THE DEMONSTRATION EROSION CONTROL PROJECT: ASPECTS OF WATER QUALITY IN ABIACA CREEK, MISSISSIPPI

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ABSTRACT

Landscape-scale stream channel erosion and ensuing incision in north Mississippi hill lands have been responsible for loss of arable land and degradation of aquatic habitats and water quality. Because of this, in 1983, Congress mandated a federal interagency demonstration project focusing on channel erosion in the upper Yazoo River drainage basin. As part of the Demonstration Erosion Control project (DEC), water quality in Abiaca Creek and six additional watersheds are routinely monitored to observe potential improvements after channel stabilization / flood control / rehabilitation technologies were implemented. Abiaca Creek watershed, located in portions of Caroll, Holmes, and Leflore Counties, Mississippi, is part of the upper Yazoo River drainage basin in north Mississippi and flows through Matthews Brake National Wildlife Refuge (MBNWR). From 1993-1996 setback levees were constructed along the lower reach of Abiaca Creek to mitigate sedimentation within MBNWR. The purpose of this study was to examine selected water quality parameters both spatially and temporally in Abiaca Creek using univariate and multivariate analyses to elucidate trends. The watershed was monitored monthly at eight sites from 1992-2002 for 14 water quality parameters. Results of spatial univariate analysis showed significant differences among sites for 13 of 14 water quality variables, whereas temporal analysis revealed differences among years for 12 of 14 variables. Exploratory multivariate analysis revealed spatial trends in water quality with upstream sites having overall better water quality than downstream ones. Observed spatial trends in water quality are influenced by localized geographic characteristics (e.g. localized land use practices, gravel mining, flood control structures, etc.). Temporal results showed a greater complexity in annual water quality with trends less evident and most likely associated with fluctuations in annual climatic conditions. Changes in water quality were cumulative due to major watershed inputs with instream reservoirs resetting dissolved oxygen and ammonia levels.

INTRODUCTION

Stream channel instability and erosion due to cultivation and land-development practices in the north Mississippi hill-land region have presented water quality and habitat degradation problems at a landscape scale (Cooper, Knight and Shields 1997). As a result, in-stream suspended sediments and bedload materials are, by volume, one of the largest pollutants in the United States (Fowler and Heady 1981). Agricultural lands are a significant source of sediments and cause concern for several reasons. They indicate the loss of productive agricultural soil, carry nutrients and pesticides that can adversely affect water quality and aquatic organisms, and degrade habitats via deposition and accumulation in streams and reservoirs (Cooper and Knight 1991).

Because of this, in 1983, Congress mandated a federal interagency demonstration project focusing on channel erosion in the north Mississippi hill land region that compose the upper Yazoo River drainage basin. In 1984, the U.S. Army Corps of Engineers, Vicksburg District and the USDA Natural Resources Conservation Service were directed to establish demonstration watersheds addressing critical erosion problems within the north Mississippi hill lands and develop measures to control flooding, reduce erosion, and stabilize stream channels (Cooper and Knight 1991; Lizotte et al. 2003a). As part of the Demonstration Erosion Control project (DEC), the USDA-ARS National Sedimentation Laboratory was requested by the U.S. Army Corps of Engineers, Vicksburg District to characterize and routinely monitor water quality in seven watersheds to assess potential improvements after flood control, rehabilitation, and channel stabilization, technologies were implemented.

Abiaca Creek, while not originally part of the DEC project (being authorized by the Energy and Water Development Appropriation Act of 1990), has similar goals as those for other DEC watersheds and has become integrated within the DEC project. Historically, the watershed has had problems of stream channel instability, erosion, habitat degradation, and loss of valuable agricultural topsoil. From 1993 to 1996, setback levees were constructed along the lower reach of Abiaca Creek to mitigate sediment deposition within Matthews Brake National Wildlife Refuge (MBNWR) caused by upstream gravel mining operations (Cooper and Davis 2000).

The purpose of this study was to examine and describe selected water quality parameters both spatially and temporally in Abiaca Creek to elucidate trends.

MATERIALS AND METHODS

Study Site

Abiaca Creek watershed (Fig. 1), a tributary of the Yazoo River, has a drainage area of approximately 246 km^2 (Cooper and Davis 2000). The watershed, located in portions of Caroll, Holmes, and Leflore Counties, Mississippi, is part of the upper Yazoo River drainage basin in the north Mississippi hill-land region and flows through MBNWR.

Sample Collection and Analysis

Surface water samples (1 L) from Abiaca Creek were collected and preserved (via ice) monthly. *In-situ* water chemistry measurements of temperature, conductivity, dissolved oxygen, and pH were conducted at each site using calibrated electronic instruments.

Aqueous samples were transported to the USDA-ARS National Sedimentation Laboratory, Oxford, Mississippi for further physical, chemical and biological analyses. Selected water parameters measured were total solids, dissolved solids (dried at 180° C), suspended solids (dried at 103-105° C), total ammonium-N (phenate method), total nitrate-N (cadmium reduction method), soluble (filterable) phosphorus (ascorbic acid), total phosphorus (persulfate digestion + ascorbic acid), chlorophyll *a* (pigment extraction and spectrophotometric determination), fecal coliforms (membrane filter technique), and enterococci (membrane filter technique). All water quality parameters were analyzed using standard methods (APHA, 1998).

Data Analysis

Descriptive statistics were used to provide means and standard deviations for all water quality parameters measured. Univariate analysis was conducted using a one-way analysis of variance (ANOVA) with Tukey's multiple range tests to ascertain significant differences among sites (spatial) and years (temporal) within Abiaca Creek for all water quality parameters (Steel, Torrie, and Dickey 1997). When assumptions for parametric tests (normality and equal variance) could not be met, a nonparametric Kruskal-Wallis ANOVA on ranks with Dunn's multiple range tests was performed to test for significance (Steel, Torrie, and Dickey 1997). Parameters were tested for significance at the 5% level. All univariate statistical analyses were completed using SigmaStat statistical software (SPSS 1997).

Multivariate exploratory analysis was performed using a principal components analysis on spatial and temporal data. Matrices of Pearson's product-moment correlation coefficients were computed and distance coefficients were derived for standardized water quality variables. A matrix of correlations among water quality variables was computed and the first two principal components extracted (Berenson, Levine, and Goldstein 1983). All multivariate statistical analyses were completed using the Numerical Taxonomy System of programs (NTSYS-pc; Rohlf 1990).

RESULTS AND DISCUSSION

Spatial Analysis

Complete description of all water quality parameters measured at each site in Abiaca Creek watershed appears in Table 1. Univariate analysis revealed significant differences for 13 of 14 water quality variables. Only temperature did not significantly vary among the eight sites examined. Temperatures were comparable to other north Mississippi hill land streams previously reported (Cooper and Knight 1991; Cooper, Knight, and Shields 1997; Lizotte et al. 2002a). Values followed seasonal fluctuations typical of temperate-zone streams and were within the range to support aquatic life (Cole 1988; Allen 1995).

Conductivity measurements and related total dissolved solids (the total concentration of soluble ions) varied by site and showed similar patterns of variation. Upstream sites in both Abiaca and Coila Creeks had lower mean values than successive downstream sites (Table 1). Although differences in these two parameters were evident among sites within the watershed, values were within the range of those previously reported for other north Mississippi hill land watersheds (Cooper and Knight 1991; Cooper, Knight and Shields 1997; Lizotte et al. 2002a) and were well within the limits to support aquatic life (Allen 1995).

Dissolved oxygen is a fundamental environmental requirement for most aquatic life and its availability determines the behavior and distribution of most aquatic organisms (Abel 2000). Oxygen levels within Abiaca watershed rarely dropped below 4 mg/L, a long-term critical concentration considered necessary to support aquatic life (USEPA 1987). Levels followed seasonal fluctuations typical of temperate-zone streams (Fig. 2). Variation in mean dissolved oxygen levels were greatest at downstream sites (1, 2, and 6) and lowest at sites 4 and 8 (Table 1) revealing influences of flood retarding structures and ensuing outflow from reservoirs Y34-8 and Y34-6 (Fig. 1).

Values for pH also varied along stream length with downstream sites typically having greater mean pH than upstream ones (Table 1). Most pH values ranged from 5.5 to 8.0 (Fig. 2). Watersheds within the north Mississippi hill land region typically have acidic stream water (Cooper and Knight 1991; Cooper, Knight and Shields 1997; Lizotte et al. 2002a) due, in part, to runoff of acidic top soils (Switzer and Pettry 1992; Eick, Brady and Lynch 1999) during storm events. However, sites 1 and 2, encompassing that portion of Abiaca Creek flowing through MBNWR, had mean pH values above 7 and ranging from about 6 to 8 (Table 1). Two factors led to more basic pH at sites 1 and 2. The stream flowed through alluvial plain soil that has a higher pH. Also, as water flow slowed from a drastic reduction in slope, it received much additional sunlight. The resulting increase in phytoplankton (increasing chlorophyll concentrations) removed H+ ions and, as is typical in unbuffered waters, shifted pH toward basic.

Particulate materials entering streams and rivers as total solids and its constituent, total suspended solids (TSS) are considered a major contaminant of water bodies in the U.S. (Cooper 1993). Suspended sediments in rivers and streams affect water quality (Angino and O'Brien 1968), and, as a result, aquatic life. Water quality impacts from sediment loading can include obstruction of light penetration and ensuing reduction in photosynthetic activity, increased loading of pesticides and nutrients adsorbed to sediment surfaces, and increases in bacterial contamination (Cooper and Knight 1989; Knight and Cooper 1996). Abiaca Creek watershed is located in a physiographic region with highly erodable soils and accelerated erosion due to agricultural practices, stream channel modification or replacement, and land-use development (Shields, Knight, and Cooper 1998). In the present study, significant differences in TSS were observed across sites. In general, upstream sites in both Abiaca and Coila Creeks had lower mean values than successive downstream sites (Table 1). Mean values ranged from 34 to 107 mg/L with most values between 10-100 mg/L (Fig. 2) and maximum values between 362-1833 mg/L (Table 1). Maximal TSS concentrations considered optimal for warm water fish production is estimated at 80-100 mg/L (Cooper and Knight 1991). Although maximum values observed in Abiaca Creek watershed exceeded this limit, concentrations typically occurred during high flows associated with storm events and were not sustained over long periods of time. Comparisons of TSS values with other watersheds in the same physiographic region were similar (Cooper and Knight 1991; Cooper, Knight and Shields 1997; Lizotte et al. 2002a).

In-stream nutrient concentrations are an integral part of stream ecosystem productivity. Excessive inputs from anthropogenic sources can alter trophic state and lead to significant eutrophication (Dodds 2002). Phosphorus, frequently a limiting factor of primary productivity in nutrient poor freshwater systems (Cole 1988; Allen 1995), can affect periphytic autotrophs that are especially sensitive to fluctuations in soluble reactive phosphorus concentrations and excessive levels can lead to nuisance algal blooms, associated depleted dissolved oxygen concentrations, degradation of habitat, and reduction in fish diversity (Allen 1995; Abel 2000). Within Abiaca Creek, both soluble phosphorus (SP) and total phosphorus (TP) mean concentrations varied significantly along stream length with downstream sites typically having greater phosphorus than upstream sites (Table 1; Fig. 3). Similar spatial patterns in TSS concentrations show the close association of phosphorus and sediment load. Mean SP concentrations ranged from 11 μg/L to 27 μg/L with the highest observed concentration of 329 μg/L occurring at site 6, just upstream of the Coila Creek – Abiaca Creek confluence (Fig. 1). Mean TP concentrations ranged from 63 μg/L to 175 μg/L with the highest observed concentration of 2,463 μg/L occurring at site 8, just downstream of flood control reservoir Y34-6 along Coila Creek (Fig. 1). However, phosphorus concentrations did not attain levels sufficient to cause oxygen depleting algal blooms. Abiaca Creek phosphorus levels were comparable with other north Mississippi hill land streams such as Otoucalofa Creek (Cooper and Knight 1991; Cooper, Knight and Shields 1997), Long Creek (Cooper and Knight 1991), and Toby Tubby Creek (Lizotte et al. 2002a).

Nitrogen, measured as dissolved inorganic nitrogen species ammonium-ion and nitrate, can, to a lesser extent than phosphorus, also be a limiting nutrient in lotic systems. Like phosphorus, neither nitrogen species reached sustained levels that would lead to eutrophication. Ammonium-ion concentrations in Abiaca Creek ranged from 70 μg/L to 149 μg/L and significantly varied by site. Levels were lowest at downstream sites (1, 2, and 6) and highest at sites 4 and 8 (Table 1; Fig. 4). Concentrations revealed influences of flood retarding structures and ensuing outflow from reservoirs Y34-8 and Y34-6 (Fig. 1) and were inverse to dissolved oxygen levels. Mean nitrate concentrations ranged from 150 μg/L (at site 5) to 226 μg/L (at site 7) with the highest observed concentration of 2,934 μg/L occurring at site 6, just upstream of the Coila Creek – Abiaca Creek confluence (Fig. 1). Although mean nitrate concentrations varied by site, no clear spatial trends were evident. Comparable ammonium-ion and nitrate concentrations occurred in other streams within the same physiographic region (Cooper and Knight 1991; Cooper, Knight and Shields 1997; Lizotte et al. 2002a).

Sestonic (suspended) chlorophyll *a*, an indirect measure of stream algal biomass (Jones, Smart and Burroughs 1984; Gregor and Marsalek 2004), can be used in conjunction with nutrient data to assess the trophic state of a lotic system (Dodds, Jones and Welch 1998; Dodds 2002). Excessive stream algal biomass (algal blooms) due to increases in nutrients (eutrophication) can have negative impacts on the lotic ecosystem such as alteration of habitat, depressed dissolved oxygen levels, discoloration of the water, and production of toxins harmful to other aquatic biota (Abel 2000). Abiaca Creek mean chlorophyll *a* concentrations varied significantly along stream length with downstream sites typically having greater chlorophyll *a* levels than upstream sites (Table 1; Fig. 3), in close association with mean total phosphorus (and to a lesser extent soluble phosphorus) suggesting phosphorus is the limiting nutrient in this system. Comparable chlorophyll *a* values occur within similar watersheds throughout the region (Lizotte et al. 2002b; Lizotte et al. 2003a; Lizotte et al. 2003b).

Stream watershed contamination by bacteria has been a continuing concern throughout the United States for several decades (Bohn and Buckhouse 1985; Cooper and Lipe 1992). Sources of bacteriological contamination are difficult to pinpoint due to the various routes through which they can enter a system, including discharge from a wastewater treatment facility, direct runoff from storm events, groundwater flow, resuspension of bottom sediments within the watershed channel by stream flow or animal disturbance, and direct contamination from animal defecation (Bohn and Buckhouse 1985; Cooper and McDowell 1989; George, Anzil and Servais 2004; Muirhead et al. 2004). In general, downstream sites had greater densities than upstream ones (Table 1; Fig.4) with the exception of fecal coliforms at site 3 (4000 colonies/100 ml) and enterococci at site 5 (655 colonies/100 ml). Bacteriological contamination observed in Abiaca Creek was similar to other north Mississippi hill land streams such as Otoucalofa Creek (Cooper and Knight 1991; Cooper, Knight and Shields 1997), Long Creek (Knight and Cooper 1989; Cooper and Knight 1991), Toby Tubby Creek, and Burney Branch Creek (Lizotte et al. 2002a).

Exploratory Principal Component Analysis (PCA), used to elucidate spatial water quality trends in Abiaca Creek, showed component I incorporating 64% of the total water quality variation. The first component had high loadings for 11 of 13 variables examined and revealed spatial trends in conductivity, pH, solids, phosphorus, and biologicals with upstream sites having overall progressively better water quality than downstream ones (Fig 5). The second component accounted for 16.5% of the total variation. Component II had a high positive loading for dissolved oxygen and a high negative loading for ammonium-N. This confirmed our observations on the influences of flood retarding structures and ensuing outflow from reservoirs Y34-8 (site 4) and Y34-6 (site 8) where dissolved oxygen levels were lowest and ammonium-ion levels greatest (Fig. 5). Other studies observed PCA to be very useful in elucidating spatial water quality trends when examining multiple parameters simultaneously (Pardo 1994; Cao, Williams and Williams 1999). Pardo (1994) noted that the use of PCA allowed a better explanation of factors influencing the dynamics of water quality within a watershed.

Temporal Analysis

Complete description of all water quality parameters measured for each year in Abiaca Creek watershed appears in Table 2. Univariate analysis revealed significant differences for 12 of 14 water quality variables. Only temperature and conductivity did not significantly vary among the eleven years examined (1992-2002).

Dissolved oxygen concentrations varied by year with 1994 having significantly greater mean dissolved oxygen levels than all other years. Dissolved oxygen levels below the critical limit of 4 mg/L occurred in only 3 of 11 years (1994, 1996, 1998; Table 2) although only 1996 had mean monthly levels below the critical limit for all sites (Fig. 2). As a result, sustained values below 4 mg/L were not evident throughout the watershed. Cooper and Knight (1991) described 2-year seasonal dissolved oxygen trends in Otoucalofa and Long Creeks that were similar to this study. Long-term (10-year +) trends in Otoucalofa Creek dissolved oxygen concentrations produced similar yearly effects observed in Abiaca Creek (Cooper, Knight and Shields 1997).

Variation in Abiaca Creek mean pH values across years showed a four to five-year cycle in this parameter. Lowest mean pH occurred in 1992 and progressively increased each year until 1995. Values declined again in 1997 and, again, progressively increased until 1998 before progressively declining until 2002 (Table 2). Yearly fluctuations in Otoucalofa Creek (another north Mississippi hill land stream) were evident, however a similar pattern in annual pH variations was not (Cooper, Knight and Shields 1997). Aquatic organisms can be sensitive to even small changes in pH and levels between 5 and 9 generally support a diversity of biota (Allen 1995; Abel 2000). The lowest and highest pH values recorded in Abiaca Creek, 5.3 (2000 and 2002) and 8.37 (1995), are within the critical pH range with fluctuations in mean monthly pH consistently between 6 and 8 (Fig 2).

Total solids and its constituent, total suspended solids (TSS) had significant but limited annual variation with 1993 and 2002 having the lowest mean annual TSS and 1996 the highest (Table 2). Highest TSS concentrations considered optimal for warm water fish diversity is estimated at 80 to 100 mg/L (Cooper and Knight 1991). Mean monthly maximum values observed in Abiaca Creek watershed occasionally exceeded this limit (Fig. 2). These increased concentrations typically occurred during high flows associated with storm events or during gravel mining operations and were not sustained over long periods of time with the exception of site 1 during 1996 when significant levee construction occurred along MBNWR (Cooper and Davis 2000). Long-term TSS concentrations produced no discernable increasing or decreasing trends. Values for the 11-year period appeared relatively stable and were similar to long-term trends observed in Otoucalofa Creek (Lizotte et al. 2003a).

All nutrient species examined in Abiaca Creek watershed showed significant annual variation. Although levels of the two measured phosphorus species fluctuated yearly, no clear trend was evident. Mean SP concentrations in 1994 were greater than all other years whereas mean TP levels in 1999 were lowest for the 11 year period (Table 2). Fluctuations in long-term trends of mean monthly total phosphorus levels in Abiaca Creek (Fig. 3) were similar to another north Mississippi hill land stream, Otoucalofa Creek (Lizotte et al. 2003a). However, higher TP levels were sustained at site 1 during 1996 (Fig. 3) when significant levee construction occurred along MBNWR (Cooper and Davis 2000). As with phosphorus, the two nitrogen species studied, ammonium-N and nitrate-N fluctuated annually, but, again, no clear trend was evident. Levels of ammonium-N in Abiaca Creek during 1999 and 2002 were less than all other years with mean concentrations of 59 and

38 µg/L, respectively (Table 2). Nitrate levels within the watershed significantly increased in 1998, peaked in 1999, and returned to previous levels by 2000 (Table 2; Fig. 4). Seasonal trends in aqueous nitrogen species levels within watersheds in regions of intensive agriculture typically show increases in the fall and winter followed by decreases in spring and summer (Shirmohammadi, Yoon and Magette 1997; Bouraoui, Turpin and Boerlen 1999). Although significant portions of the Yazoo basin are intensively farmed, seasonal trends in ammonium-N and nitrate-N concentrations in Abiaca Creek watershed (Fig. 4) are not indicative of impacts from intensive agricultural practices.

Annual variations in mean chlorophyll *a* concentrations within Abiaca Creek watershed were evident. Mean concentrations were lowest during 1992 (3.87 µg/L) and highest in 1998 (14.84 µg/L) with an overall trend of increasing chlorophyll *a* levels from 1992 to 2002 (Table 2) but not in association with any annual nutrient values. Mean monthly values indicate general seasonal trends with increases during spring and summer followed by decreases during fall and winter (Fig 3). Similar temporal trends in chlorophyll *a* concentrations was observed by Lizotte et al. (2003b) for Otoucalofa Creek in the Yazoo basin. Possible explanations, aside from nutrients, for the overall increase in chlorophyll *a* levels annually include possible reservoir aging and reduction in canopy cover, the influence of flood control structures (i.e. setback levees along MBNWR) altering flows and allowing for more stable habitat, and improved control and mitigation of urban and rural pesticide runoff, specifically herbicides, allowing an increase in primary productivity.

Yearly changes in bacterial contamination were evident within Abiaca Creek watershed. Variation in fecal coliform densities across years showed 1992 had the lowest mean density and 1994 the highest (Table 2). Mean monthly fecal coliform densities failed to produce any seasonal trends (Fig. 4) and suggest the source of contamination could be primarily wildlife. Annual variation in enterococci densities showed 1995 had the lowest mean density and 2001 the highest. Mean densities were generally lower from 1992 to 1996 and increased from 1997 to 2002. While both runoff and increasing discharge levels with associated suspended solids flush regions in and around the watershed where wildlife and livestock may defecate, neither bacterial contaminant measured coincided with suspended solids levels and is similar to results observed in similar watersheds by Cooper and Knight (1991).

Exploratory PCA was conducted to elucidate temporal water quality trends in Abiaca Creek watershed. Analysis showed the first three components incorporating just 66.3% of the total water quality variation. The first principal component accounted for 29.9% of the total water quality variation. It had high positive loadings for 5 of 12 parameters and revealed temporal trends in TS, TSS, TP, ammonium-N, and fecal coliform levels with fluctuations every 1 to 2 years (Fig. 5). Principal component II accounted for 18.5% of the total variation and had high loadings for TS, TSS, and SP with fluctuations cycling every 5 to 6 years (Fig. 5). The third principal component accounted for 17.9% of the total variation in water quality and loaded high for dissolved oxygen and fluctuated every 2 years (Fig. 5).

SUMMARY

Spatial water quality trends in Abiaca Creek watershed changed longitudinally from upstream to downstream with upstream sites having overall better water quality than downstream ones. Dissolved oxygen and ammonium-N levels were influenced by localized flood control structures. Overall water quality was also influenced by local geographic characteristics such as land-use practices, gravel mining operations and flood control structures. Temporal water quality trends were increasingly complex and had varying cyclic fluctuations varying from 1 to 5 years for various water quality parameters. Temporal trends were influenced by climatic conditions and varying localized events such as changes in land-use practices, gravel mining operations, and construction of setback levees along MBNWR.

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Table 1. Descriptive statistics, mean±SD (range), of selected water quality parameters from 8 sites within Abiaca Creek watershed (1992-2002).

Water quality parameter	Abiaca Creek Site							
	1	2	3	4	5	6	7	8
Temperature (C)	18.7±7.4 (4.3-31.3)	18.5±7.1 (4.5-30.7)	18.3±6.1 (5.1-27.9)	18.7±6.1 (5.9-28.9)	18.3±5.9 (6.1-27.5)	19.3±6.3 (6.0-29.4)	18.0±3.5 (9.2-27.3)	19.5±6.7 (6.1-29.9)
Conductivity (μmhos/cm)	92.4±30.0 (20.2-170.0)	90.9±27.8 (18.6-164.0)	78.6±26.3 (16.0-138.0)	74.9±33.6 (15.9-164.5)	58.2±12.9 (5.0-91.0)	76.8±22.3 (14.0-124.0)	50.3±8.2 (9.0-85.0)	66.7±19.8 (16.3-114.0)
Dissolved oxygen (mg/L)	9.20±1.87 (3.45-14.47)	9.17±1.75 (3.79-14.38)	8.91±1.53 (3.06-13.35)	8.07±1.93 (3.82-12.45)	8.88±1.36 (5.66-12.65)	9.18±1.53 (4.80-12.91)	8.95±1.27 (4.35-11.82)	8.74±1.69 (3.30-13.06)
pH	7.34±0.57 (5.96-8.37)	7.22±0.51 (5.92-8.23)	6.93±0.53 (5.90-8.32)	6.64±0.49 (5.60-7.99)	6.95±0.54 (5.80-8.20)	6.93±0.48 (6.00-8.02)	6.50±0.59 (5.30-8.00)	6.77±0.52 (5.70-8.10)
Total solids (mg/L)	176±117 (73-698)	177±141 (74-1344)	135±88 (66-599)	123±77 (43-620)	109±161 (37-1379)	176±232 (58-1929)	88±62 (37-421)	117±72 (53-564)
Dissolved solids (mg/L)	77±22 (11-150)	78±21 (0-148)	70±20 (0-150)	65±19 (0-110)	57±17 (0-96)	69±18 (12-119)	55±21 (5-219)	63±17 (23-134)
Suspended solids (mg/L)	98±122 (0-631)	99±146 (0-1252)	64±97 (0-558)	58±82 (0-531)	53±164 (0-1321)	107±233 (0-1833)	34±55 (0-362)	53±77 (0-503)
Soluble phosphorus (μg/L)	27±21 (0-99)	22±25 (0-239)	17±26 (0-212)	11±16 (0-149)	11±13 (0-73)	18±33 (0-329)	13±19 (0-146)	15±21 (0-170)
Total phosphorus (μg/L)	175±146 (0-876)	166±144 (0-883)	142±120 (6-661)	123±117 (0-731)	94±120 (0-714)	179±248 (0-1475)	63±84 (0-475)	132±225 (7-2463)
Ammonium-N (μg/L)	84±97 (0-579)	88±95 (0-548)	97±115 (0-728)	149±124 (0-851)	90±106 (0-907)	80±81 (0-525)	70±107 (0-1007)	102±114 (0-939)
Nitrate-N (μg/L)	178±180 (0-1590)	164±147 (0-1430)	191±149 (0-1254)	203±212 (0-1656)	150±123 (0-611)	200±276 (0-2934)	226±286 (0-2158)	167±173 (0-1465)
Chlorophyll a (μg/L)	12.85±16.91 (0-91.89)	12.63±21.22 (0-122.39)	10.13±12.00 (0-77.77)	11.47±13.52 (0-73.97)	6.01±8.68 (0-43.50)	12.48±23.21 (0-216.90)	5.75±9.69 (0-77.09)	9.78±11.34 (0-68.26)
Fecal coliform (# colonies/100 ml)	2946±5373 (0-37600)	2610±5319 (0-31600)	4001±19506 (0-210000)	2518±6242 (0-55600)	1951±6121 (0-59000)	2344±6470 (0-64000)	1381±3893 (0-30800)	1130±1729 (0-11600)
Enterococci (# colonies/100 ml)	847±2078 (0-20800)	795±2299 (0-20000)	690±1953 (0-20000)	599±2038 (0-20000)	655±1256 (0-9000)	606±1970 (0-20000)	432±1161 (0-8560)	384±691 (0-4000)

Table 2. Descriptive statistics, mean±SD (range), of selected water quality parameters for 11 years (1992-2002) within Abiaca Creek watershed.

Water quality parameter	Year				
	1992	1993	1994	1995	1996
Temperature (C)	19.4±6.7 (4.3-30.7)	18.0±6.2 (6.5-28.9)	18.8±6.2 (6.6-30.1)	19.1±6.6 (6.6-20.3)	18.5±6.5 (7.2-30.4)
Conductivity (μmhos/cm)	76.5±28.5 (38.0-168.0)	77.4±31.0 (9.0-170.0)	67.9±22.3 (34.0-120.0)	76.5±26.0 (5.0-132.0)	70.9±27.9 (26.0-132.0)
Dissolved oxygen (mg/L)	8.69±1.68 (6.10-13.00)	8.74±1.22 (5.04-10.90)	9.48±1.57 (3.97-13.44)	9.25±1.47 (6.52-12.75)	8.41±2.18 (3.06-11.80)
pH	6.38±0.43 (5.58-7.90)	6.77±0.60 (5.56-8.16)	7.11±0.45 (5.85-8.03)	7.33±0.54 (6.05-8.37)	7.33±0.43 (6.46-8.32)
Total solids (mg/L)	120±56 (67-419)	130±87 (52-599)	135±99 (54-626)	112±108 (43-1037)	211±254 (48-1929)
Dissolved solids (mg/L)	71±18 (22-120)	84±24 (43-219)	65±15 (29-107)	67±20 (0-150)	60±23 (10-101)
Suspended solids (mg/L)	48±57 (0-351)	47±80 (0-524)	73±103 (0-554)	49±113 (0-983)	151±256 (0-1833)
Soluble phosphorus (μg/L)	14±12 (0-42)	20±20 (0-92)	35±18 (5-86)	10±8 (0-41)	12±10 (0-66)
Total phosphorus (μg/L)	143±169 (14-1475)	160±192 (18-1325)	163±155 (5-883)	104±95 (2-661)	175±206 (16-1475)
Ammonium-N (μg/L)	86±51 (1-305)	111±72 (5-441)	151±135 (24-1007)	101±59 (9-251)	112±116 (1-851)
Nitrate-N (μg/L)	119±46 (3-225)	204±187 (25-1430)	154±106 (9-921)	144±60 (5-343)	165±85 (25-616)
Chlorophyll a (μg/L)	3.87±3.87 (0.00-21.25)	5.97±7.17 (0.55-43.89)	6.76±6.33 (0.00-32.71)	10.89±15.02 (0.15-69.22)	4.78±4.21 (0.00-17.44)
Fecal coliform (# colonies/100 ml)	687±1253 (0-6720)	2471±4194 (0-20160)	5633±22782 (120-210000)	2020±2232 (20-11800)	3219±3084 (0-16000)
Enterococci (# colonies/100 ml)	467±1007 0-8560)	768±1302 (0-5760)	282±418 (0-2000)	111±150 (0-660)	268±337 (0-1400)

Table 2. Continued.

Water quality parameter	Year					
	1997	1998	1999	2000	2001	2002
Temperature (C)	18.3±5.6 (5.0-26.5)	19.7±6.1 (8.3-28.9)	18.5±6.3 (4.7-29.6)	19.3±5.6 (6.3-29.9)	18.2±6.1 (5.3-29.3)	17.8±6.9 (4.5-28.0)
Conductivity (μmhos/cm)	69.1±22.4 (35.0-125.0)	73.0±27.2 (30.0-146.1)	73.8±28.4 (20.9-132.0)	79.7±31.7 (19.9-164.5)	71.6±30.0 (15.9-136.1)	74.0±26.2 (34.0-137.1)
Dissolved oxygen (mg/L)	8.65±1.31 (5.30-12.40)	8.47±1.61 (3.82-11.20)	9.22±1.71 (5.19-12.30)	9.10±1.71 (5.52-14.47)	9.00±1.75 (4.44-12.80)	8.76±1.55 (4.63-12.71)
pH	6.64±0.40 (5.60-7.60)	7.04±0.54 (6.00-8.20)	7.18±0.34 (6.50-8.00)	6.87±0.66 (5.30-8.30)	6.79±.61 (5.50-8.30)	6.59±0.53 (5.30-7.60)
Total solids (mg/L)	133±112 (42-996)	126±62 (49-410)	126±74 (47-500)	185±238 (41-1379)	135±98 (37-724)	105±43 (48-337)
Dissolved solids (mg/L)	60±19 (11-104)	64±21 (0-110)	64±22 (12-148)	74±18 (28-115)	55±18 (8-96)	72±16 (34-112)
Suspended solids (mg/L)	73±112 (0-958)	57±60 (0-322)	61±75 (0-434)	111±238 (0-1321)	72±97 (0-646)	34±40 (0-256)
Soluble phosphorus (μg/L)	15±19 (0-97)	21±25 (0-155)	12±11 (0-48)	8±10 (0-56)	23±53 (0-329)	15±18 (0-99)
Total phosphorus (μg/L)	134±126 (0-706)	148±260 (23-2463)	44±37 (2-209)	130±148 (5-714)	143±141 (6-702)	119±116 (0-595)
Ammonium-N (μg/L)	77±62 (0-269)	112±134 (0-907)	59±149 (0-939)	115±109 (0-571)	88±92 (0-548)	38±92 (0-728)
Nitrate-N (μg/L)	227±367 (0-2934)	267±269 (12-1656)	355±364 (0-1961)	143±78 (17-408)	150±104 (1-795)	150±72 (12-437)
Chlorophyll a (μg/L)	13.65±14.74 (0.00-94.12)	14.84±21.34 (0.00-122.39)	11.18±18.07 (0.00-111.47)	14.75±27.65 0.00-216.90)	12.96±15.03 (0.00-119.40)	9.35±9.75 (0.00-53.48)
Fecal coliform (# colonies/100 ml)	972±1245 (0-7659)	2278±4020 (0-26500)	1120±3859 (0-29500)	2097±4949 (0-28000)	4351±13335 (0-64000)	1598±4952 (0-37600)
Enterococci (# colonies/100 ml)	506±584 (0-4000)	913±1714 (0-7200)	866±2650 (0-20800)	629±1130 (0-7600)	1437±4356 (0-20000)	734±883 (0-5100)

Figure 1. Sampling sites for Abiaca Creek watershed, Mississippi.

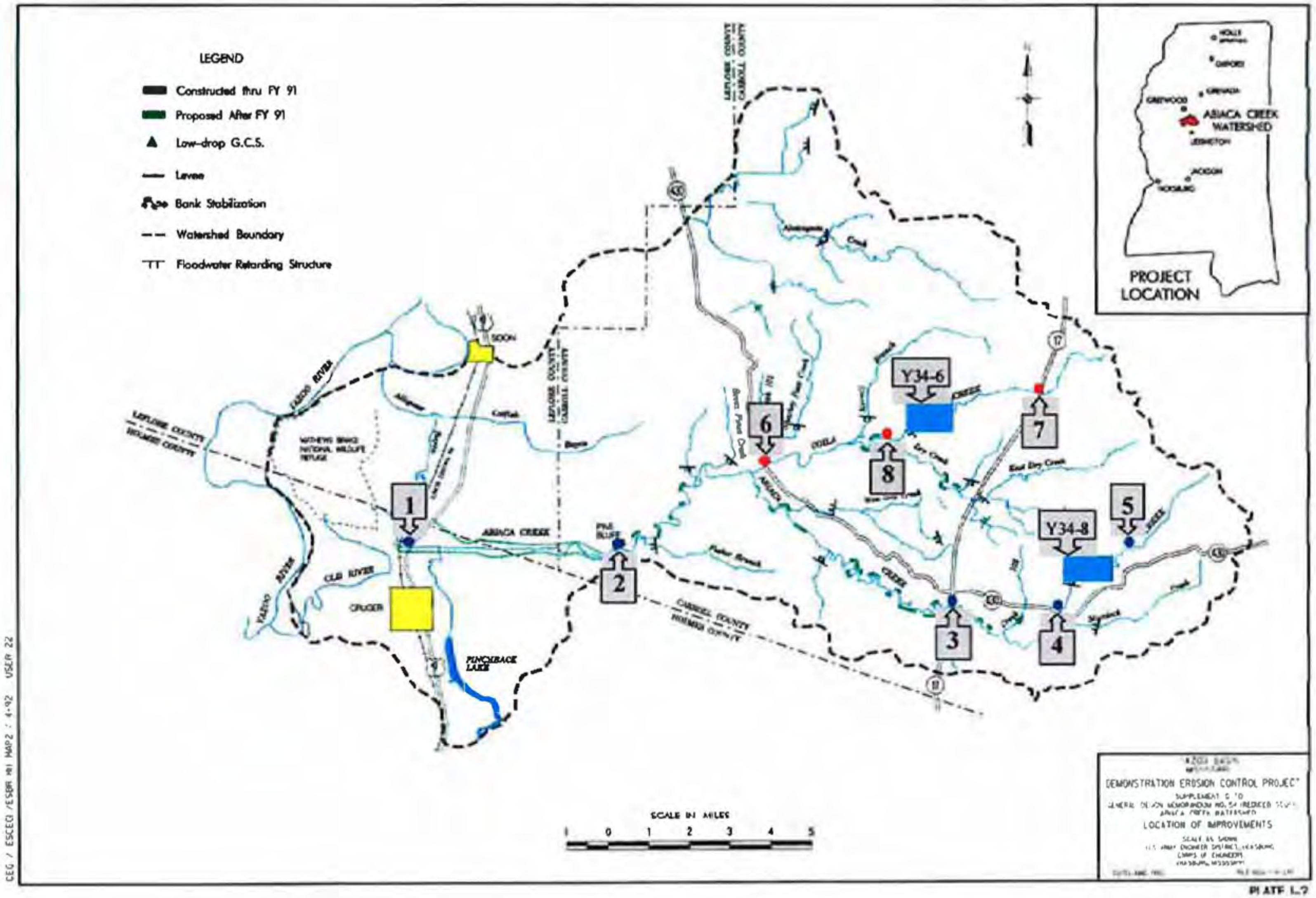

Figure 2. Monthly dissolved oxygen, pH, and suspended solids measurements for sites 1, 5, and all sites (mean) for Abiaca Creek watershed, Mississippi, from 1992-2002.

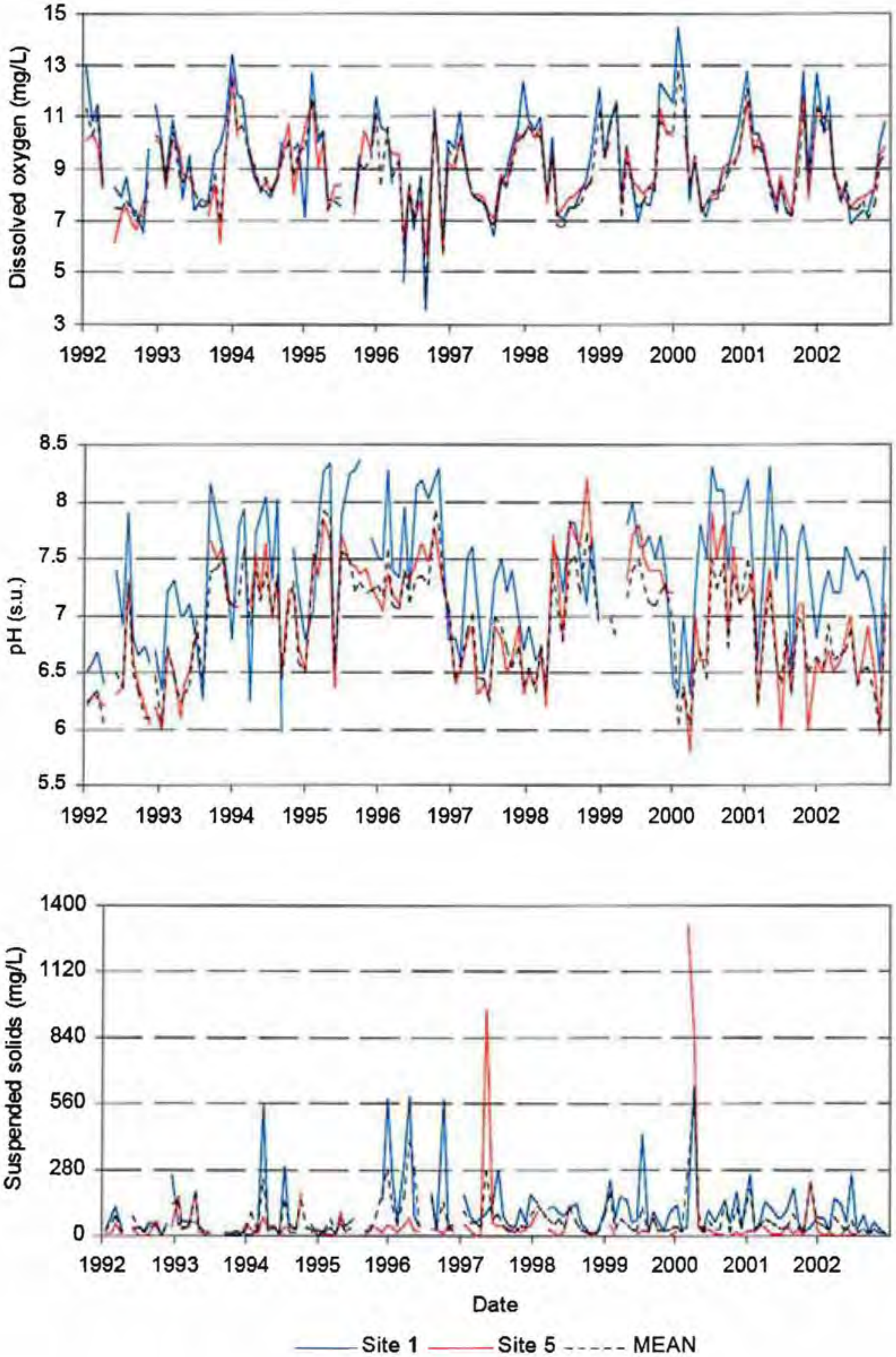

Figure 3. Monthly soluble phosphorus, total phosphorus, and chlorophyll *a* measurements for sites 1, 5, and all sites (mean) for Abiaca Creek watershed, Mississippi, from 1992-2002.

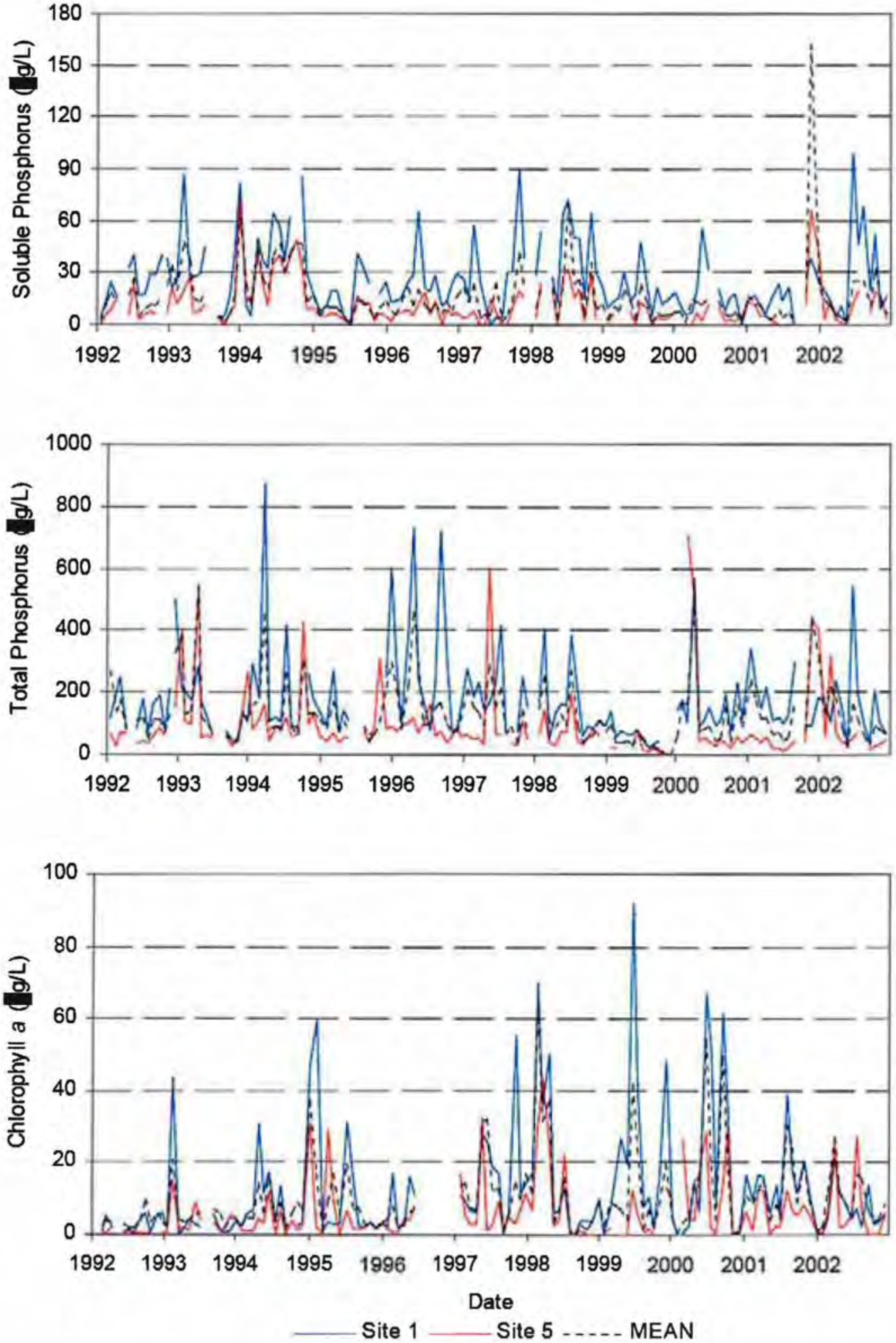

Figure 4. Monthly ammonium-N, nitrate-N, and fecal coliform measurements for sites 1, 5, and all sites (mean) for Abiaca Creek watershed, Mississippi, from 1992-2002.

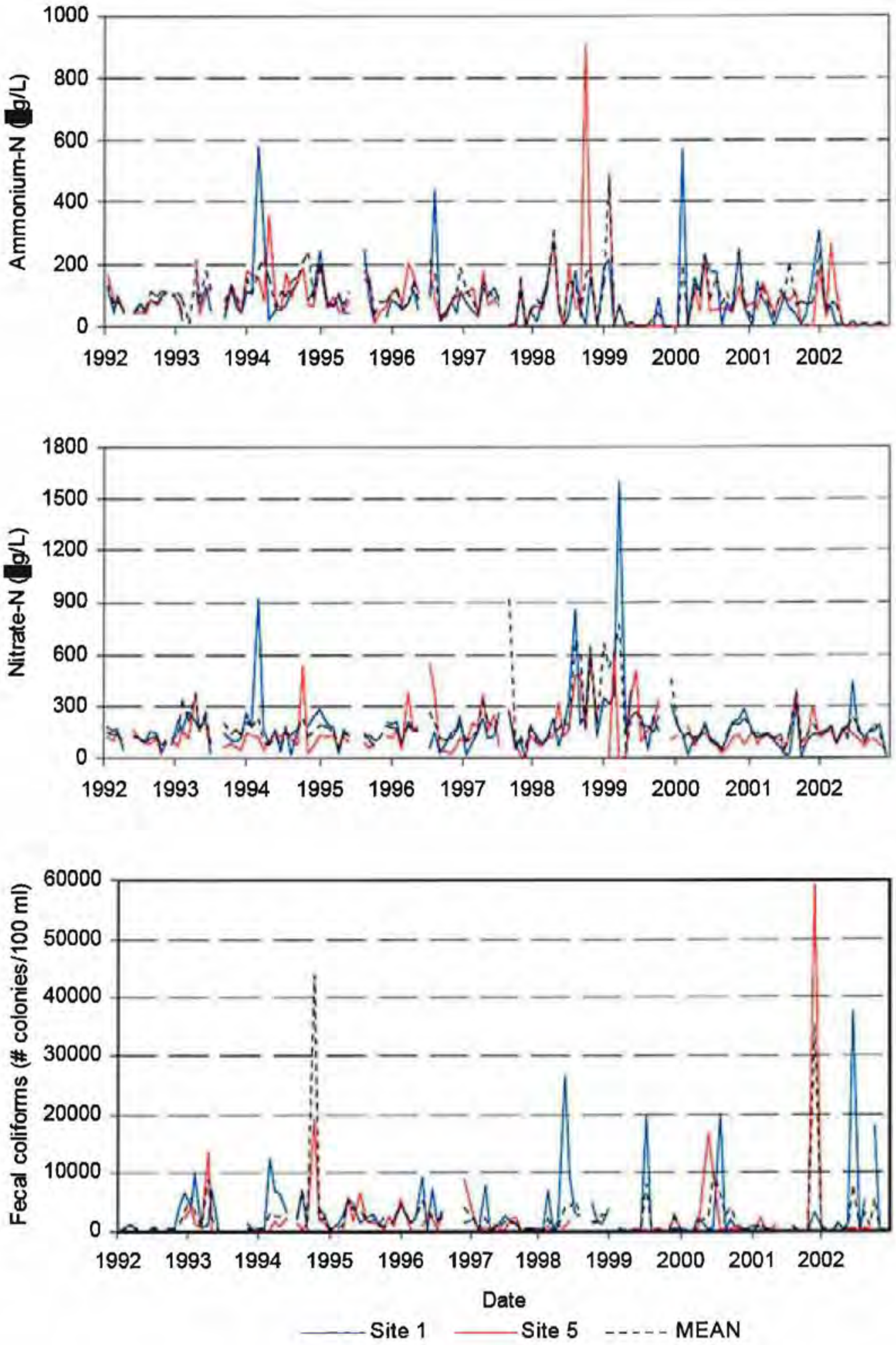

Figure 5. Plot of A) spatial variation of the first two principal components of water quality variation among eight sites and B) temporal variation of the first three principal components of water quality variation among 11 years within Abiaca Creek watershed, Mississippi.