from all sources of P on each such application site while meeting the agronomic requirements for the growth of grasses, crops and other desirable plant life."*

The statement of intent of the agreement sought to

> *"ensure that nutrient management protocols are used in the watershed to reduce the risk of harm to Plaintiffs' Water Supply due to Land Application of Nutrients and The City of Decatur's WWTP discharge, while at the same time recognizing the right of the Poultry Defendants and their Growers to continue to conduct poultry operations in the Watershed within such protocols and the importance of clean lakes, safe drinking water and a viable poultry industry to the economies of NE Oklahoma and NW Arkansas."*

January 1, 2004 was the proposed deadline to submit a new P index to the court, which provided less than six months from the issuing of the settlement agreement. In the event that the P index Team is unable to agree on a P index by the deadline, either party may request a conference with the Court to determine the process, including an evi-

Table 1. Characteristics and statistics of the Eucha/Spavinaw watershed and nutrient management plans written in 2004.

Landuse (Percent)	
Forest (51.3)	
Pasture (42.9)	
Rangeland (0.1)	
Urban (1.3)	
Water (1.7)	
Row crop (2.6)	
Total land area	1076 km^2
Nutrient management planning (NMP) 2004	
Number of fields receiving NMPs	970
Total area	8,024 ha
Average field size	8.3 ha
Mean application rate (Mg ha^{-1})	
Eucha/Spavinaw P index (ESPI)	3.14
Arkansas phosphorus index for pastures (APIP)*	5.15
APIP - 500†	7.84
Total litter recommended by ESPI for application	25,457 Mg
Estimated total litter produced	82,187 Mg

*** Approximate application rate recommended by Arkansas phosphorus index for pastures (APIP) using measured water soluble P levels in poultry litter.**

† Approximate application rate recommended by APIP using 500 mg kg^{-1} default value for water soluble P in poultry litter.

Table 2. The Arkansas phosphorus index for pastures*, site characteristics, and calculation methodology.

Characteristic	P loss category	Loss rating value
	P source characteristics	
Soil test P	**Continuous variable**	**0.000666* STP† (lb ac^{-1})**
Soluble manure P rate	**Continuous variable**	**0.404* SRP‡ applied (lb ac^{-1})**
	P transport characteristics	
Soil erosion (t ac^{-1} yr^{-1})	<1	0
	1 to 2	0.1
	2 to 3	0.2
	3 to 5	0.4
	>5	1.0
Soil runoff class	Negligible	0.1
	Very low	0.15
	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	June to October	0.1
	March to May	0.2
	November to February	0.5
Harvest management	Hayed only	0.1
	Hayed and grazed	0.2
	Grazed only	0.3
	Other site characteristics	
Annual precipitation (mm)	0 to 254	0.2
	254 to 508	0.4
	508 to 762	0.6
	762 to 1016	0.8
	1016 to 1270	1.0
	1270 to 1524	1.2
	1524 to 1778	1.4
Best management practices	Approved BMPs	0.9

* **Arkansas phosphorus index for pastures = P source x P transport x Precipitation x BMPs.**

† **Mehlich III soil test phosphorus.**

‡ **Soluble reactive phosphorus.**

dentiary hearing, by which they may present a proposal for the Court to determine an appropriate P index. Alas, the Court would appoint a Special Master to recruit, train, and oversee a four-member watershed management team, report to the Court and Parties, and assist the watershed management team in preparing, monitoring, and carrying out nutrient management plans. The P index Team was given the responsibility to develop a new P index by the deadline with only general guidelines as to what the new P index must encompass.

The purpose of this paper is to describe the approach taken by the University of Arkansas to develop a P index to meet the court settlement agreement and subsequent impact on nutrient management planning within the watershed in 2004. As litigation expands, we hope to convey valuable insight into how science measures up to legal mandates and the court process.

Development of Eucha-Spavinaw phosphorus index approach. To meet the time frame of the settlement agreement, the University of Arkansas used the P index for pastures already in use in Arkansas at that time (Table 2; DeLaune et al., 2004b) as a starting point, introducing revisions deemed necessary to achieve the mandate of the settlement agreement. Modifying the Arkansas phosphorus index for pastures was expedient because it was already used by the state agencies, had a well-established scientific foundation (DeLaune et al., 2004a), and represented a nationally-recognized approach to manage P (Sharpley et al., 2003). Also, the Arkansas phosphorus index for pastures was developed to represent conditions found in the Eucha/Spavinaw watershed, such as pastures receiving poultry litter applications. The Arkansas phosphorus index for pastures consists of a multiplicative matrix consisting of P source, P transport, best management practices, and precipitation components (Table 2). Data from rainfall simulation studies were used to develop weighting factors for the P source component, which includes soil test P and the amount of water soluble P applied (Table 2; DeLaune et al., 2004a). Transport factors, including soil erosion, runoff class, flooding frequency, application method, application timing, and grazing management, were determined by collaboration of several state and federal agencies. The rating scale for the Arkansas phosphorus index for pastures ranges from 0 to 1.8 and provides an estimate of annual P loss from a field in lb P ac^{-1} yr^{-1} (DeLaune et al., 2004b).

A multi-disciplinary P index team within the University of Arkansas Division of Agriculture was formed to review the Arkansas phosphorus index for pastures and suggest modifications that would result in a P index specific to the Eucha/Spavinaw watershed and the settlement agreement. The settlement agreement stated that although the new P index, as developed or with modification, may have broader application or be of interest to other watersheds or parties not involved in the Eucha/Spavinaw watershed, the P index should be developed

Table 3. The Eucha/Spavinaw phosphorus 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})
Soluble manure P rate	Continuous variable	0.4* SRP‡ applied (lb ac^{-1})
Particulate P soil erosion factor	Continuous variable	RUSLE2 value* STP/667
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
Other site characteristics		
Best management practices (BMPs)	Approved BMPs	0.9

* **Eucha/Spavinaw P index (ESPI) = P source x P transport x BMPs.**

† **Mehlich III soil test phosphorus.**

‡ **Soluble reactive phosphorus.**

particularly for the existing physical, geological, and hydrological conditions and characteristics of the Eucha/Spavinaw watershed. Because the new P index would be watershed specific, the new index was named the Eucha-Spavinaw P index.

Revisions. After reviewing possible revisions to the Arkansas phosphorus index for pastures to meet the settlement agreement, six revisions were implemented within the framework of the index. The Eucha/Spavinaw P index is multiplicative, with three terms: Eucha/Spavinaw P index = P source x P Transport x BMPs. The source term includes soil test P, soluble P application rate, and a soil erosion factor (Table 3). The transport term is comprised of soil runoff class, flooding frequency, application method, application timing, and harvest management (Table 3). The calculated Eucha/Spavinaw P index value is multiplied by 0.9 for each eligible best management practice (BMP) that adheres to the Natural Resources Conservation Service (NRCS) conservation practice standards for water quality as determined by nutrient management planners. The weighting factor of 0.9 for BMPs provides a credit for implementation, creating incentive for farmers to use BMPs. Once the final Eucha/Spavinaw P index value is calculated, fields are assigned a rating category with specific recommendations (Table 4). Once developed, Eucha/Spavinaw P index was evaluated by a panel of four scientists actively involved in P management to provide a final assessment before release.

Precipitation factor. The precipitation factor found in the Arkansas phosphorus index for pastures was deleted in the Eucha/Spavinaw P index. In the Arkansas phosphorus index for pastures, a loss rating value of one is assigned for areas receiving 1016 to 1270 mm (40 to 50 in) of annual rainfall (Table 2). The annual rainfall throughout Arkansas falls within this range, thus the precipitation factor is always one for nutrient management plans written in Arkansas. As the Eucha/Spavinaw P index is specific to Eucha/Spavinaw watershed, which receives annual rainfall within this range, there is no need for the precipitation factor.

P source weighting factors. Within the framework of a P index, each site characteristic is assigned a weighting factor based on the reasoning that particular site characteristics may be more important than others in allowing potential P movement from a site (Lemunyon and Gilbert, 1993). Weighting factors (loss rating values) for the source term in the Arkansas phosphorus index for pastures were determined by regression analysis of runoff data (DeLaune et al., 2004a). Weighting factors in the P source component of Arkansas phosphorus index for pastures were rounded from three significant digits to one significant digit in Eucha/Spavinaw P index (Tables 2 and 3). This had virtually no impact on the overall Eucha/Spavinaw P index value; however, concern had been expressed regarding the number of significant figures and confusion in the accuracy of the Arkansas phosphorus index for pastures if used to provide a quantitative prediction of annual P loss.

Runoff class. Runoff curve number along with slope percentage is used to determine the soil runoff class for a specific site (Table 5). Recently, Arkansas NRCS implemented a modification of the runoff class table used in the Arkansas phosphorus index for pastures. The University of Arkansas Division of Agriculture recommended eliminating overlapping values in the slope and runoff curve number categories. For example, slope categories were less than 1, 1 to 3, 3 to 8, 8 to 15, and greater than 15 in the initial table. Thus, a planner could select more than one category for a slope of three or eight percent. Eliminating overlapping values in the slope and runoff curve number categories reduces the confusion by end users as well as inconsistencies in input values used in the Eucha/Spavinaw P index.

Other changes within the table resulted directly from modifications made by Arkansas NRCS. First, a very low runoff class rating was eliminated from the table and replaced with a low rating. Also, a low rating was changed to a medium rating for one scenario (Runoff curve number = 81 to 85; slope = 1.1 to 3) (Table 5).

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 1.0 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 1.0 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 P index 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 P index 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 t ac^{-1}. 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 P index to a lower risk category, with long-tem goal of a P index less than 55.

Soil erosion. In the Arkansas phosphorus index for pastures, annual soil erosion is calculated using the Revised Universal Soil Loss Equation (RUSLE) and is included in the transport component. Based on annual soil loss (t ac^{-1} yr^{-1}), the erosion component is divided into five categories: less than 1, 1 to 2, 2 to 3, 3 to 5, and greater than 5 t ac^{-1} yr^{-1} with loss rating values of 0, 0.1, 0.2, 0.4, and 1, respectively (Table 2). The erosion component has little or no influence on the final P index value because typical RUSLE values for pastures are less than 1 t ac^{-1} yr^{-1} (2.24 Mg ha^{-1} yr^{-1}), which gives a loss rating factor of 0 in the Arkansas phosphorus index for pastures (Table 2). Also, the Arkansas phosphorus index for pastures P source component was developed and evaluated based on water-soluble P concentrations in runoff water (DeLaune et al., 2004a).

To account for runoff P concentrations in the particulate fraction where higher erosion rates and higher soil P levels exist, the erosion factor was moved to the P source component (Table 3). Annual soil erosion is calculated using RUSLE2 and multiplied by Mehlich III P concentration in the soil (Table 3). Adding the erosion factor to the source term will enhance the assessment of each field by better accounting for particulate P loss, and as a result, the Eucha/Spavinaw P index values will be greater for fields with higher risk of soil erosion or elevated soil P levels. For example, the erosion factor for a field with a 0 to 10 cm (0 to 4 in) Mehlich III soil P value of 112.5 mg kg^{-1} and RUSLE2 value of 0.5 t ac^{-1} yr^{-1} (1.12 Mg ha^{-1}) is 0.11 (compared to a rating of 0 in the transport component of Arkansas phosphorus index for pastures). Similarly, a field with the same annual soil erosion and Mehlich III soil P value of 225 mg kg^{-1} increases the soil erosion factor to 0.22. Hence, the Eucha/Spavinaw P index accounts for the potential increase in P losses with elevating soil P levels and erosion potential.

Table 5. Runoff class based on field slope and runoff curve number.

Slope (%)	Runoff curve number							
	<50	50-60	60-65	66-70	71-75	76-80	81-85	>85
<1	N	N	N	N	N	L	L	M
1.1-3	N	N	N	L	L	L	M	M
3.1-8	N	N	L	L	M	M	H	H
8.1-15	L	L	L	M	M	H	H	VH
>15	L	L	M	M	H	H	VH	VH

N = Negligible, L = Low, M = Moderate, H = High, VH = Very high.

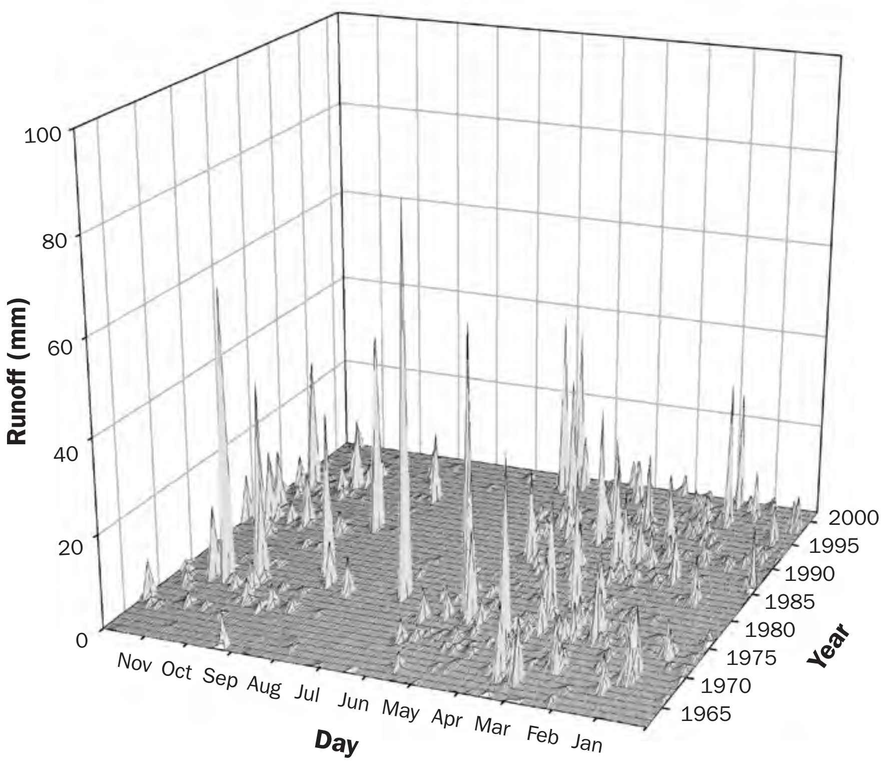
Application timing. Application timing is an important transport factor and poultry litter applications must be balanced to minimize P loss while still meeting the agronomic requirements for the growth of desired grasses and crops. The application timing factor within the transport component is included to increase the P index under scenarios where the risk of runoff from pastures is greatest. The application timing factor is divided into three time frames within Arkansas P index for pastures (Table 2). The original Arkansas P index for pastures used historical stream flow and rainfall data to determine these time frames, assuming stream flow is surrogate for runoff and that the greatest risk of runoff occurred in November through February (Table 2). However, the use of stream flow without separation of flow components may not represent the true risk of surface runoff from pastures since stream flow is generally greatest during times when evapotranspiration is low. Furthermore, historical stream flow data from the Eucha/Spavinaw watershed was not used in determining time frames in Arkansas P index for pastures.

Time frames for the application timing factor in Eucha/Spavinaw P index were determined using a hydrograph separation technique and daily mean discharge data from 1962 to 2002 from the U.S. Geological Survey stream gauge no. 07191220 at Spavinaw Creek near Sycamore, Oklahoma (http://waterdata.usgs.gov/nwis/discharge/?site_no=07191220; Figure 1). The catchment area of Spavinaw Creek at this gauging station is approximately 344 km^2 (133 mi^2). Stream flow data was separated into base flow and surface runoff components using the computer software program Base Flow Index with a turning point factor (F) of 0.5 (BFI; Wahl and Wahl, 1995; Wahl and Tortorelli, 1997).

Runoff values calculated from 41 years of measured data in the watershed showed temporal variability at both daily and monthly scales (Figure 2, Table 6) indicating a need to adjust the application timing factor in the Eucha/Spavinaw P index. The average annual runoff for the watershed was 11.9 cm (4.7 in). After the months were sorted in order of increasing discharge, it was found that the year could be divided into three distinctive timeframes. These timeframes are: (1) July through October (runoff volume less than 0.5 cm; 0.2 in); (2) November through February (runoff volume varied from 0.7 to 1.2 cm; 0.3 to 0.5); and (3) March through

Figure 2

The average amount of surface runoff estimated within the Eucha/Spavinaw watershed using historical stream flow (1962 to 2002).



June (runoff volume varied from 1.2 to 1.7 cm; 0.5 to 0.7). For simplicity, we gave the application timing factor a value of 1 for the entire year and, based on the distribution of cumulative runoff during each timeframe, new weighting factors were determined.

Table 6. Months arranged in increasing order of average monthly runoff amount for Spavinaw Creek near Sycamore, Oklahoma, U.S. Geological Survey gauge station based on 41 years of data (1962 to 2002).

Month	Runoff (cm)
August	0.1
July	0.5
October	0.5
September	0.5
January	0.7
February	1.1
May	1.2
December	1.2
November	1.2
June	1.6
April	1.6
March	1.7
Total	**11.9**

The weighting factors based on runoff hydrology alone are 0.1 for July through October, 0.4 for November through February, and 0.5 March through June (Table 7).

Once risk intervals were determined, they were reviewed and discussed with forage specialists with respect to meeting the agronomic crop needs and the potential for P uptake. The July-Oct interval is a low runoff risk period. Cool season crop needs, particularly Tall fescue, would benefit from litter applications between September and October. However, application rates should not exceed 4.5 Mg ha^{-1} (2 t ac^{-1}) during this period due to the potential for fescue toxicosis. No forage benefit would occur from a fall application of litter to bermudagrass since it is entering the dormant stage. Therefore, fall applications of litter to bermudagrass are not recommended. So the loss rating value for the risk interval of July through October remained 0.1 (Tables 3 and 7).

Both bermudagrass (warm season) and fescue (cool season) forages need and benefit from spring applications of nutrients, with April-June representing a time of maximum nutrient uptake and plant growth. As there is little plant growth and nutrient uptake during winter months, litter applications during this time were perceived to enhance the risk of P loss. Therefore, the monthly runoff hydrology values were partitioned into new intervals that consider runoff as well as meeting the agronomic needs of the crop (Table 7). Basically, this means the month of March is included during the winter period and the ideal time for litter application from a production standpoint is compressed into the interval between April-June. The loss rating value becomes 0.5 for the winter interval (Nov-March) and 0.4 for the spring interval (April-June) (Tables 3 and 7).

Rating scale. A P index rating scale provides guidance in determining a sites vulnerability to P loss and subsequent management options. As the Arkansas P index for pastures rating scale provides an estimate of annual P loss, there had been confusion in the region regarding the breakpoints selected in the rat-

Table 7. Relative risk of application timing as a function of hydrology and meeting the agronomic requirement for crop growth.

Eucha/Spavinaw phosphorus (P) index				
Based on runoff alone		Based on plant growth, P uptake potential, and runoff		
Application timing	Loss rating value	Application timing	P uptake and growth	Loss rating value
July - Oct	0.1	July - Aug Sept - Oct	Very low Ideal for cool season grasses	0.1
Nov - Feb	0.4	Nov - March	Low for cool and warm season grasses	0.5
March - June	0.5	April - June	Ideal for cool season and warm season grasses	0.4

ing scale and the interpretation of the Arkansas P index for pastures as a quantitative or qualitative index. DeLaune et al. (2004b) found annual P loads from two small pastures over six-year periods to be highly correlated to the Arkansas P index for pastures values ($r^2 = 0.83$). In the Blackland Prairie of Texas, Harmel et al. (2005) found the Arkansas P index for pastures to be poorly correlated to annual P loads, but highly correlated to annual average soluble P concentrations from four pastures (1.2 to 7.9 ha; 3 to 20 ac, $r^2 = 0.84$). A review through literature encompassing various pasture conditions found estimates of annual P loss in the Arkansas P index for pastures rating scale (0.0 to >1.8) to be reasonably consistent with scientific literature values (Table 6).

The current Arkansas P index for pastures allows litter applications at rates to meet nitrogen needs of the crop while in the low (less than 0. 6) or medium risk category (0.6 to less than 1.2). However, once the index is in the high category (1.2 to less than 1.8), application rates are based on crop P needs (DeLaune et al., 2004b). Because application rates based upon P requirements are generally less than 2.24 Mg ha^{-1} (less than 1.0 t ac^{-1}), no litter is typically applied due to current spreading technology [i.e. difficulty in calibrating litter application rates less than 3.36 Mg ha^{-1} (less than 1.5 t ac^{-1})]. Hence, the medium category essentially becomes a cutoff level for applying P. The settlement agreement states that a new P risk-based index shall be developed to achieve the least amount of P loading reasonably attainable from the application site while still meeting the agronomic requirements for the growth of grasses, crops and other desirable plant life. Although it was not known how this related to the Arkansas P index for pastures rating scale, we did know that a more restrictive P index than Arkansas P index for pastures was desired by the Court. To be more restrictive (least amount of P loading) while still meeting the agronomic requirements, the medium category was adjusted downward (1.2 to 1.0) to encompass a greater number of field conditions within the high category. The Eucha/Spavinaw P index rating scale was also normalized to a scale ranging from 0 to 100 [(Initial Eucha/Spavinaw P index value/1.8) x 100 = Final Eucha/Spavinaw P index value)](Table 4).

One reason for the normalizing scale, was to clarify the intent of the Eucha/Spavinaw P index as a risk-based assessment tool to write and develop nutrient management plans. This specific P index is not a predictive model and with the current values so closely correlated to actual P loading in the literature, a strong tendency exists to think and use the index in that matter. The validity of the P index approach to assess the potential risk for P loss has been shown in several regions of the United States (Sharpley, 1995; Jokela et al., 1997; Bolinder et al., 1998; McFarland et al., 1998; Coale et al., 2002). There is a great deal of research that validate transport and source factors included in various P indices; however, there is little research comparing P index ratings to actual measured P loss (Sharpley et al., 2001; Eghball and Gilley, 2002; DeLaune et al., 2004b; Harmel et al., 2005). While there is a recognized confidence that P indices can accurately sort fields into appropriate risk categories and that index ratings are strongly related to P losses, more large scale site specific research is warranted. Hence, index values from 0 to greater than 100 in the Eucha/Spavinaw P index are unitless, (Table 2) and follow an initiative by other indices in Northeastern and Mid-Atlantic regions to ensure that indices are consistent across state boundaries (Sharpley et al., 2003).

Other changes. Recommendations were also made to the Court that all manure planned for land application must be sampled and analyzed for water soluble P and that actual analyzed P values be used in the calculation of the Eucha/Spavinaw P index. In contrast, a default soluble P value is used for all manure types and management scenarios in the calculation of Arkansas P index for pastures (500 mg kg^{-1}; 1 lb t^{-1}).

Court order. The University of Arkansas Division of Agriculture submitted a report to the court January 5, 2004 detailing the development and framework of the Eucha/Spavinaw P index. To assist the court in determining an appropriate P index, an evidentiary hearing was held on February 9, 2004. In lieu of selecting a final P index for the Eucha/Spavinaw watershed, the Court established a trial implementation period, lasting until Dec 31, 2004. As a result of the evidentiary hearing, the Court issued an Order on February 13, 2004 stating that the Eucha/Spavinaw P index would be implemented during the trial period to develop nutrient management plans within the Eucha/Spavinaw watershed for the year 2004.

Although the Eucha/Spavinaw P index was selected, the Court did not believe that the index fully accounted for total P loading, and did not represent, "the least amount of total P loading reasonably attainable…from all sources of P." As a result, the Court outlined modifications to Eucha/Spavinaw P index in the Court Order including: 1) that nutrients not be applied to any site having a Mehlich III soil test P level of 300 mg kg^{-1} or greater; 2) soil samples would be collected at a 0 to 10 cm (0 to 4 in) depth; and 3) that the total amount of litter applied annually not exceed two-thirds of the amount of litter produced annually within the Eucha/Spavinaw watershed by the poultry defendants and their contract growers (Table 6).

The Court also mandated that litter samples be analyzed for water soluble P according to Self-Davis and Moore (2000). The Special Master was assigned to maintain a cumulative record of the amounts of litter recommended to be applied within the watershed as nutrient management plans were written. The Court also stated its intent to implement a joint quantitative P index by January 2005. If no joint quantitative P index could be developed by January, then the Court would determine an appropriate P index based upon the 2004 trial period.

Nutrient management planning: Watershed management team. Nutrient management plans were completed by the four-member watershed management team supervised by the court appointed Special Master. The watershed management team began writing nutrient management plans in February 2004. As required, each member made field site visits to note landscape characteristics, management practices, and collect soil and manure samples.

By court mandate, soil samples were collected at a depth of 0 to 10 cm (0 to 4 in). Manure samples were collected from broiler and pullet houses, turkey houses, laying hen houses, and stacking sheds. All samples, soil and manure, were sent to A&L Analytical Laboratories in Memphis, Tennessee. The lab analyzed soil samples for Mehlich III P using a 10:1 extraction: soil ratio (Mehlich, 1984). Manure samples were analyzed for water-soluble P by extracting 20 grams of fresh litter with 200 mL of double deionized water (Self-Davis and Moore, 2000). Phosphorus concentrations for all samples were determined using inductively coupled plasma spectrometry (ICP). Once the results were returned to the watershed management team, nutrient management plans were written for each of the visited fields.

Impact of nutrient management plans. The watershed management team began writing nutrient management plans soon after the Court Order was issued. The Special Master provided a progress report for findings within the watershed through July 2004 as well as a draft final report to the Court for findings through 2004. Each reported that the average spreading rate recommended through nutrient management plans was similarly on the order of approximately one-third the rates that were commonly reported to have been land applied prior to the implementation of the Eucha/Spavinaw P index. Furthermore, the Special Master reported that the amount of poultry litter authorized to be spread represented one-third or less of the amount of litter understood to be typically produced in the watershed per year. The Special Master, as well as the P index Team, concluded that overall implementation of Eucha/Spavinaw P index and the Court's Order substantially reduced the amount of litter being land applied.

The Eucha/Spavinaw watershed management team provided a final spreadsheet summarizing all nutrient management plans written during 2004 (Table 1). Nutrient management plans were written for 970 fields totaling approximately 8,024 ha (19,812 ac). The mean recommended litter application rate for the 970 fields was 3.14 Mg ha^{-1} (1.4 t ac^{-1}). This mean includes a recommended application rate of zero for 79 fields that had Mehlich III soil test P concentrations greater than 300 mg P kg^{-1}. The total amount of litter recommended for litter application was 25,457 Mg (28,062 t) on 7,604 ha (18,775 ac). Reports have indicated that approximately 82,187 Mg (90,000 t) of litter is produced within the Eucha/Spavinaw watershed annually (personal communication, Sheri Heron, BMPs Inc.). Based upon this assumption, approximately 31 percent of the total litter produced in the watershed was recommended for land application. Hence, the goal set forth by the Court that the total amount of litter applied annually not exceed two-thirds of the amount of litter produced annually was easily achieved. Excess litter is reportedly being shipped out of the watershed, remaining in storage (stacking sheds or poultry houses—no cleanout), or shipped to a local pelleting/granulating plant. It should be noted that all calculations are an estimate of what actually occurred within the watershed because the actual amount of litter land applied within the watershed is not well documented. Reports from the Eucha/Spavinaw watershed management team indicated that several growers receiving nutrient management plans did not apply any litter due to timing of the nutrient management planning (i.e. receiving plan after preferred time of application), or the fact that such low application rates were recommended. Therefore, it is justifiable to conclude that the actual amount of litter applied to the fields with nutrient management plans within the watershed was less than the amount recommended. The Special Master has indicated that the watershed management team will make onsite visits to all growers in the Eucha/Spavinaw watershed by the end of 2005 to document and quantify the amount of litter sold, spread, or shipped.

A more restrictive rating scale, a greater weighting factor for spring applications, and the new erosion factor within the source term are all reasons for lower application rates. However, requiring the analysis of water soluble P for all litter planned for land application may have been the most influential factor determining the Eucha/Spavinaw P index values. Rather than using a default value of 500 mg kg^{-1} for soluble P content in litter, actual measured values were input into the Eucha/Spavinaw P index. The overall mean soluble P concentration in 353 analyzed manure samples was 1219 mg P kg^{-1},(2.4 lb t^{-1}; ranging from 158 to 3988 mg kg^{-1}, 0.32 to 8.0 lb t^{-1}) (Unpublished data, Eucha/Spavinaw watershed Management Team). This far exceeded the default value used in the Arkansas P index for pastures at this time of 500 mg kg^{-1} (1 lb t^{-1}). Using the assumption that Mehlich III soil P values were the same for depths of 10 and 15 cm (4 and 6 in), Arkansas P index for pastures was calculated for each of the fields using data from the watershed management team. This assumption has a very minor impact on the overall Arkansas P index for pastures calculation. Calculations were also conducted to give an Arkansas P index for pastures value of 1.19, which is the highest rating value allowed for litter application. Using the default water soluble P value of 500 mg kg^{-1} (1 lb t^{-1}) in Arkansas P index for pastures resulted in an average recommended application rate of 7.84 Mg ha^{-1} (3.5 t ac^{-1}) (Table 1). The recommended Arkansas P index for pastures application rate decreased to 5.15 Mg

Table 8. Total phosphorus loss from grazed and pastured watersheds.

Reference	Total P export (kg ha^{-1} yr^{-1})	Location	Comments
Beaulac and Reckow, 1982	0.14 to 4.90	GA, IA, MD, NC, OH, OK, SD	Grazed and pastured watersheds, fertilized and unfertilized
DeLaune et al., 2004a	0.28 to 2.8	AR	Idle pasture with fertilization
Gillingham and Thorrold, 2000	0.11 to 1.67	New Zealand	Sheep and/or cattle grazed pastures
Pickup et al., 2003	0.22 to 1.34	AR,OK	Model predictions based on stream sampling
Smith et al., 1992	0.02 to 4.39	OK	Idle to heavy grazing, gullied/poor to excellent condition

Table 9. Requirements for nutrient management planning within the Eucha/Spavinaw watershed as set forth by the February 13, 2004 court order.

Court order requirements
- Trial implementation period until December 31, 2004.
- Nutrient management plans written based upon the Eucha/Spavinaw P index.
- No application to sites having Mehlich-III P values greater than 300 mg/kg.
- Soil samples for Mehlich-III P analysis collected from a 0 to 10 cm depth (0 to 4 in).
- All litter planned for land application analyzed for soluble P.
- Total amount of litter applied annually not to exceed 2/3 of total litter produced annually within the watershed.

ha^{-1} (2.3 t ac^{-1}) when measured water soluble P concentrations in litter were used (Table 1). Litter application rates recommended by the Eucha/Spavinaw P index were 39 percent lower than Arkansas P index for pastures recommended rates using measured water soluble P in litter and 60 percent lower than Arkansas P index for pastures recommended rates using the default value. Clearly, the Eucha/Spavinaw P index proved to be more restrictive than previously used management strategies throughout the Eucha/Spavinaw watershed.

Although the Court's intent, no joint quantitative P index had been developed for implementation by the end of 2004. Therefore, the Eucha/Spavinaw P index was recommended to, and agreed upon by, the Court for continued use through 2005. Slight modifications have been made to the Eucha/Spavinaw P index since initial implementation; however, these modifications do not affect the calculation of the Eucha/Spavinaw P index but rather changes have been made to the software in order to make P index more user friendly to planners. As requested by the Court, a list of remedial actions that could reasonably be implemented to lower the Eucha/Spavinaw P index value in the future is now provided within the P index program when P index values approach the threshold of a risk category (i.e. Eucha/Spavinaw P index = 50 to 55, approaching high risk category). Furthermore, modifications have been made to the Eucha/Spavinaw P index program which will allow no poultry litter applications greater than 4.48 Mg ha^{-1} (2 t ac^{-1}) to cool season grasses or any fall applications and no greater than 6.72 Mg ha^{-1} (3 t ac^{-1}) to warm season grasses. As of the fall of 2005, the watershed management team has reported similar recommended litter rates as 2004.

Summary and Conclusion

In response to court-imposed demands, the Eucha/Spavinaw P index was developed in less than six months for the watershed. There were no specific guidelines for the development of the new P index, only that the P index should achieve the least amount of total P loading while meeting the agronomic requirements for plant life and reduce the risk of harm to the water supply while recognizing the importance of a viable poultry industry. The new P index was developed by modifying Arkansas phosphorus index for pastures, which was already in use in Arkansas at the time of the court settlement and represented many of the conditions found in the Eucha/Spavinaw watershed. Modifications made to Arkansas P index for pastures to better reflect specific physiographic conditions of the Eucha/Spavinaw watershed and meet court mandates included: deleting the precipitation factor, rounding weighting factors in the source component, adding a new soil erosion factor to the source component, implementing a new runoff class table, developing new time frames within the application timing factor, and revising the rating scale. Recommendations were also made to the Court that all manure planned for land application be sampled and analyzed for water soluble P and that actual analyzed P values be used in the calculation of the Eucha/Spavinaw P index.

After an evidentiary hearing, the Court issued an Order stating that the Eucha/Spavinaw P index would be used to write nutrient management plans during a trial implementation period extending through 2004. However, the Court did not believe that the Eucha/Spavinaw P index represented "the least amount of total P loading reasonably attainable…from all sources of P." Therefore, the Court imposed further modifications to the Eucha/Spavinaw P index including that nutrients not be applied to any site having a Mehlich III soil test P level of 300 mg kg^{-1} or greater, soil samples be collected at a 0 to 10 cm (0 to 4 in) depth, and that the total amount of litter applied annually not exceed two-thirds of the amount of litter produced annually within the Eucha/Spavinaw watershed by the poultry defendants and their contract growers.

Reports from the trial implementation period showed that approximately 31 percent of the total litter produced within the Eucha/Spavinaw watershed was recommended for land application. Excess litter is currently being shipped out of the watershed, although well documented data are lacking. Litter application rates recommended by the Eucha/Spavinaw P index were as much as 60 percent lower than application rates that would be recommended with Arkansas P index for pastures as currently used.

The lack of edge-of-field data validating P indices, such as the Eucha/Spavinaw P index, and their capability of accurately assessing the loss of P from individual fields is an important issue. Foundational nutrient management plans must be as science based as possible and extend as far as possible, if not, respective parties within a court setting will mandate how nutrient management plans are written. There will be an increasing role of environmental considerations in developing nutrient management plans. Interdisciplinary input is necessary for developing and defending P indices and nutrient management plans. Scientists are advised to interact and seek advice from impartial lawyers prior to court appearances.

References Cited

Beaulac, M.N. and K.H. Reckhow. 1982. An examination of land use: Nutrient export relationships. Water Resources Bulletin 18:1013-1024.

Bolinder, M.A., R.R. Simard, S. Beauchemin, and K.B. MacDonald. 1998. Indicator of risk of water contamination: Methodology for the phosphorus component. Pp. 11-21. *In:* Agri-environmental Indicators Project Report No. 24. Agriculture and Agri-food Canada, Ottawa, Ontario.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications 8:559-568.

Coale, F.J., J.T. Sims, and A.B. Leytem. 2002. Accelerated deployment of an agricultural nutrient management tool: The Maryland phosphorus site index. Journal of Environmental Quality 31:1471-1476.

DeLaune, P.B., P.A. Moore, Jr., D.K. Carman, A.N. Sharpley, B.E. Haggard, and T.C. Daniel. 2004a. Development of a phosphorus index for pastures fertilized with poultry litter: Factors affecting phosphorus runoff. Journal of Environmental Quality 33:2183-2191.

DeLaune, P.B., P.A. Moore, Jr., D.K. Carman, A.N. Sharpley, B.E. Haggard, and T.C. Daniel. 2004b. Evaluation of the phosphorus source component in the phosphorus index for pastures. Journal of Environmental Quality 33:2192-2200.

Eghball, B. and J.E. Gilley. 2002. Phosphorus risk assessment index evaluation using runoff measurements. Journal of Soil and Water Conservation 56(2):202-206.

Gburek, W.J., A.N. Sharpley, L. Heathwaite, and G.J. Folmar. 2000. Phosphorus management at the watershed scale: A modification of the phosphorus index. Journal of Environmental Quality 29:130-144.

Gillingham, A.G. and B.S. Thorrold. 2000. A review of New Zealand research measuring phosphorus in runoff from pastures. Journal of Environmental Quality 29:88-96.

Haggard, B.E., P.A. Moore, Jr., I. Chaubey, and E.H. Stanley. 2003. Nitrogen and phosphorus concentrations and export from an Ozark plateau catchment in the United States. Biosystems Engineering 86(1):75-85.

Harmel, R.D., H.A. Torbert, P.B. DeLaune, B.E. Haggard, and R.L. Haney. 2005. Field evaluation of three phosphorus indices on new application sites in Texas. Journal of Soil and Water Conservation 60(1):29-42.

Jokela, W.E., F.R. Magdoff, and R.P Durieux. 1997. Soil testing for improved phosphorus management. Vermont cooperative Extension Service, Publications Distribution Center, Burlington, Vermont.

Lemunyon, J.L. and R.G. Gilbert. 1993. The concept and need for a phosphorus assessment tool. Journal of Production Agriculture 6:483-486.

McFarland, A., L. Hauck, J. White, W.Donham, J. Lemunyon, and S. Jones. 1998. Nutrient management using a phosphorus risk index for manure application fields. Pp. 241-244. Proceedings of Manure Management in Harmony with the Environment and Society. Soil and Water Conservation Society, Ankeny, Iowa.

Mehlich, A. 1984. Mehlich 3 soil test extractant: A modification of Mehlich 2 extractant. Communications in Soil Science and Plant Analysis 15:1409-1416.

Pickup, B.E., W.J. Andrews, B.E. Haggard, and W.R. Green. 2003. Phosphorus concentrations, loads, and yields in the Illinois River Basin, Arkansas, and Oklahoma, 1997-2001. U.S. Geological Survey Water-Resources Investigations Report No. 03-4168.

Self-Davis, M.L. and P.A. Moore, Jr. 2000. Determining water-soluble phosphorus in animal manure. Pp. 74-76. *In:* Methods of Phosphorus Analysis for Soils, Sediments, Residuals, and Waters. G.M. Pierzynski (ed.) Southern Cooperative Series Bulletin No. 396. (http://www.soil.ncsu.edu/sera17/publications/sera17-2/pm_cover.htm).

Sharpley, A.N. 1995. Identifying sites vulnerable to phosphorus loss in agricultural runoff. Journal of Environmental Quality 24:947-951.

Sharpley, A.N. 2000. (ed.) Agriculture and Phosphorus Management: The Chesapeake Bay. CRC Press, Boca Raton, Florida.

Sharpley, A.N., R.W. McDowell, J.L. Weld, and P.J.A. Kleinman. 2001. Assessing site vulnerability to phosphorus loss in an agricultural watershed. Journal of Environmental Quality 30:2026-2036.

Sharpley, A.N., J.L. Weld, D.B. Beegle, P.J.A. Kleinman, W.J. Gburek, P.A. Moore, Jr., and G. Mullins. 2003. Development of phosphorus indices for nutrient management planning strategies in the United States. Journal of Soil and Water Conservation 58(2):137-152.

Smith, S.J., A.N. Sharpley, W.A. Berg, J.W. Naney, and G.A. Coleman. 1992. Water quality characteristics associated with southern plains grasslands. Journal of Environmental Quality 21:595-601.

U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS). 2004. Oklahoma phosphorus assessment worksheet. USDA-NRCS practice standard: Nutrient management code 590. Stillwater, Oklahoma.

U.S. Department of Agriculture (USDA) and U.S. Environmental Protection Agency (USEPA). 1999. Unified national strategy for Animal Feeding Operations. March 9, 1999. (http://www.epa.gov/o20wm/finafost.htm).

U.S. Environmental Protection Agency (USEPA). 2000. 2000 National Water Quality Inventory. EPA Homepage. (www.epa.gov/305b/2000report)

U.S. Geological Survey (USGS). 1999. The quality of our nation's waters: Nutrients and pesticides. U.S. Geological Survey Circular No. 1225. 82 pp. USGS, Information Services, Denver, Colorado.

Wahl, K.L. and R.L. Tortorelli. 1997. Changes in flow in the Beaver-North Canadian river basin upstream from Canton Lake, western Oklahoma. U.S. Geological Survey Water Resources Investigative Report No. 96-4304.

Wahl, K.L. and T.L. Wahl. 1995. Determining the flow of Comal Springs at New Braunfels, Texas: Texas Water '95, American Society of Civil Engineers, San Antonio, Texas, August 6-17, 1995: 77-86