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SW—Soil and Water

Nitrogen and Phosphorus Concentrations and Export from an Ozark Plateau Catchment in the United States

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In 1993–1995, the Beaver Lake Basin contained about 2000 poultry houses producing about 200 000 Mg yr^{-1} of poultry litter, and 8000 and 4000 Mg yr^{-1} of nitrogen (N) and phosphorus (P), respectively. Most of the poultry litter was land applied as a fertiliser to meet forage N requirements, making it susceptible to transport from the landscape during episodic precipitation events. Nitrogen and P concentrations were measured in four sub-watersheds of Beaver Lake, a reservoir on the White River in Arkansas, USA, to assess possible relationships between pasture land use and stream nutrient concentrations and export. Surface water samples were collected 17 times annually for 2 years from ten total stream sites within the four watersheds. Samples were analysed for soluble reactive P (SRP), total P (TP), ammonium-N (NH_4-N), nitrate-N (NO_3-N), total Kjeldhal N (TKN) and total N (TN). Discharge was measured at four gauged stream stations, and nutrient export was calculated using the US Geological Survey ESTIMATOR software and non-biased re-transformation from log space. Stream SRP, NO_3-N and TN concentrations (geometric-mean) increased linearly with per cent of pasture in watersheds, whereas N and P export coefficients increased exponentially with pasture land use. Nutrient export (kg yr^{-1}) increased with basin size, but nutrient yield (kg km^{-2} yr^{-1}) decreased with basin size. Nutrient yield was from three times to over 10 times greater than nutrient yields observed in regional undeveloped streams and the average of the Hydrologic Benchmark Network of the US Geological Survey. It is apparent that pasturelands in this basin affect stream nutrient concentrations and export to Beaver Lake and its tributaries. This investigation emphasises the need to carefully manage poultry litter because small losses of nutrients compared to the total amount of nutrients produced in a basin may still impact stream nutrient concentrations and export.

Introduction

The growing influence of non-point source impacts on the nation's water quality gained substantial public prominence with the release of US Environmental Protection Agency's 1996 water quality report to Congress, and the 1998 report chronicles similar impairments. Nitrogen (N) and phosphorus (P) loading to rivers and streams often limits the aesthetic value of affected water bodies and the goods and services these ecosystems provide (National Research Council, 1992; Carpenter *et al.*, 1998). Non-point sources may be responsible for $>90\%$ of the P load of about one-third of US rivers and streams (Newman, 1996). Drivers of non-point source (NPS) pollution vary regionally, reflecting a combination of land uses, climate, and edaphic conditions; however, it is clear that agricultural land use is a major contributor to NPS contamination of surface and groundwater (Carpenter *et al.*, 1998).

The issue of NPS nutrient loading has come into sharp focus in the state of Arkansas in the last 10 years due to the rapid growth of the poultry industry. Arkansas has ranked first in the United States in poultry production during the early 1990s, with the production of over one billion broilers each year (Arkansas Agricultural Statistics Service, 1995). This industry creates a substantial amount of waste along with commercial products; each individual broiler produces approximately 1 kg of poultry litter, including manure and bedding, and poultry litter is typically applied as a fertiliser on pastures. In the past, poultry manure has been applied to fields based on N demand of crops, and only recently has animal waste been applied on a P basis. The environmental consequences of N based applications included high loads of P, heavy metals and organic compounds in runoff and eventually in the receiving fresh water ecosystems. From 2·2 to 7·3% of total P (TP) in poultry litter applied to pasture surfaces can be lost in runoff, 80% of which is in the dissolved reactive (*i.e.* biologically available) form (Edwards & Daniel, 1993).

Within the Ozark Plateaus, livestock and poultry waste is recognised as a major source of nutrient loading (Davis & Bell, 1998). Further, annual fertiliser use in the White River basin has increased by 77% for P and by 200% for N between 1965 and 1985 (Alexander & Smith, 1990). Petersen (1992) reported trends of increasing N and P concentrations in streams of northwest Arkansas between 1981 and 1989, often associated with human activity and/or poultry farming. Concern for the potential for NPS loading and eutrophication of regional streams, rivers, and reservoirs has subsequently increased in the past 5 years as well. The objectives of this study were to: (1) determine the relationship between land use and stream N and P concentrations in the watershed; (2) estimate nutrient export from the four catchments; and (3) investigate the relationship between nutrient export and land use in the catchments.

2. Materials and methods

2.1. *Site description*

Beaver Lake was constructed in 1963 and is the first of a series of reservoirs on the White River in the Ozark Plateau of northwestern Arkansas. In addition to the White River, Richland Creek, Brush Creek, War Eagle Creek and several smaller streams supply water to the impoundment (*Fig. 1*). Watershed geology consists of limestone, dolomite, sandstone, shale and chert. The Boone and St Joe Formations contain the major regional aquifer. As water moves rapidly without much natural filtering in these formations, the aquifer is highly susceptible to groundwater nitrate contamination by non-point sources such as septic tanks, poultry houses, fertiliser, and landfills. Land cover is a mixture of urban and suburban developments, hardwood forests and agricultural lands. In 1992, the basin contained over 2000 confined animal operations in an area of about 300 000 ha. *Figure 1* shows the location of the study watershed within Arkansas, drainage network and sub-basins, water-quality monitoring sites, and distribution of land use within the watershed.

Ten locations on Beaver Lake tributaries were chosen as sampling sites (Table 1, *Fig. 1*). For most sampling points, sites were situated at the base of the drainage but also sufficiently upstream of the reservoir so that discharge was not affected by impoundment. Sites included (from east to west): two sampling points in the War Eagle Creek basin (sites 1 and 2); one in the Brush Creek basin (site 3); four sites in the Richland Creek drainage (sites 4–7); one site each at the base of the East Fork (site 8); and West Fork (site 9) of the White River. Site 10 was at the head of the Beaver Lake Reservoir on the White River.

2.2. *Field and laboratory procedures*

All sites were sampled approximately 17 times annually for 2 years from August 1993 to June 1995. Samples for year 1 were collected from August 1993 through July 1994 and samples for year 2 from August 1994 through June 1995. Water samples were collected immediately below the water surface with a horizontal style Alpha sampler from bridge crossings or by grab samples from the stream bank. Approximately 500 m*l* of stream water were collected at each site. A 25 m*l* aliquot was immediately filtered through a 0·45 μm membrane filter and acidified to pH 2 with 6 N HCl. The remaining volume of sample was stored on ice and in the dark for later analysis.

Total Keldjhal N (TKN) and TP digestions were performed on acidified, unfiltered subsamples using H_2SO_4 with K_2SO_4 and HgO as catalysts (EPA, 1983). Total P was determined colorimetrically on digests by the automated split reagent ascorbic acid method (EPA, 1983). The automated salicylate-nitroprusside method (Technicon, 1976) was used to measure TKN. Ammonium-N (NH_4-N) and nitrate-N (NO_2-N $+ NO_3$-N, hereafter referred to as NO_3-N) concentrations were measured on acidified, filtered samples utilising a modified microscale determination method (Sims *et al.*, 1995). Total N (TN) is simply the sum of TKN and NO_3-N. The automated ascorbic acid reduction method (APHA, 1992) was used to determine soluble reactive P (SRP) on the acidified, filtered samples.

2.3. *Data analysis*

Watershed boundaries were delineated using ArcView and 1:24 000 digital elevation model (DEM) data

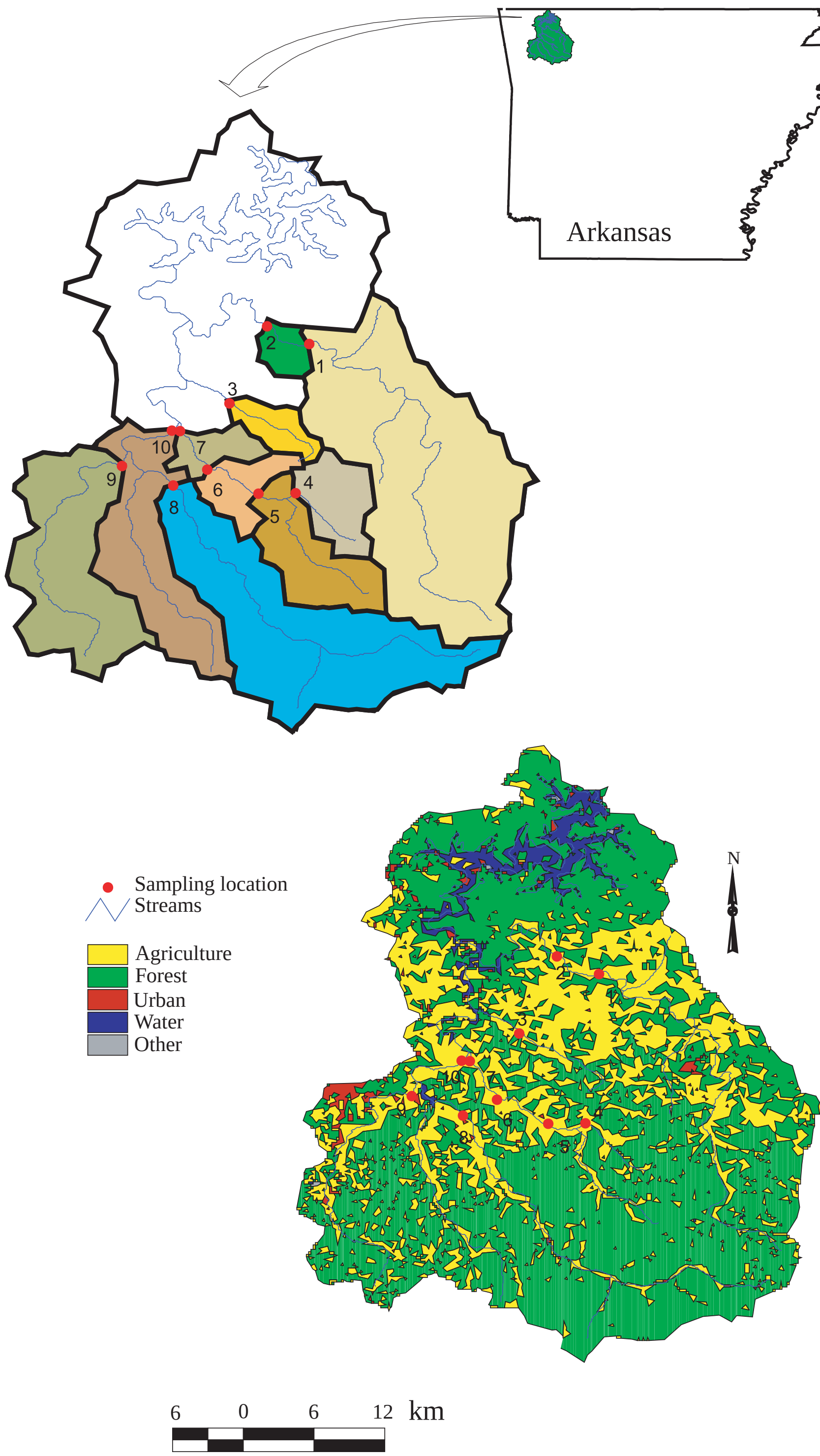

Fig. 1. Location of the Beaver Lake Basin, sampling sites, sub-basins, and the portion of land use categories within the watershed (watershed numbers correspond to numbers in Table 1)

obtained from the US Geological Survey. Water-quality sampling locations were used as the outlets for each sub-basin. Per cent land use for each category and sub-basin was determined using 1992 digital land use – land cover data and ArcView. Simple linear regression was used to assess the effect of land use on water quality by regressing geometric mean nutrient concentrations against the per cent pasture (arcsin transformed; Zar,

Table 1
List of tributary sampling stations within the Beaver Lake Basin, their respective latitude and longitude, sub-basin area, and per cent pasture and forest cover within each sub-basin

Site	*Stream station*	*Sub-basin*	*Latitude*	*Longitude*	*Area, ha*	*Pasture, %*	*Forest, %*
1	Upper War Eagle Creek	War Eagle	36°12′02·4″N	93°50′15·4″W	67 439	37	60
2	Lower War Eagle Creek	War Eagle	36°13′38·6″N	93°54′05·8″W	72 462	38	59
3	Brush Creek	Brush	36°07′57·1″N	93°56′53·6″W	5160	55	42
4	Drake's Creek	Richland	36°01′17·1″N	93°51′36·3″W	4220	31	67
5	Upper Richland Creek	Richland	36°01′09·8″N	93°54′32·3″W	23 985	29	69
6	Middle Richland Creek	Richland	36°02′52·7″N	93°58″30·1″W	30 728	34	64
7	Lower Richland Creek	Richland	36°06′15·3″N	94°00′26·6″W	36 202	37	60
8	West Fork White River	White	36°03′15·1″N	94°04′58·1″W	31 875	31	61
9	East Fork White River	White	36°01′44·0″N	94°01′05·6″W	49 070	16	82
10	White River	White	36°06′21·8″N	94°00′40·8″W	106 408	25	71

1984) in each sub-basin, and the level of significance was set at 0·05. Multiple regression analysis was not used because pasture and forested land uses were strongly related (coefficient of determination, $R^2 = 0{\cdot}98$), and urban land use was 2–4% in all sub-basins except one. Site 10 was excluded from this analysis because upstream point source contributions would interfere with the relationship between land use and nutrient concentrations.

Flow data for War Eagle Creek, Brush Creek, Richland Creek, and White River were obtained from United States Geological Survey stream gauge data, as modified by EGIS (1996). Streamflow was separated into seasonal base flow and storm runoff using a deterministic procedure proposed by the British Institute for Hydrology (1980); the Base Flow Index computer software was developed by Wahl and Wahl (1995) to provide an automated technique for base flow separation. Storm samples were defined as those collected when base flow was less than 70% of total streamflow. Nutrient export coefficients were estimated by log-linear regression of load L and concentration C, discharge Q, time T and seasonal factors (Cohn *et al.*, 1989) using the US Geological Survey ESTIMATOR software program in a concentrations model:

$$\ln(C) = \beta_1 + \beta_2 \ln(Q) + \beta_3 T + \beta_4 \sin(2\pi T) + \beta_5 \cos(2\pi T) \quad (1)$$

and in a load model:

$$\ln(L) = \beta_1 + \beta_2 \ln(Q) + \beta_3 T + \beta_4 \sin(2\pi T) + \beta_5 \cos(2\pi T) \quad (2)$$

where: L is load in kg d^{-1}; C is concentration in mg l^{-1}; T is time in Julian days; and Q is mean daily discharge in m^3 s^{-1}. Simple retransformation from log values was not employed, because this estimator may be biased, and under normal circumstances can underestimate export (Ferguson, 1986); therefore, the ESTIMATOR program implements a minimum variance unbiased estimator (MVUE) described in Cohn *et al.* (1989). Daily loads were estimated and then summed to produce annual loads, and relations between nutrient load, yield and basin characteristics were also evaluated.

The sampling strategy used to estimate nutrient loads in streams also plays a role in the accuracy and precision of the estimates. Robertson and Roerish (1999) suggested that semi-monthly sampling for 2-year studies resulted in not only the least biased but also the most precise estimates when using regression techniques. Furthermore, Green and Haggard (2001) demonstrated that 35 samples collected over a 3-year period provided the information required to accurately estimate nutrient loads via the regression method for high frequency sampling and integration. The streams draining the Beaver Lake Basin were sampled 17 times annually, less than semi-monthly, but greater than or equal to 25% of the samples were collected during storm events. The sampling strategy used for this project adequately represents the range of flow and concentration conditions required producing good estimates of nutrient loads.

3. Results

3.1. *Discharge*

Low flows and few surface runoff events characterised discharge at all sites during summer and autumn (June–October), particularly during 1994, and higher seasonal base flows and more frequent floods characterised discharge during winter and spring (*Fig. 2*). Base flow and numbers and sizes of floods were greater in year 2 at all four gauged sites. Summer base flows were not proportional to basin size, and ranged from 0·2 m^3 s^{-1} at

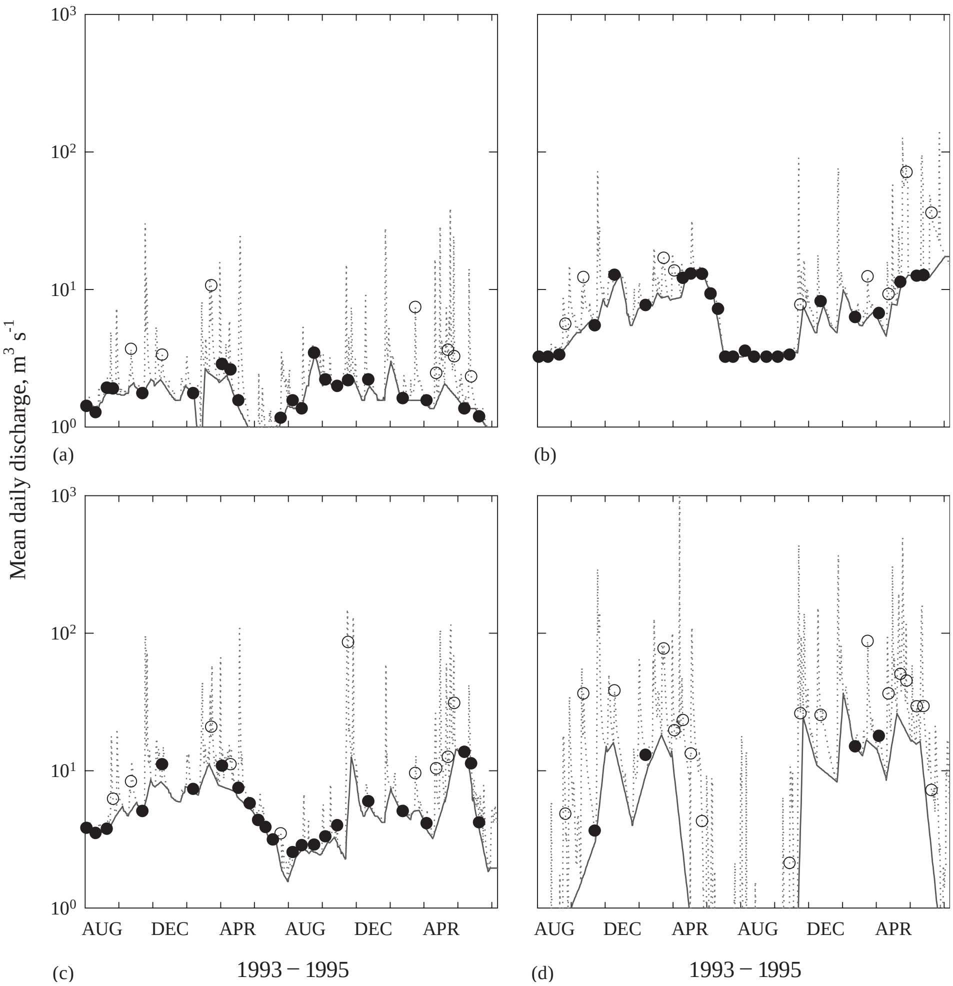

Fig. 2. Sampling date, mean daily discharge and base flow separation at Brush Creek, Richland Creek, War Eagle Creek, and White River during the study period; (a) Brush Creek, site 3; (b) Richland Creek, site 7; (c) War Eagle Creek, site 2; (d) White River, site 10; —, seasonal base flow; ..., total stream flow; ●, base flow water quality sample; ○, surface runoff water quality sample

the White River gauge site (where basin size was largest), to 1 m^3 s^{-1} at Brush Creek and 2–3 m^3 s^{-1} at Richland and War Eagle Creeks. However, maximum discharge for floods did increase in a downstream direction (*i.e.* with basin size), as the largest floods occurred in White River. Hydrograph separation suggested that water-quality samples were collected when seasonal base flow was less than 70% of total flow, *e.g.* surface runoff or storm events, in 8, 9, 10 and 18 out of 33 sampling dates in Brush Creek, Richland Creek, War Eagle Creek and the White River, respectively.

3.2. *Stream nutrient concentrations*

In these streams, N is far more plentiful than P, and N:P ratios are consistently 80–110:1. Inorganic N is dominated by NO_3, whereas NH_4 was generally below detection limits. At all sites average NO_3 and TN concentrations were greater in year 1 than year 2, but no consistent annual trend was evident for either SRP or TP. Seasonal patterns of nutrient concentrations varied annually and between sites; however, N and P concentrations generally peaked in concentration during both autumn and spring high flows.

Only the sub-basin outlets (sites 2, 3, 7, 8 and 9) were used to examine the relationship between land use and annual log-mean nutrient concentrations in the water column of the respective streams. In the White River sub-basin, sites 8 and 9 were used to avoid external influences on nutrient concentrations from the City of Fayetteville's wastewater treatment plant. Sites 2 and 7 were the basin outlets for War Eagle and Richland Creek watersheds. A positive correlation was observed between the proportion of pasture in the sub-basins

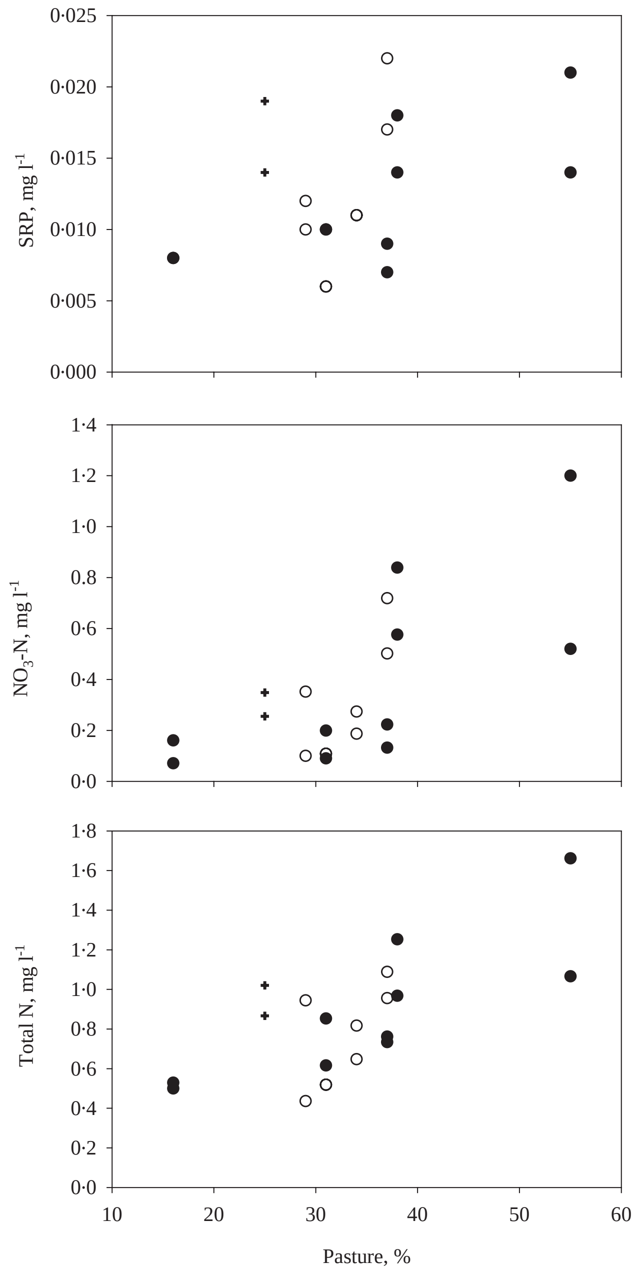

Fig. 3. Geometric mean soluble reactive phosphorus, NO_3-N, and total nitrogen as a function of per cent pasture in the Beaver Lake Basin; SRP, soluble reactive phosphorus; ●, basin outlets, sites 2, 3, 7–9; ○, upstream sites, sites 1, 4–6; +, point source impacted site, site 10

(arc-sin square root transformed, Zar, 1984) and annual geometric-mean SRP (regression coefficient $R = 0{\cdot}73$, number of samples $n = 10$, probability $P < 0{\cdot}02$), NO_3 ($R = 0{\cdot}76$, $n = 10$, $P < 0{\cdot}01$) and TN ($R = 0{\cdot}87$, $n = 10$, $P < 0{\cdot}001$) (*Fig. 3*), whereas NH_4, TKN and TP were not significantly correlated. Pasture land use accounted for over 50% of the variation of the change in annual geometric-mean SRP, NO_3-N and TN concentrations between sub-basins outlets.

3.3. *Stream nutrient export*

The relationships between nutrient concentrations [$\ln(C)$] and discharge [$\ln(Q)$] were variable between constituents and were not consistently significant; however, the relationship between nutrient loads [$\ln(L)$] and discharge were consistently significant for all parameters ($P < 0{\cdot}05$). In some cases a significant trend in concentration and/or load with time and season was displayed, but results were variable within and among streams. The concentration model explained between 8 and 57% of the variation in nutrient concentrations, whereas the load model explained between 40 and 96% in nutrient loads.

Average N and P export from the White River watershed was greater than from any other sub-watershed (Table 2), but average unit-area N and P yield was least. Conversely, average annual N and P export in Brush Creek watershed was least but when weighted on a unit area basis the export was greatest. Annual nutrient export minus the wastewater treatment plant (WWTP) load (FTN Associates, Ltd, 1992) increased with increasing basin size in the four sub-watersheds of Beaver Lake, whereas unit area nutrient export decreased exponentially with watershed size (*Fig. 4*). Total N, NO_3 and SRP export per unit area increased exponentially with per cent pasture, whereas TP export per unit area was not related exponentially to per cent pasture in the sub-basins (*Fig. 4*).

4. Discussion

4.1. *Stream nutrient concentrations*

In Northwest Arkansas, the Beaver Lake/White River Basin contains over 2000 poultry houses in an area of approximately 300 000 ha producing about five flocks of poultry per year and 200 000 Mg yr^{-1} of poultry litter. In general, poultry litter is approximately 4% TN and 2% TP (Moore *et al.*, 1997), representing a TN and TP source of about 8000 and 4000 Mg yr^{-1}, respectively, in the Beaver Lake Basin. Most often, poultry litter is land applied as a fertiliser to pastures; however, some poultry litter is used as alternative by-products such as feed supplements or compost. Approximately 80% of the poultry houses are contained with the subwatersheds where nutrient concentrations and export were measured.

Table 2
Estimated nutrient loading and the confidence interval (95% CI) from the regression models of the four gauged sub-basins in the Beaver Lake Basin

Sub-basin	*Yr*	*SRP, Mg*	*(95% CI)*	*TP, Mg*	*(95% CI)*	*NO_3-N, Mg*	*(95% CI)*	*TN, Mg*	*(95% CI)*
Brush	1	2·0	(1·2–3·3)	3·5	(2·2–5·4)	101	(51–180)	130	(86–187)
Creek	2	1·6	(0·9–2·8)	3·5	(2·0–5·7)	58	(30–105)	97	(63–142)
	avg	1·8		3·5		80		113	
Richland	1	3·0	(1·8–4·8)	9·1	(5·5–14·3)	201	(77–445)	278	(170–430)
Creek	2	5·0	(2·6–8·7)	16·9	(8·7–29·9)	158	(42–434)	361	(198–610)
	avg	4·0		13·0		180		320	
War Eagle	1	8·4	(4·4–14·8)	14·3	(9·4–20·8)	279	(172–430)	370	(251–527)
Creek	2	7·1	(3·4–13·4)	10·5	(6·5–16·1)	202	(115–330)	301	(194–448)
	avg	7·8		12·4		240		336	
White	1	15·5	(5·3–37·0)	43·2	(23·3–74·1)	363	(106–934)	530	(340–795)
River	2	25·4	(9·4–55·8)	49·0	(28·2–79·7)	362	(109–898)	592	(390–862)
	avg	20·4		46·1		362		561	
Total	1	29·0	(12·7–59·8)	70·1	(40·5–115)	943	(406–1990)	1307	(847–1939)
Export	2	39·1	(16·3–80·8)	79·9	(45·3–131)	781	(296–1767)	1351	(845–2063)
	avg	34·1		75·0		862		1329	

Yr, year; SRP, soluble reactive phosphorus; TP, total phosphorus; NO_3-N, nitrate nitrogen; TN, total nitrogen; avg, average load of years 1 and 2 ($Mg\,yr^{-1}$).

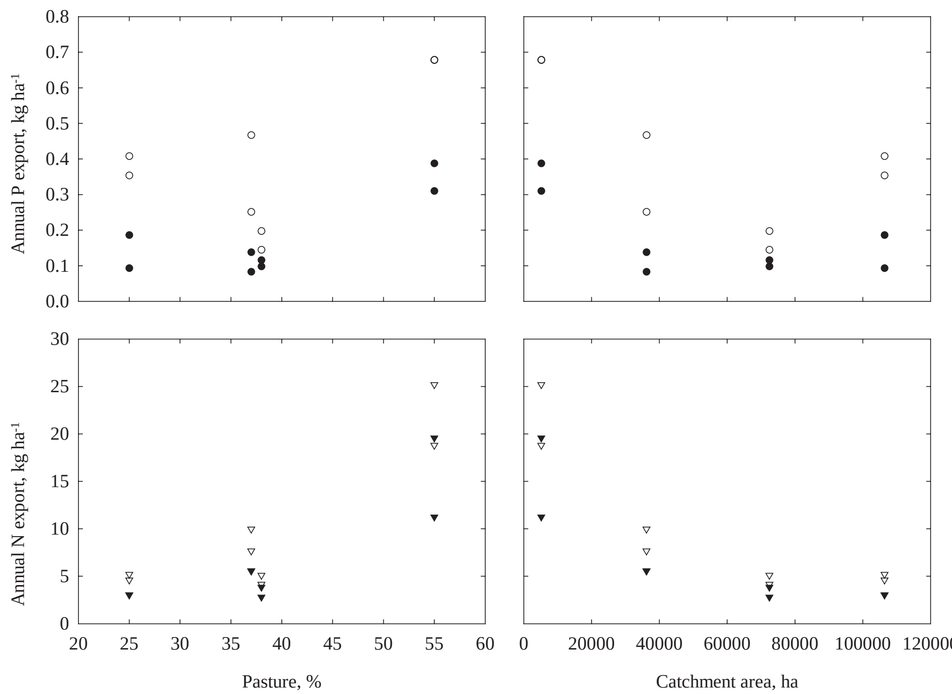

Fig. 4. Annual nutrient export as a function of per cent pasture and catchment area in the Beaver Lake Basin; ●, soluble reactive phosphorus; ○, total phosphorus; ▼, NO_3-N; ▽, total nitrogen

When P fertilisers are applied to pastures, the P concentrates in the top portion of the soil (Kingery *et al.*, 1994). Although P leaching can occur in deep sandy organic soils (Sims *et al.*, 1998), P does not leach in Northwest Arkansas soils because the silt loams of the region have a higher clay content with depth, and these higher clay sub-soils have increased P buffering capacity. Thus, the mechanism for P loading into the streams is via surface runoff, which varies in each sub-basin with soil type, slope, vegetation, antecedent moisture, management, *etc.* Pastures in northwest Arkansas have shown a positive correlation between soil P and P in runoff water

(Pote *et al.*, 1999). Furthermore, Edwards and Daniel (1993) reported an increasing relationship between P loading from poultry litter to soils and runoff P levels.

However, even though soil P levels or P loading onto a certain pasture may be high, inorganic and sediment-bound P in runoff can be low or even zero if there is no surface runoff. Loss of P from upland areas is regulated by P source factors (soil P, soil fertiliser and management) combined with P transport factors (runoff and erosion) (Gburek & Sharpley, 1998). The flow path of P transport from all positions throughout the basin has considerable effect on the amount of P reaching streams, rivers, and eventually reservoirs and lakes (Gburek & Pionke, 1995). The source of surface runoff may be variable within the watershed, and certain portions of the watershed may produce large amounts of surface runoff.

Unlike P, NO_3 molecules have low affinity for exchange or covalent bonding in soils and seldom form a precipitant. Whereas P transport is via overland flow, NO_3 movement may be through surface runoff, subsurface flow and/or groundwater flow. Nitrate in excess of plant requirements may leach through the soil and reach the stream via groundwater or inter-flow (Lowrance, 1992). Various studies have confirmed that agricultural leachates were a major source of NO_3 contamination in subsurface flow and ground water (Lowrance *et al.*, 1984; Sharpley *et al.*, 1987). The Beaver Lake Basin contains karstic geological features that allow for ground water movement without much natural filtering. The range of NO_3-N concentrations in streams draining the Beaver Lake Basin was from an annual geometric mean of 0·1 to 1·2 mg l^{-1}. These high concentrations are probably reflective of regional ground water enrichment associated with agricultural activity within the Ozark Plateau (Petersen *et al.*, 1999).

Regardless of the nature of the flow path with which terrestrial applied nutrients reach aquatic ecosystems, the results of this investigation suggest the proportion of pastureland in the sub-basins is an important determinant in annual stream nutrient concentrations. Increasing nutrient concentrations were observed, with increasing proportion of pasture in streams of the Beaver Lake Basin, and several investigations have shown similar increasing relationships in basins throughout the United States (Byron & Goldman, 1989; Jordan *et al.*, 1997; McFarland & Hauck, 1999). Thus, land application of poultry manure to pastures in northwest Arkansas may have impacted in-stream nutrient concentrations. Although per cent pasture did explain a significant portion of the variation (about 50%) in annual geometric mean nutrient concentrations in streams, many other factors such as nutrient cycling and processing in the upland area, riparian zone, surface–ground water interaction and the stream channel also contribute to the variability of stream nutrient concentrations (Fenn & Poth, 1999; Meyer *et al.*, 1988).

4.2. *Stream nutrient export*

In the Beaver Lake Basin, 65 and 45% of the P and N entering the reservoir is the form of SRP and NO_3, respectively. Thus, a large portion of the nutrient load is considered to be bioavailable to algae in the reservoir. Overall, the greatest amount of nutrients were transported from the White River watershed (the largest catchment) and the least from Brush Creek watershed (the smallest catchment). Prairie and Klaff (1986) suggested that stream TP export from basins dominated by pasture (greater than 90% on an area basis) was an exponential function of catchment size, but TP yield from forest systems was a linear function of catchment size. Nutrient yields from streams draining the Beaver Lake Basin decreased exponentially with catchment size despite exhibiting a slight dominance of forest in the sub-basins. However, nutrient yields in these sub-basins also increased exponentially with the proportion of pasture. Furthermore, the per cent pasture in the four sub-basin outlets was approximately a linear function of catchment size ($R = 0{\cdot}92$, $n = 4$, $P < 0{\cdot}08$) and none of the sub-basins were dominated (greater than 90%) by any one-land use category. Thus, the proportion of pasture in these sub-basins not only impacted absolute nutrient concentrations (annual geometric mean) but most likely nutrient export in the streams draining the basin.

The annual average TP export from the Beaver Lake Basin was 0·34 kg ha^{-1} yr^{-1}, within the range of export for both pastures (0·3 – 2·8) and forests (0·1 – 0·4) in the USA (Beaulac & Reckhow 1982, Young *et al.* 1996). Annual average TN export (6·0 kg ha^{-1} yr^{-1}) in this basin was greater than the range (2–3·5 kg ha^{-1} yr^{-1}) reported for forest systems in the USA, but well within the range of TN loss from streams draining catchments dominated by pastures (2–11 kg ha^{-1} yr^{-1}). Nutrient yields are also about half of that observed in the Illinois River Basin during 1997 through 1999, an Ozark Plateaus catchment near this basin (Green & Haggard, 2001). The nutrient yields from the Beaver Lake Basin were compared to the average nutrient yield in undeveloped, pristine streams during 1990 through 1995 (Clark *et al.*, 2000). Average annual NO_3 and TN yields were over 10 and 6 times greater, respectively, in the Beaver Lake Basin than the average values reported for all streams of the Hydrologic Benchmark Network, North Sylamore Creek in the Ozark Plateau (north-central Arkansas, USA) and the Cossatot River in the Ouchita Mountains (southeast Oklahoma and southwest Arkansas, USA) (*Fig. 5*). Similarly, SRP and TP export were over three times greater in the Beaver Lake Basin. These differences are possibly reflective of the presence of confined animal agriculture and the practice of land applying animal manure because the area is not dominated by urban-suburban land use or row-crop agriculture (generally less than 4%).

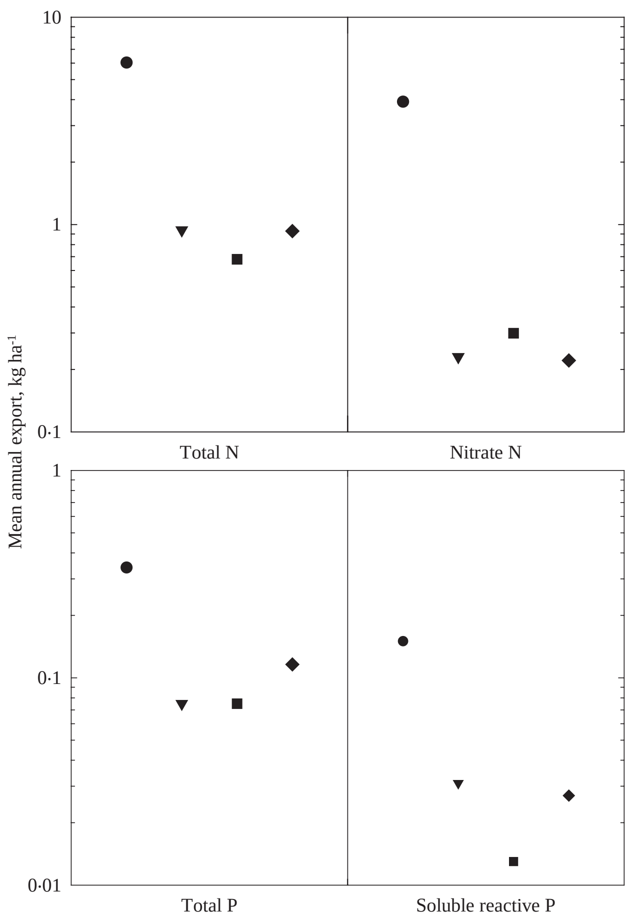

Fig. 5. Comparison between Beaver Lake Basin nutrient yields and those of relatively undeveloped areas reported by Clark et al. (2000); ●, average from this study, 1993–1995; ▼, average from undeveloped catchments, 1990–1995; ■, average from North Sylamore Creek, 1990–1995; ◆, average from Cossatot River, 1990–1995

The nutrient loads reported within this report were compared to the National Eutrophication Survey (EPA, 1977) and a comprehensive study by FTN Associates, Ltd (1992) (Table 3). It appears that TP and TN loads into this reservoir are equivalent to pre-tertiary WWTP treatment in the mid-1970s, and the TP and TN loads are approximately 1·5 and 1·3 times greater than reported in 1992. However, nutrient transport and loads within streams are dynamic and highly dependent on the amount of water passing a fixed point because load is a function of discharge. Thus, loads are not always comparable between years because of variation in annual runoff.

In the Beaver Lake Basin, the poultry industry produces a considerable amount of N and P (8000 and 4000 $Mg\,yr^{-1}$) in the Beaver Lake Basin; it is assumed that about 80% is produced in the subwatersheds where N and P export were measured. The N and P exported in the Beaver Lake subwatersheds was about 1290 and 70 $Mg\,yr^{-1}$, excluding WWTP inputs; this amount is only 16 and 2% of the total N and P produced from the poultry industry. Similar percentages have been estimated in neighbouring catchments (Storm *et al.*, 2002; Nelson *et al.*, 2002) with large numbers of poultry houses.

5. Conclusions

Ten stream sites were sampled from August 1993 through July 1995 17 times per year in the Beaver Lake Basin, southwestern portion of the Ozark Plateaus in northwest Arkansas, USA. Stream soluble reactive phorphorus (SRP), NO_3-N and total nitrogen (TN)

Table 3
Nutrient loading estimates from this study, the National Eutrophication Survey (EPA, 1977), and FTN Associates, Ltd (1992)

Sub-basin	*EPA (1977)*		*FTN (1992)*		*Current Study*[*]	
	TP, $Mg\,yr^{-1}$	*TN, $Mg\,yr^{-1}$*	*TP, $Mg\,yr^{-1}$*	*TN, $Mg\,yr^{-1}$*	*TP, $Mg\,yr^{-1}$*	*TN, $Mg\,yr^{-1}$*
White River	10·4	443	22·7	399	46·1[†]	560[†]
Richland Creek	3·6	113	3·8	98	13·0	320
War Eagle Creek	12·1	391	12·7	439	12·4	370
WWTP	43·5	155	6·2	39		
Total	69·5	1103	45·4	975	71·5	1250

TP, total phosphorus; TN, total nitrogen; WWTP, wastewater treatment plant; total, sum of export from the White River, Richland Creek and War Eagle Creek sub-basins and WWTP.
[*] average from both years in this study.
[†] In the current study White River loading includes WWTP.

concentrations (geometric-mean) increased linearly with per cent of pasture in each sub-watershed, whereas N and P export coefficients increased exponentially with pasture land use. Nutrient export in $kg\,yr^{-1}$ increased with basin size, but nutrient yield in ($kg\,km^{-2}\,yr^{-1}$) decreased with basin size. This investigation emphasised the need to carefully manage poultry litter because small losses of nutrients compared to the total amount of nutrients produced in a basin may still impact stream nutrient concentrations and export. Furthermore, nutrient export in this basin is considerably greater than that observed in relatively undeveloped basins across the USA, specifically in two catchments in Arkansas, USA. Nutrient uptake, transformation and transport from the terrestrial through the aquatic ecosystem must be addressed to fully understand the impacts of increased agricultural land use on stream nutrient concentrations and export.

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