

Nitrogen and phosphorus levels in the Yazoo River Basin, Mississippi[†]

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ABSTRACT

Nitrogen (N) and phosphorus (P) loadings to aquatic ecosystems are linked to environmental problems such as hypoxia. Presented is an assessment of accessible data on nutrient sources, sinks and inputs to streams within the Yazoo River Basin of northern Mississippi. Spatial trends were examined by plotting the temporal mean and median concentration for each site versus contributing drainage area, and seasonal patterns were examined by comparing monthly mean and median concentrations computed across a range of sites. Mean total N values were computed for 75 sites with periods of record ranging from 3.3 to 28.6 years. The global mean (mean of site means) total N concentration for the Delta was 3.3 mg l⁻¹ but only 1.2 mg l⁻¹ for the Hills, and both were about two to four times higher than US Environmental Protection Agency (US EPA) criteria for each of these ecoregions. Total P data were found for 122 sites with periods of record ranging from 3.2 to 28.6 years. Delta mean N and P concentrations were inversely proportional to contributing drainage area, while those of Hill sites were not. The Hill mean P concentration was 0.15 mg l⁻¹, while the mean for Delta sites was more than four times greater, 0.66 mg l⁻¹. These values are about four to five times the levels set as criteria by the US EPA. Delta N and P concentrations peak strongly in spring when agricultural fertilizers are applied and stream flows are highest. Concentrations of N in Hill streams do not exhibit seasonal patterns, but mean monthly P levels are correlated with mean monthly discharge. Published in 2009 by John Wiley & Sons, Ltd.

KEY WORDS nitrogen; phosphorus; nonpoint source pollution; hypoxia; Yazoo River

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INTRODUCTION

Productivity cycles in disturbed aquatic ecosystems are often dominated by anthropogenic inputs of Nitrogen (N) and phosphorus (P) (Carpenter *et al.*, 1998; Caraco and Cole, 1999). Human impacts on the global N cycle are significant, primarily due to the use of synthetic fertilizer, which accounts for more than half of the human alteration of the N cycle. Overall, human fixation of atmospheric N during fertilizer manufacture, combustion of fossil fuel, and production of legumes increased globally by a factor of 2–3 between 1960 and 1990, thus contributing significantly to nonpoint source flux of N (Howarth *et al.* 2002; Committee on the Causes and Management of Coastal Eutrophication, 2000). Agricultural sources contribute more than 70% of the N and P delivered to the Gulf of Mexico by the Mississippi and Atchafalaya Rivers (Alexander *et al.*, 2008). Corn and soybean cultivation is the largest contributor of N (52%), followed by atmospheric deposition (16%), while P originates primarily from animal manure (37%) and from fertilization of corn and soybeans (25%). Because of the detrimental results of over enrichment, nutrient transport from the continental United States into coastal waters is of great concern. Between 1960 and 2000 the

flux of N from the Mississippi River into the Gulf of Mexico has tripled and the flux of P has doubled, creating a seasonal hypoxic zone spread over up to 20 000 km² (Rabalais *et al.*, 1999; Aulenbach *et al.*, 2007). Similar phenomena have been reported for more than 400 marine ecosystems comprising 245 000 km² worldwide (Diaz and Rosenberg, 2008). The Yazoo River Basin, which supports intensive cultivation, contributes about 3% of the water discharge in the Lower Mississippi River, and the proximity of the basin to the Lower Mississippi suggests that relatively high percentages of the Yazoo N and P yields are delivered to the Gulf (Alexander *et al.*, 2008). Periodic anoxia has been observed in some Yazoo Basin streams (Mississippi Department of Environmental Quality-Mississippi State University, 2003, Killgore *et al.*, 2008), but definitive links to N and P concentrations have not been established. Herein, we examine available data for Yazoo basin stream concentrations of N and P and assess seasonal and spatial patterns to assess the magnitude of nutrient pollution and provide a basis for future work to support management schemes.

The Yazoo River Basin encompasses 34 600 km² and is separated into two distinct topographic regions of roughly equal size, the Bluff Hills (Hills) and the Mississippi Alluvial Plain (Delta). The Delta supports large-scale agriculture, while the Hills support much more heterogeneous land use and smaller areas of cultivation. Hill soils (primarily loess and loess-derived alluvium) are highly erodible, and channels are extremely unstable,

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producing average annual sediment yield about twice the national average ($\sim 1000 \text{ t km}^{-2}$) for watersheds of this size (Shields *et al.*, 1995). Streams in the Hills tend to be channelized and thus have straight and wide channel beds composed of either sand, sand and gravel, or cohesive clay, and steep, high banks prone to failure (Simon and Darby, 2002). To capture sediment and control Delta flooding, flood control reservoirs were constructed on the Coldwater (Arkabutla Lake), Tallahatchie (Sardis Lake), Yocona (Enid Lake), and Yalobusha (Grenada Lake) Rivers from 1940 to 1954. These reservoirs are located along the boundary between the Hills and the Delta and control runoff from about two-thirds of the Hills region (Figure 1).

About two-thirds of the Delta is cultivated for row crops, and about two-thirds of row cropland is irrigated. Major crops of the Delta include soybeans, cotton, corn, rice, grain sorghum and catfish. Soils in this region consist of clay and fine sand from alluvial deposition of the ancestral Mississippi and Ohio Rivers (Guedon and Thomas, 2004). Bottomland soils are often heavy clay but may be sandy silts, while low sandy ridges occasionally occur in ridge and swale topography. However, much of the productive land has been laser-leveled and is drained by a network of ditches. Streams in the Delta are typically sluggish due to the limited slope, and are periodically turbid from sediment runoff. Bottom material varies from clay to fine sand. Most river and stream channels have been straightened to facilitate drainage.

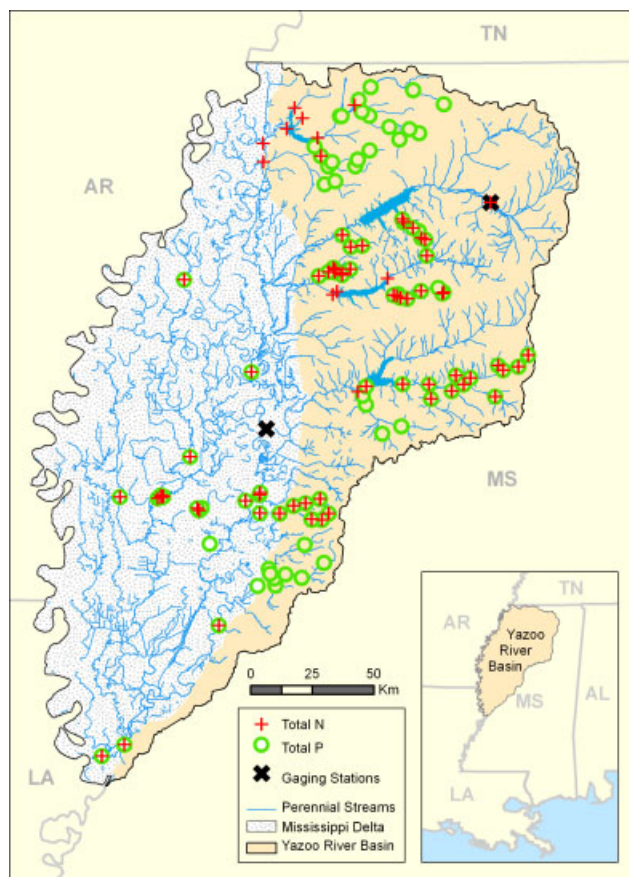


Figure 1. Yazoo River Basin, Mississippi, USA.

DATA

Spatial and temporal trends in stream N and P concentrations were examined using data compiled from existing water quality data bases. Metadata compiled by FTN Associates (2003) were examined, and Yazoo Basin sites sampled at least quarterly or more frequently for at least 3 years were identified. Sample collection dates ranged from 1974 to 2005. Data for the Delta are sparse relative to the Hills. No sites were located within any of the four major flood control reservoirs (Figure 1), and few data were available for reservoir tailwaters. Most data were obtained by the US Geological Survey (44 sites) or the USDA-ARS National Sedimentation Laboratory (96 sites). Actual data were retrieved from the USGS website (<http://nwis.waterdata.usgs.gov/usa/nwis/qwdata>) using search criteria including site type, location (latitude and longitude of a polygon enclosing the Yazoo River Basin), and parameter codes. A similar retrieval was run using the STORET database websites [legacy (pre 2000) and modern (post 2000) at <http://www.epa.gov/storet/dbtop.html>]. Data from only one site and one date were obtained from the modern STORET retrieval, and therefore the analyses described below were based on data from legacy STORET only.

Data from both USGS and STORET were those listed under the parameter codes for both total and dissolved concentrations of N, Kjeldahl N, nitrite plus nitrate, nitrite, nitrate and total P (00 600, 00 625, 00 630, 00 631, 00 620, 00 618, 00 615, 00 613, and 00 665, respectively). Similar data were available from our laboratory for about 96 sites on streams in 17 Hill watersheds collected at varying intervals between 1985 and 2005. Metadata for the various original data sources indicated that methods and measurement units were consistent for a given parameter.

Hydrologic gaging coverage of the Yazoo Basin was spotty over the period of interest (1974–2005). Mean daily discharges for the period of record for a gage on a large Delta stream (years 1995–2005, station 07 281 600) and an upstream Hill gage on the same stream (years 1995–2005, station 07 268 000) were retrieved from the US Geological Survey website. Gage locations are shown in Figure 1. These data were used to compute monthly mean discharges for comparison with monthly mean nutrient concentrations.

TOTAL NITROGEN AND NITRATE CONCENTRATIONS

Total N values (TN, parameter 00 600) were extracted from the data set. A minimum of 3 years of record and at least 30 samples were required for inclusion of a site in the analysis described here. For sites and dates without TN values, TN was computed following an approach similar to that prescribed by Goolsby *et al.* (1999) and Aulenbach *et al.* (2007) based on Rickert (1992). Briefly, if no total Kjeldahl N (TKN, parameter 00 625) value was available, no total N value was computed. If TKN was

available, then TN was computed as follows:

$$\text{TN} = \text{TKN} + \text{NO}_2 + \text{NO}_3$$

where $\text{NO}_2 + \text{NO}_3$ was set equal to

total $\text{NO}_2 + \text{NO}_3$ (00630) if available, and if not dissolved $\text{NO}_2 + \text{NO}_3$ (00631) if available, and if not total NO_3 (00620) if available, and if not dissolved NO_3 (00618), and if not

then no value of TN was computed. If $\text{NO}_2 + \text{NO}_3$ was below detection but TKN was not, then $\text{TN} = \text{TKN}$.

If total or dissolved NO_3 (00620 or 00618) was used, then total or dissolved NO_2 (00613 or 00615) was added if it was available. This approach is based on the assumption that total $\text{NO}_2 + \text{NO}_3$ is dominated by dissolved NO_3 , which is typical of observations in freshwater ecosystems in this region. Our data set included only two measurements of dissolved NO_3 (00618).

This procedure produced total N values for 75 sites with periods of record ranging from 3.3 to 28.6 years. About 58% of total N data were from years 2000–2004, inclusive. Nineteen of the sites were located in the Delta and 56 were in the Hills. The global mean (mean of site means) total N concentration for the Delta was 3.3 mg l^{-1} but only 1.2 mg l^{-1} for the Hills. Coefficients of variation for site means (standard deviation of all measurements at that site divided by the average of all measurements at that site) ranged from 0.4 to 2.1 for the Delta and 0.4 to 1.9 for the Hills. Summary statistics were computed for each site, and scatter plots were prepared showing concentration as a function of contributing drainage area (Figure 2). For each Delta site, 45 to 282 samples were available, and 35 to 179 were available for each Hill site. Delta sites were either very small streams with drainage areas $<10 \text{ km}^2$ or large rivers with drainage areas $>1000 \text{ km}^2$. The smallest Delta sites drained only cultivated fields. Only one Delta site had a drainage area between 10 and 1000 km^2 . Conversely, Hill sites were concentrated in the $10\text{--}1000 \text{ km}^2$ size class, with only four sites on smaller streams and nine sites on larger streams. Delta mean and median total N values were negatively correlated with contributing drainage area, and power functions fitted to Delta means and medians plotted well above Hill means and medians (Figure 2B and C). Only two Hill sites had mean total N concentrations that plotted above the power law curve of concentration as a function of drainage area based on Delta site means. One site drained an urban watershed (Burney Branch), and the other was within a suburban–rural transitional zone (Mussacuna Creek).

The dashed horizontal lines in Figure 2B and C are the regional criteria for rivers and streams developed by the US EPA under Section 304 of the Clean Water Act (U. S. Environmental Protection Agency, 2000, 2001). The observed total N concentrations typically exceed these levels. The Delta portion of the Yazoo Basin is part of aggregated Ecoregion X, while the Hills are part of

aggregated Ecoregion IX. Total N criteria are 0.69 and 0.76 mg l^{-1} for the Hills and Delta, respectively (U. S. Environmental Protection Agency, undated, 2000, 2001).

Some form of nitrate was reported for a slightly larger number of sites than for total N. Therefore statistics for nitrate concentration were computed for 115 sites with periods of record ranging from 3.2 to 19.8 years. Each site was sampled between 45 and 638 times. These 115 sites included 56 of the sites used in the TN analysis. Twelve sites were in the Delta and 103 were in the Hills. Total $\text{NO}_2 + \text{NO}_3$ concentrations were developed as follows. Total $\text{NO}_2 + \text{NO}_3$ was assumed equal to

total $\text{NO}_2 + \text{NO}_3$ (00630) if available, and if not dissolved $\text{NO}_2 + \text{NO}_3$ (00631) if available, and if not total NO_3 (00620) if available, and if not dissolved NO_3 (00618), and if not then no value of $\text{NO}_2 + \text{NO}_3$ was computed.

If total or dissolved NO_3 was used, then total or dissolved NO_2 was added if it was available. This approach is based on the assumption that total $\text{NO}_2 + \text{NO}_3$ is dominated by dissolved NO_3 . For purposes of this analysis, values reported as less than detection limits (either <0.2 or $<0.1 \text{ mg l}^{-1}$) were set equal to 0.5 times the detection limit.

Global means were 1.7 mg l^{-1} for the Delta (about half of the total N mean) and 0.34 mg l^{-1} for the Hills (about one-fourth of the total N mean). As for total N, scatter plots of concentration versus drainage area were prepared (Figure 2). Nine Delta sites were from small streams with drainage areas $<10 \text{ km}^2$, and three were from large rivers with drainage areas $>1000 \text{ km}^2$, but none were from intermediate sized sites. The smallest Delta sites drained only cultivated fields as described by Rebich (2004). Ninety-three of the 103 Hill sites were from intermediate-sized ($10\text{--}1000 \text{ km}^2$) drainage areas. Similar to total N, Delta mean and median total $\text{NO}_2 + \text{NO}_3$ values were negatively correlated with contributing drainage area, and power functions fitted to Delta means and medians plotted well above Hill means and medians (Figure 2B and C).

Total N concentrations were examined for seasonality by plotting mean concentration (averaged across all available sites and through all time) versus month of the year for Delta and Hill sites (Figure 3A). Total N data were obtained for the same 75 sites represented in Figure 2. Delta mean total N concentrations were higher than Hill total N mean concentrations throughout the year and exhibited strong seasonal behavior similar to that reported by Pennington (2004) for TKN at 22 sites on Delta rivers sampled between 1992 and 1997. Pennington (2004) reported peak concentrations in March that smoothly declined to a minimum in August, while our computations showed that peak levels occurred slightly later (in May) and increasing concentrations in late Fall. Hill total N levels fluctuated between 1 and 2 mg l^{-1} and exhibited no seasonality. Much higher (up to 23 mg l^{-1}) monthly average total N levels were computed for small channels (watershed sizes $0.1\text{--}6 \text{ km}^2$) in the Delta. Mean monthly

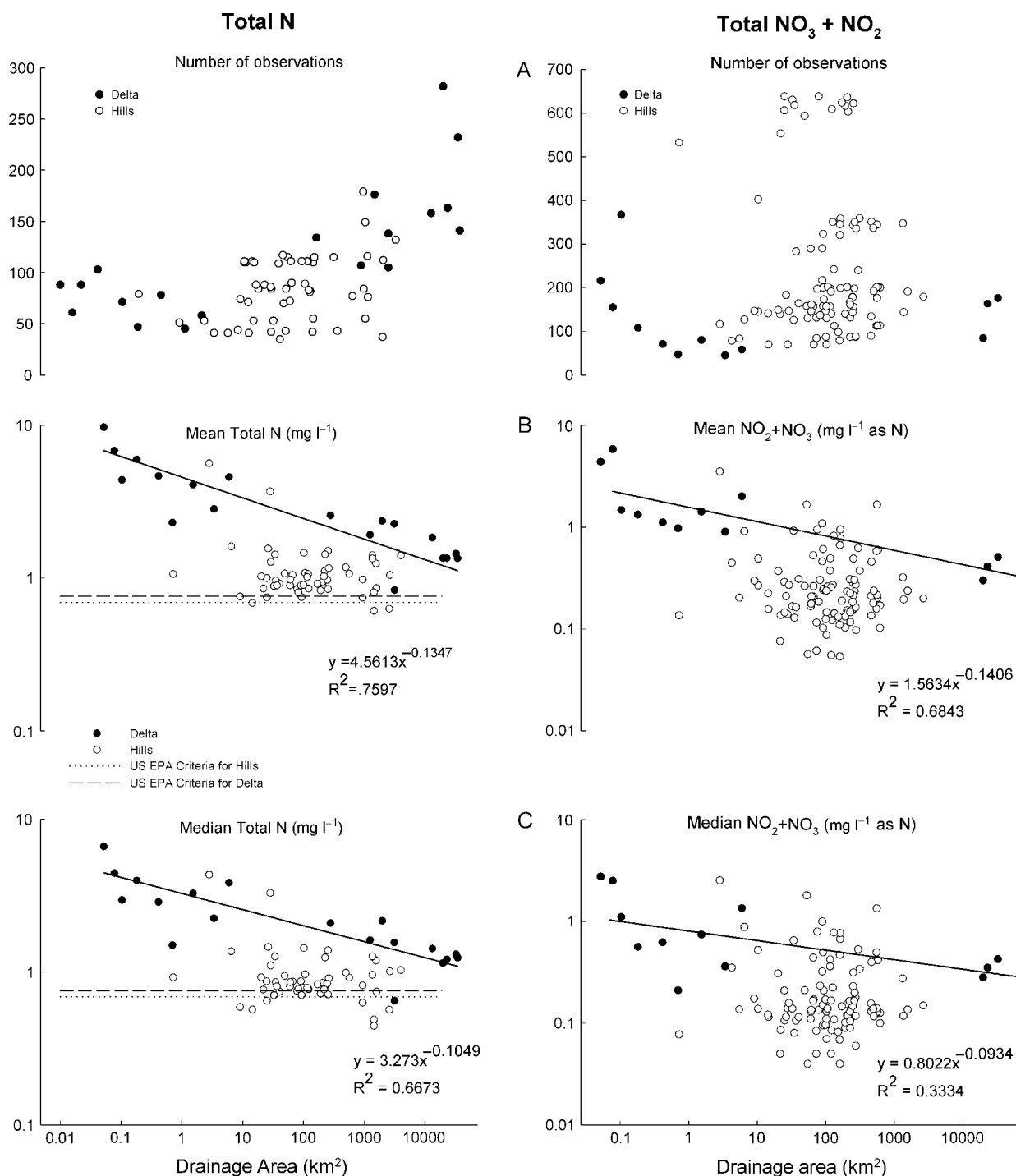


Figure 2. Nitrogen concentrations in mg l^{-1} versus contributing drainage area for sites along streams in the Yazoo Basin. (A) Number of samples, (B) Mean concentration, and (C) Median concentration. Values of total N and $\text{NO}_2 + \text{NO}_3$ determined as described in text. Curves are regressions based on Delta data only, and R^2 and equations are for these regressions.

discharge for a large Delta stream (years 1995–2005, station 07 281 600) is also shown in Figure 3A for comparison with total N. Monthly mean total N concentrations were significantly correlated with monthly mean discharges ($r = 0.88$, $p \leq 0.0002$).

Nitrate levels were also examined for seasonality by plotting mean concentration (averaged across all sites and through all time) versus month of the year for Delta and Hill sites (Figure 3B). Nitrate levels for both regions were relatively low. Delta mean total $\text{NO}_2 +$

NO_3 concentrations were higher than Hill concentrations except for 2 months in the fall. Delta levels varied seasonally, with monthly mean total $\text{NO}_2 + \text{NO}_3$ peaking near 0.6 mg l^{-1} in July and gradually declining to less than 0.2 mg l^{-1} in October. Delta monthly nitrate means peaked 2 months later than total N, and were only about 10–25% as great as total N. Hill concentrations varied between 0.3 and 0.4 mg l^{-1} . Nitrate means for both regions were correlated with monthly mean discharge ($r > 0.66$, $p \leq 0.02$).

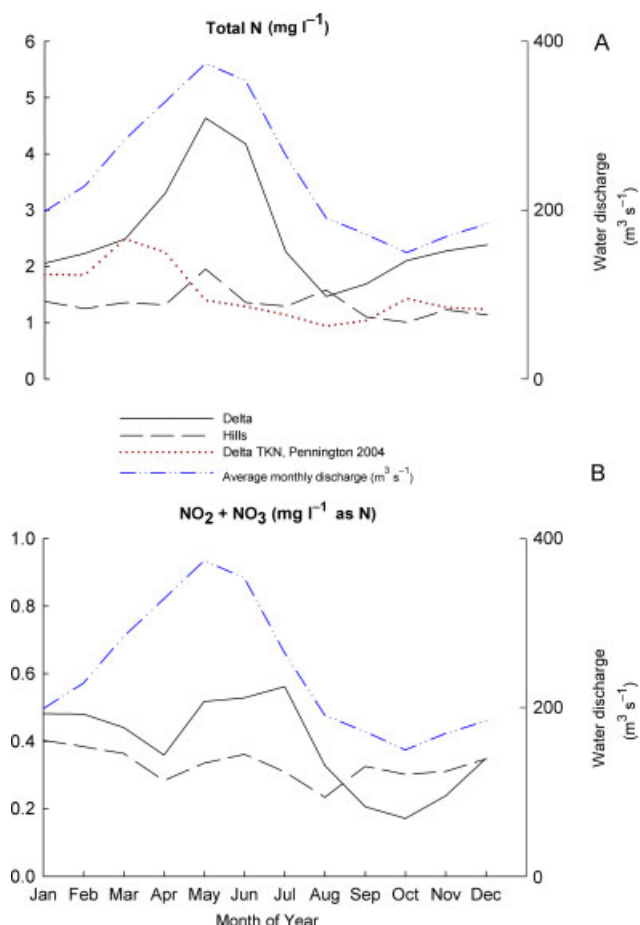


Figure 3. Mean (A) total nitrogen and (B) nitrite plus nitrate concentrations of each month for stream sites in the Yazoo Basin. Mean monthly discharge is for USGS gage 7281600, which is located on a major Yazoo River tributary in the Delta as shown in Figure 1. Values of total N and $\text{NO}_2 + \text{NO}_3$ determined as described in the text.

TOTAL PHOSPHORUS CONCENTRATIONS

Total P concentration data was retrieved for 122 sites with periods of record ranging from 3.2 to 28.6 years. A minimum of 3 years of record and at least 30 samples were required for inclusion of a site in the analysis. About 58% of total P data were from years 1990 to 1999, inclusive, and 18% were from 2000 to 2004, inclusive. Summary statistics were computed for each site, and scatter plots were prepared showing concentration as a function of contributing drainage area (Figure 4). Between 70 and 643 samples were collected from each Hill site, while Delta sites were sampled 45 to 367 times each (Figure 4A). Only two Delta sites had contributing drainage areas between 10 and 1000 km^2 , but only ten Hill sites fell outside this interval. Delta P concentrations were inversely proportional to contributing drainage area, while Hill sites were not. Hill P means (Figure 4B) and medians (Figure 4C) plot below regression lines for Delta P on concentration versus drainage area scatter plots, indicating the overall lower values observed there. In fact, only one Hill site mean plots above the power law curve of concentration as a function of drainage area based on Delta site means (Figure 4B), and it is from a site draining an urban watershed (Burney

Branch). Mean total P for Burney Branch was 1.47 mg l^{-1} , about four times greater than the next greatest Hill site mean. The Hill overall mean P concentration was 0.15 mg l^{-1} while the overall mean for Delta sites was more than four times greater, 0.66 mg l^{-1} . Variations in observed P concentrations were within expected limits, with coefficients of variation for Delta sites ranging from 0.39 to 2.00 and for Hill sites from 0.65 to 2.55. Highest levels of median total P occurred at sites receiving runoff from small ($\sim 0.2 \text{ km}^2$), cultivated watersheds in the Delta, while lowest median levels were found at Hill sites that drained forested watersheds between 10 and 20 km^2 in size.

Concentrations reported here typically exceed the regional criteria for rivers and streams developed by the US EPA (Figure 4B and C). Total P criteria are 0.0356 and 0.128 mg l^{-1} for the Hills and Delta, respectively (U. S. Environmental Protection Agency, undated, 2000, 2001). The total P criteria for the Delta has been flagged as inordinately high, and the US EPA has recommended further study to determine if it reflects measurement error, notational error, statistical anomaly, natural enriched conditions, or cultural impacts (U. S. Environmental Protection Agency, 2001).

Total P concentrations were also examined for seasonality by plotting mean concentration (averaged across all available sites and through all time) versus month of the year for Delta and Hill sites (Figure 5). Delta mean total P concentrations were higher throughout the year and exhibited strong seasonal behavior quite similar to that reported by Pennington (2004) for 22 sites on Delta rivers sampled between 1992 and 1997. Pennington (2004) reported peak concentrations in April that smoothly declined to a minimum in September, while our computations showed peak levels occurred slightly later (in May), concurrent with total N and nitrate peaks. Hill total P concentrations were positively correlated with monthly mean discharge ($r = 0.89$, $p < 0.0001$), but Delta P concentrations were not.

DISCUSSION

Extra-basin sources

Nutrients enter wetlands, streams, and lakes in the Yazoo River Basin from the atmosphere, from point source discharges, and in runoff. Dissolved N also enters surface waters in groundwater. Nutrients in runoff and groundwater are derived from soils, legumes, atmospheric deposition, human or animal wastes and fertilizer. Average estimated N and P inputs to the Yazoo Basin just from fertilizer, manure and atmospheric deposition are about 124 000 and 16 000 metric tons, respectively (Ruddy *et al.*, 2006; Shields *et al.*, 2008). About 77% of all estimated N input and 76% of all estimated P input are in the form of fertilizer applied to farms, with an additional 10% and 23% of the N and P, respectively, from livestock manure. Nonfarm fertilizer input comprises less than 1% of the nutrient loadings.

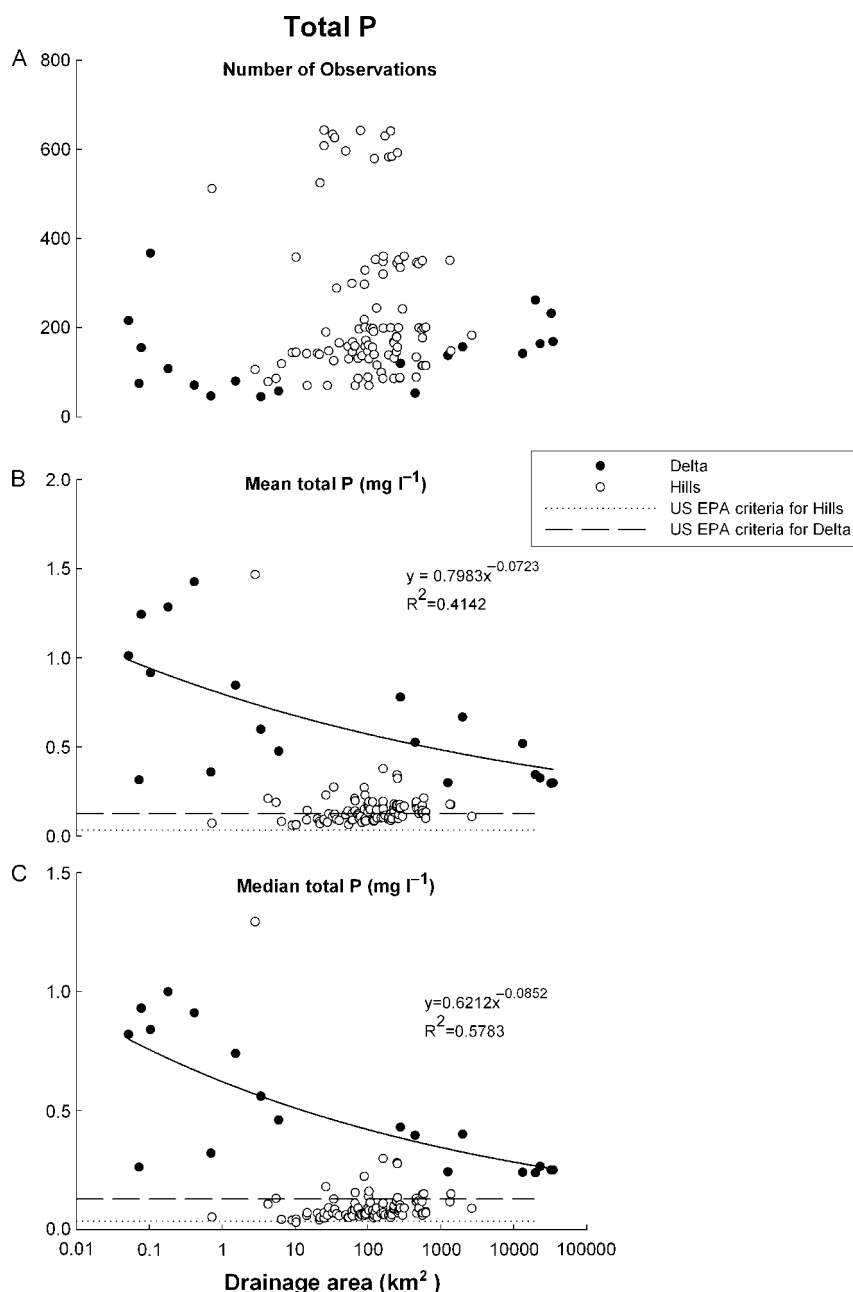


Figure 4. Total phosphorus concentrations in mg l^{-1} versus contributing drainage area for sites along streams in the Yazoo Basin. (A) Number of samples, (B) Mean concentrations, and (C) Median concentrations. Curves are regressions based on Delta data only and R^2 values and equations are for these regressions.

Differences between Delta and Hill region land use patterns appear to account for most of the difference in nutrient concentrations, consistent with other reports for the southeastern Coastal Plain of the US (Harned *et al.*, 2004). The Delta receives a higher nutrient loading than the Hills due to fertilizer applications to row crops. About 56% of both N and P inputs to the basin were from fertilizer applied to Delta farms, while about 20% of inputs were due to manure input to Hill counties. Yazoo basin-wide mean annual N and P loading rates average 3.39 and 0.43 t km^{-2} , respectively (Ruddy *et al.*, 2006; Shields *et al.*, 2008). Nationally, most watersheds with greater than 2.24 t km^{-2} mean annual N loading have average stream N concentrations greater than 2.9 mg l^{-1}

(Kleiss *et al.*, 2000). However, as shown in Figure 2B, 12 of 19 Delta and 54 of 56 Hill site mean concentrations were lower than this, perhaps because of a warmer, wetter climate that increases microbial activity in the winter and also due to the increased uptake of N by plants during the longer growing season (Kleiss *et al.*, 2000).

Transport of nutrients from land to water

Information on nutrient flux from land to water is available from long-term studies of runoff quality from fields and small plots, but not from larger areas. These studies highlight the unsteady nature of nutrient flux from cultivated lands. Often the yield from a single storm can be nearly equal to the annual average (Schreiber *et al.*,

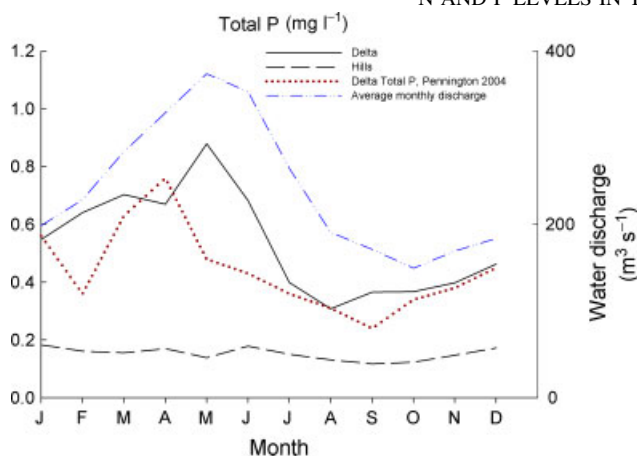


Figure 5. Mean total phosphorus concentrations of each month for stream sites in the Yazoo Basin. Mean monthly discharge is for USGS gage 7268000, which is located on a major stream in the Hills upstream of a flood control reservoir as shown in Figure 1.

2001), and levels tend to be elevated following fertilizer applications (McDowell *et al.*, 1989). Most of the N and P leaving experimental fields and erosion plots has been associated with eroded sediment, and annual yields have been correlated with runoff volume (McDowell and McGregor, 1984; McDowell *et al.*, 1989). Yields are highest for conventionally tilled lands, two to six times lower for conservation- and no-till fields, and about 20 times lower for forested lands (Schreiber *et al.*, 2001). Delta stream N and P concentrations were highly correlated with suspended sediment concentration and turbidity, and are highest in late winter and early spring (Pennington, 2004). A recent survey of Wisconsin streams showed that dissolved nitrate is the major form of dissolved N in streams draining agricultural landscapes (Stanley and Maxted, 2008). Since Delta monthly nitrate means were only about 30–40% as great as total N (Figure 3, also see Rebich and Demcheck, 2007), it seems likely that much of the N that is transported in Delta streams and rivers is in particulate form associated with suspended sediment rather than as dissolved nitrate.

The total yields of N and P from Yazoo Basin fields and forests may be roughly estimated by multiplying published average annual yields for fields and plots times the reported areas for each major land use (Shields *et al.*, 2008). Loads from cropland were estimated to account for 93% of the total N load and 90% of the total P load. The average annual load of total N reaching Yazoo Basin streams was about half of the amount input to the watershed in the form of manure, chemical fertilizer and atmospheric deposition. Of course, these estimates are very rough and do not take into account N sources such as eroded soils or legumes. Presumably the difference between the mass of applied N and the N load reaching streams is due to removal in the form of crops and storage and processing in field edges, ditches, ephemeral streams, wetlands, ponds, and lakes. Dabney *et al.* (2004) noted low shallow groundwater nitrate concentrations adjacent to an intensively cropped area in the Delta and suggested that the “warm soil temperatures, abundant rainfall, and a

year-round labile carbon supply” led to high rates of soil denitrification. Lack of accessible water quality data for the four major flood control reservoirs presents a major problem in understanding Yazoo Basin nutrient budgets since reservoirs often have significant effects on riverine nutrient transport (Straškraba *et al.*, 1995; Henson *et al.*, 2007; Bosch, 2008).

In contrast to N, the estimated average P load reaching Yazoo Basin streams was nearly twice as great as the average mass of P applied to the watershed in the form of fertilizer or manure (Ruddy *et al.*, 2006; Shields *et al.*, 2008). Yazoo Basin soils, particularly those in the Delta, are rich in P (Brown *et al.* undated, Locke *et al.* 2001, Walker *et al.* 2003, Ochs and Milburn 2003) and Delta farmers remove more P in harvested crops than they apply in fertilizer (Dabney *et al.*, 2004). The relatively high P concentrations in streams may be due to eroded soils, which may contain as much as 0.10% P (Yuan *et al.*, 2005). Since rates of sediment yield for the Hill watersheds are so high ($\sim 1,000 \text{ t km}^{-2} \text{ year}^{-1}$, Shields *et al.*, 1995), and since most of this sediment is derived from streambank erosion (Simon and Thomas, 2002) a soil P content of only 0.02% (Bledsoe *et al.* 2001; Hubbard *et al.*, 2003) would provide an annual P input from Hill streambank erosion of about 3400 t, assuming the Hills comprise about half or 17 000 km² of the Yazoo Basin. In fact, since P is preferentially associated with finer (clay) sediments, suspended sediments from smaller watersheds are greatly enriched in P relative to watershed soils (Duffy *et al.*, 1978), reaching levels of 0.10% P even in runoff from forested watersheds.

Yazoo Basin nutrient export

Detailed analysis of nutrient flux from the Yazoo Basin into the Mississippi River has been presented by Runner *et al.* (2002) and Coupe (2006). They found Yazoo Basin's total N contributions to the Mississippi were only half as great as the earlier estimates for the Lower Mississippi Basin and selected watersheds within the Upper Mississippi and Ohio Basins during 1980–1996. Using the mean measured load of total N in the Yazoo River for 1996–2004 reported by Coupe (2006), 0.744 t km^{-2} , and the watershed area of 34 600 km², the mean annual flux of total N is 25 700 t, or about 21% of the mean estimated input in the form of fertilizer and atmospheric deposition (Ruddy *et al.*, 2006). This figure is also about 37% of the total N load reaching Yazoo Basin streams estimated by Shields *et al.* (2008), highlighting the importance of sites and processes that act as N sinks within the basin.

The average annual loads of total N and nitrate (NO₃) in the Yazoo River accounted for 1.4 and 0.7%, respectively, of the total loads in the Mississippi River during 1996–2000. The Yazoo Basin produced 2.8% of the flow of the Mississippi River during the same period (Runner *et al.*, 2002). While Yazoo Basin's N yield is measurable and certainly important, reducing exported N by 30%, a figure suggested by the Mississippi River/Gulf

of Mexico Watershed Nutrient Task Force (2001), would not necessarily produce a measurable N reduction or improved ecological conditions in the Gulf of Mexico (Bianchi *et al.*, 2008). Furthermore, Yazoo Basin N yields are much lower than those for corn-belt watersheds of the Upper Midwest (Goolsby and Battaglin 1993, 2000; Alexander *et al.*, 2000; Kleiss *et al.*, 2000; U. S. Environmental Protection Agency, 2007). Nevertheless, reduced nutrient concentrations in Yazoo Basin streams, particularly in the Delta, might have beneficial impacts on water quality and aquatic ecology within the basin itself. The degree to which the current nutrient levels impair Yazoo Basin stream ecosystems, if at all, is currently unknown.

Coupe (2006) also used measured water discharges and total P concentrations to compute an estimated mean annual Yazoo Basin P yield of 0.183 t km^{-2} for the period 1996–2004. Using this figure and the watershed area of $34\,600 \text{ km}^2$, the mean annual flux of total P is 6330 t, or about 40% of the mean estimated P input to the watershed in the form of fertilizer and atmospheric deposition as presented above. This figure is also about 21% of the total P load reaching Yazoo Basin streams estimated by Shields *et al.* (2008), highlighting the importance of sites and processes such as sediment deposition and storage zones that act as P sinks (Alexander *et al.*, 2008). The average annual loads of total P and orthophosphorus in the Yazoo River accounted for only 3.4 and 1.6%, respectively, of the total loads in the Mississippi River during 1996–2000 (Runner *et al.*, 2002).

SUMMARY AND CONCLUSIONS

Available data regarding N and P concentrations within the Yazoo River Basin is patchy and fragmented in space and time, particularly with regard to concurrent stream flow data that would allow computation of loads and budgets. The lack of available data for the four large flood control reservoirs that mediate flows and fluxes from the Hills to the Delta is a major hindrance to understanding the system. However, it is clear that nutrient transport differs widely for the two major physiographic regions (Delta and Hills). Concentrations of total N and nitrate in the Delta peak strongly in spring and early summer when agricultural fertilizers are applied and runoff occurs from bare, tilled soil. Total P concentrations in the Delta peak in spring (May), corresponding to periods of higher runoff. Concentrations of N and P in Hill streams do not exhibit seasonal trends, but tend to be only one-third to two-thirds as great as the Delta levels. Concentrations in Delta streams tend to decrease with increasing watershed size, perhaps reflecting dilution from Hill tributaries, instream retention and processing, or as an anomaly of the available data, since the only small Delta watersheds that have been monitored were intensely cultivated. Average nutrient concentrations throughout the Yazoo Basin exceed EPA criteria by factors of 3–4. However, links between nutrient levels and stream ecosystems in

the Yazoo basin, particularly in the Delta, are either unknown or poorly established.

Yields of N and P from the Yazoo basin to the Lower Mississippi River are about 37 and 21%, respectively, of the estimated loads that are input to the Yazoo basin. The difference between the amount of N and P that are input to the basin as fertilizer, manure, and atmospheric deposition and the amount that reaches the Mississippi River highlights the importance of processes such as sedimentation, denitrification and uptake that occur in lakes, streams and wetlands. Clearly, the ecological services provided by these features should be carefully managed at the landscape scale.

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