WATER QUALITY UNDER NATURAL CONDITIONS: COMPARISONS OF URBAN, RURAL, AND REFERENCE WATERSHEDS IN NORTH MISSISSIPPI

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ABSTRACT

Objectives of this study were to examine and compare physical, chemical, and biological water quality parameters in three north Mississippi hill land stream watersheds having distinctly different land uses. As part of the Demonstration Erosion Control (DEC) Project in the Yazoo Drainage Basin, routine monitoring of water quality is performed in seven north Mississippi hill land stream watersheds which have been rehabilitated to control flooding, reduce erosion and stabilize stream channels. Evaluation of water quality improvement in these rehabilitated watersheds presents difficulties due to the lack of both long-term water quality data before rehabilitation and expected maximal recovery. The use of reference streams under natural conditions as surrogates for comparison has become increasingly valuable. Three creeks were monitored at three sites in March, June, September and December from 1998 to 2000. Burney Branch Creek is an urban land use stream that flows through the city of Oxford, Mississippi and has the highest watershed development. Toby Tubby Creek is primarily a rural land use stream that is buffered by a large forested wetland. Bay Springs Branch is a spring fed reference stream located in Holly Springs National Forest and flows through the University of Mississippi Field Station and wildlife refuge. Comparisons of temperature, dissolved oxygen, and suspended solids values among the three streams were not significantly different. Comparisons of overall conductivity measurements and dissolved solids concentrations showed Burney Branch > Toby Tubby > Bay Springs Branch. Overall comparisons of nutrient data showed Burney Branch > Toby Tubby Creek and Bay Springs Branch and overall microbial analyses showed Burney Branch > Bay Springs Branch. Seasonal interactions were observed for nitrate-N and fecal coliform data. Seasonal nitrate-N concentrations showed Burney Branch Creek > Toby Tubby Creek and Bay Springs Branch in March, Bay Springs Branch in June, and Bay Springs Branch > Toby Tubby Creek in September. Seasonal fecal coliform counts showed Burney Branch Creek > Bay Springs Branch in June and Toby Tubby Creek > Bay Springs Branch in December. Despite widely different land uses surrounding these streams, comparisons of overall water quality indicated Bay Springs Branch had moderately better water quality than Toby Tubby Creek and significantly better water quality than Burney Branch Creek.

INTRODUCTION

Deterioration of water quality in stream watersheds has been a concern throughout the United States, especially in regions with accelerated soil erosion such as the north Mississippi loess hills (Cooper and Knight 1991). Water quality degradation can be attributed to many factors including sediment transport and associated pesticides, nutrients, and animal and municipal waste. As part of the Demonstration Erosion Control (DEC) Project in the Yazoo Basin, north Mississippi, routine water quality monitoring is conducted in seven stream watersheds. Rehabilitation of these watersheds began in 1985 using several types of erosion and/or flood control structures to mitigate erosion and channel instability. The DEC project is a cooperative interagency project involving the US Army Corps of Engineers, the USDA Natural Resources Conservation Service and the USDA Agricultural Research Service. The goals of the DEC project include flood control, reduction of erosion and channel instability, water quality and environmental enhancement, total watershed planning, and demonstration of innovative management techniques (Cooper and Knight 1989; Lizotte et al. 2001).

Determining and evaluating water quality improvement in rehabilitated watersheds

presents difficulties. First, the lack of long-term baseline water quality data before rehabilitation limits the ability to assess changes in water quality after rehabilitation. Second, the absence of water quality data in the original undisturbed watershed makes it difficult to determine the expected maximal recovery. Because of the limited and often absent amount of water quality data prior to rehabilitation, the use of a reference stream or watershed has become increasingly valuable (Hughes, Larsen, and Omernik 1986; Shields, Knight, and Cooper 1997). Reference streams provide baseline water quality data under natural conditions that can then be readily compared with altered streams. Appropriate comparisons between a designated reference watershed and other altered watersheds should include the following criteria. First, the reference watershed should have similar ecological, geophysical and geochemical characteristics. Second, it should be as minimally impacted by human activity as possible (i.e. development, agriculture, etc.). Third, it should be similar in size (differ by less than 1 order of magnitude). Finally, the reference watershed should be located within the same geographic region (Hughes, Larsen, and Omernik 1986).

The objectives of the current study were to examine and compare physical, chemical, and biological water quality parameters in three north Mississippi hill land stream watersheds having distinctly different land uses.

MATERIALS AND METHODS

Study Sites

Three streams were monitored for water quality in this study (Fig. 1). Burney Branch Creek is a second order stream (Strahler 1964) draining a watershed of approximately 28 km^2. The headwaters are located within the city limits of Oxford, Mississippi, Lafayette County and the creek flows south about 8.8 km to the Yocona River. Watershed land use is approximately 50% commercial and residential development interspersed with small areas of crops and pasture. Burney Branch also is the receiving water for treated sewage effluent from the University of Mississippi. Toby Tubby Creek is a fourth order stream located in Lafayette County, Mississippi, draining a watershed of about 38 km^2. The creek flows to the northwest about 12.5 km to Sardis Reservoir. Watershed land use is primarily forested wetland (about 50%) interspersed with small areas of crops, pasture and residential development in the uppermost portion of the headwaters (Shields, Knight, and Cooper 1997). Bay Springs Branch Creek is a first order spring fed reference stream located in Holly Springs National Forest, Lafayette County, Mississippi, that flows through the University of Mississippi Field Station and wildlife refuge. The watershed drains approximately 8 km^2 and flows to the east about 2.5 km to Puskus Creek. Watershed land use is predominantly forested wetland (>50%) interspersed with small areas of residential development, pasture and crops.

Data Collection and Analysis

Three sample collection sites along each of the three streams were selected for water quality monitoring. Surface water samples were collected and preserved (using ice) once during March, June, September, and December from 1998 to 2000. Physical and chemical water parameters of pH, temperature, dissolved oxygen, and conductivity were measured instantaneously using calibrated electronic instruments at each sampling event.

Preserved samples were transported to the USDA-ARS National Sedimentation Laboratory, Oxford, Mississippi, for further physical, chemical, and biological analyses. Water quality parameters measured included dissolved solids, suspended solids, filterable orthophosphate, total orthophosphate, nitrate-N, ammonium-N, and fecal coliform and enterococci bacterial counts.

Analytical and chemical methods were conducted using standard methods procedures (American Public Health Association 1992). A two-way analysis of variance (ANOVA) with Tukey's multiple range tests was conducted to test for interactions of stream and season, and significant difference among streams for all water quality parameters. When assumptions (normality and equal variance) for parametric tests could not be met, a nonparametric Kruskal-Wallis ANOVA on ranks with Dunn's multiple range tests was used to test for significant differences among streams for all water quality parameters. Parameters were tested for significance at the 5% level. All statistical analyses were completed using SigmaStat statistical software (Jandel Scientific 1995).

RESULTS AND DISCUSSION

General Water Quality

Mean and/or median water quality values and their respective confidence intervals are presented in Figures 2 and 3. No significant differences were observed for either temperature or dissolved oxygen concentrations among the three creeks examined. Values for both parameters followed seasonal fluctuations typical of temperate-zone streams and were within the range to support aquatic life (Cole 1988; Allen 1995).

Median pH values were significantly different among creeks with Toby Tubby Creek having more acidic water than Burney Branch Creek. Most pH values were between 5.5 and 7.5 with mean and median values from 6.3 to 6.8 (Fig. 2). Watersheds in the north Mississippi loess hill region typically have acidic water due to runoff of acidic soils (Switzer and Pettry 1992; Eick, Brady, and Lynch 1999) during storm events and further acidification due to the prevalence of coniferous trees within this region (Duffy, Schreiber, and McDowell 1989). Cooper and Knight (1991) observed similar acidic pH values from two larger watersheds, Otoucalofa Creek and Long Creek located within the same region as the three creeks in the current study. The slightly more basic water in Burney Branch Creek can be attributed to sample sites located within the city of Oxford downstream of a wastewater treatment facility, potentially increasing the water's buffering capacity.

Total dissolved solids (TDS), the total concentration of soluble ions, and related conductivity measurements were significantly different among all three creeks (Fig. 2). Bay Springs Branch creek had the lowest observed TDS and conductivity, whereas Burney Branch had the highest and Toby Tubby had intermediate levels. The differences in TDS and conductivity among creeks can be associated with differences in sources of soluble ions. Sources of soluble ions in Bay Springs Branch are primarily from groundwater (natural spring aquifer) and direct precipitation. Sources of soluble ions in Toby Tubby are attributable to runoff from precipitation, direct precipitation and groundwater. Burney Branch has soluble ion sources from the previously mentioned factors in addition to anthropogenic sources, specifically, sample sites located within the city of Oxford that were downstream of a wastewater treatment facility. Despite differences in TDS and conductivity among all three creeks, all measurements were well within limits to support aquatic life (Allen 1995).

Solids

Instream total suspended solids (TSS) are, by volume, the largest pollutants in the United States (Fowler and Heady 1981). Sediment loading in stream waters from watershed and channel erosion significantly impacts water quality since associated pollutants such as pesticides and nutrients further degrade the water body (Knight and Cooper 1996). All three of the creeks examined in the current study are located in a 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, there were no significant differences for TSS among any of the three creeks examined. Mean and median TSS concentrations ranged from 16 to 50 mg/L with most values between 10-100 mg/L (Fig. 2) and maximum values of 202 mg/L (Bay Springs Branch), 142 mg/L (Toby Tubby), and 752 mg/L (Burney Branch). Maximum TSS concentrations considered optimal for warm water fish production is estimated at 80 to 100 mg/L (Cooper and Knight 1991). Although maximum values exceeded this limit, concentrations occurred during high flows associated with storm events and were not sustained over long periods of time. Comparisons of TSS values with other watersheds within the same region showed all three creeks had lower mean TSS concentrations than either Otoucalofa or Long Creeks. All three watersheds in the present study have relatively small (<40 km^2) drainages and comparably less runoff, flow and sustained discharge during storm events than in larger watersheds such as Long Creek. In addition, Toby Tubby and Bay Springs Branch watersheds have significant riparian zones (50% or greater forested wetland) that reduce sedimentation by decreasing erosion via sediment storage and bank and channel stabilization (Cooper et al. 2000).

Nutrients

Phosphorus is frequently a limiting factor of watershed primary productivity in nutrient poor

freshwater systems (Cole 1988; Allen 1995). Periphytic autotrophs in these systems are especially sensitive to soluble reactive phosphorus concentrations and excessive levels can lead to nuisance algal blooms and associated depleted dissolved oxygen concentrations, degradation of habitat, and reduction in fish diversity (Allen 1995).

Burney Branch Creek had significantly greater median filtered orthophosphate and total orthophosphate concentrations than either Bay Springs Branch or Toby Tubby Creeks (Fig. 2). The source of much of the phosphorus observed in Burney Branch is from the University of Mississippi municipal wastewater treatment facility that uses the creek as receiving water for their effluent. Mean total phosphorus (adjusted from total orthophosphate) concentrations observed in Burney Branch (urban land-use), Toby Tubby (rural land-use) and Bay Springs Branch (reference) creeks (0.53, 0.072, and 0.066 mg/L, respectively) were comparable with those observed in other north Mississippi hill land streams. Cooper, Knight, and Shields (1997) observed a mean total phosphorus concentration of 0.34 mg/L at a single site along Otoucalofa Creek just downstream of a municipal wastewater treatment facility in the city of Water Valley, Mississippi. In the same study, the authors observed mean total phosphorus concentrations in Otoucalofa Creek along forested areas ranging from 0.07 to 0.11 mg/L. Also, Cooper and Knight (1991) noted mean total phosphorus concentrations in Long Creek (agricultural watershed) ranging from 0.095 to 0.163 mg/L.

Because all north Mississippi hill land stream watersheds are part of the Yazoo drainage basin and their waters eventually flow into the Yazoo River, total phosphorus measurements in this study are compared with those observed in the Yazoo River. Coupe (1998) reported mean total phosphorus concentrations in the Yazoo River at Redwood and below Steele Bayou ranging from 0.2 to 0.31 mg/L. Total phosphorus values observed in the Yazoo River are more similar to those observed in watersheds of the north Mississippi loess hills region associated with urban land-use (Cooper, Knight and Shields 1997, this study). Greater phosphorus concentrations reported in the Yazoo River are associated with the greater sediment load of this higher order river.

Comparisons of phosphorus levels from the reference watershed in this study (Bay Springs Branch) with reference sites of other studies show Bay Springs Branch had lower total phosphorus concentrations. Mean total phosphorus concentration was 0.066 mg/L in Bay Springs Branch Creek watershed whereas the Meherrin River watershed (forested Peidmont) in Virginia and Warner Creek watershed (reference sites) in Maryland had mean concentrations of 0.12 and 0.11 mg-P/L, respectively (Humenik et al. 1978; Shirmohammadia, Yoon, and Magette 1997). Lower concentrations of phosphorus observed in both Bay Springs Branch and Toby Tubby Creeks is typical of streams having significant riparian zones and flowing through regions of limited agriculture and development.

Ammonia (measured as ammonium ion) levels were similar for both Bay Springs Branch and Toby Tubby Creeks but Burney Branch Creek had significantly greater concentrations than either creek (Fig. 2). Mean NH_4-N concentration for the reference stream (Bay Springs Branch) was 0.049 mg/L and ranged from 0 to 0.310 mg/L. Toby Tubby and Burney Branch Creeks had mean NH_4-N concentrations of 0.078 and 0.154 mg/L, respectively. Again, the greater NH_4-N levels in Burney Branch are associated with the upstream municipal wastewater treatment facility at the University of Mississippi. The NH_4-N concentrations observed in this study were relatively lower than those observed in other north Mississippi hill land streams. Cooper and Knight (1991) observed mean NH_4-N concentrations ranging from 0.101 to 0.131 mg/L in a forested watershed (Otoucalofa Creek) and 0.092 to 0.173 mg/L in an agricultural watershed (Long Creek). In the same study, the authors observed a mean NH_4-N concentration of 0.674 mg/L at a single site just downstream of a municipal wastewater treatment facility in the city of Water Valley, Mississippi. Ammonia levels in the present study did not attain concentrations causing adverse effects on aquatic biota since aqueous pH was usually acidic.

Nitrate-nitrogen concentrations in the three creeks studied showed interactions among creek and season. Seasonal fluctuations of differences in mean NO_3-N concentrations were observed. During March, Burney Branch had greater NO_3-N levels than either Toby Tubby or Bay Springs Branch Creeks (Fig. 3). During

June, Burney Branch had significantly greater NO_3-N concentrations than Bay Springs Branch Creek only, whereas, in September, Bay Springs Branch had similar NO_3-N concentrations with Burney Branch and significantly greater concentrations than Toby Tubby Creek. During December, nitrate-N concentrations were not significantly different among the three watersheds studied (Fig. 3). Overall mean nitrate-nitrogen concentrations for Bay Springs Branch, Toby Tubby and Burney Branch creeks were 0.510, 0.358, and 1.082 mg/L, respectively. Comparisons of NO_3-N concentrations found in the present study with other north Mississippi hill land streams showed higher mean concentrations of this species of nitrogen in all three watersheds in this study. Cooper and Knight (1991) found mean NO_3-N levels in Otoucalofa Creek (forested watershed) and Long Creek (agricultural watershed) ranged from 0.047 to 0.111 and 0.084 to 0.201 mg/L, respectively. The relatively greater concentrations of nitrate-nitrogen found in the present study, especially in the reference watershed (Bay Springs Branch, a spring-fed watershed), are possibly due to inputs from groundwater and not exclusively from runoff. Burwell et al. (1977) found significant nitrate-nitrogen (84% of the average annual soluble nitrogen) discharged in subsurface flow into Missouri valley deep loess watersheds. Nitrogen concentrations reported in the present study for the reference stream, Bay Springs Branch, and Toby Tubby Creek were not at concentrations that would cause nuisance conditions or adverse effects on aquatic biota within these watersheds. Burney Branch Creek had nitrogen levels that were moderately greater than either Bay Springs Branch or Toby Tubby Creeks but were still below levels causing nuisance or adverse conditions.

Biologicals

Bacterial contamination of rural, urban, and pristine watersheds has been a significant concern throughout the United States for several decades (Bohn and Buckhouse 1985; Cooper and Lipe 1992). Several studies have examined bacterial contamination in all three types of watersheds (Faust 1982; Cooper and Knight 1989; Niemi and Niemi 1991) and have observed wide variation both within and among watersheds with different land use. Non-point sources of bacterial contamination are difficult to ascertain due to the many possible routes including direct runoff and groundwater flow from storm events, resuspension of bottom sediments within the watershed channel by stream flow or animal disturbance, and direct contamination from animal defecation (Bohn and Buckhouse 1985).

Fecal coliform (FC) densities in the current study showed seasonal influences among the three creeks examined (Fig. 3). During March, all three creeks had the lowest mean fecal coliform densities of any season with Bay Springs Branch, Toby Tubby, and Burney Branch having 111, 200, and 1944 colonies/100 ml, respectively. No signficant differences among the creeks were observed during March. In, June FC in all three creeks increased with Burney Branch Creek having significantly greater FC densities than Bay Springs Branch and Toby Tubby Creek FC intermediate between the two creeks. Mean FC densities in June for Bay Springs Branch, Toby Tubby, and Burney Branch Creeks were 1170, 2711, and 13433 colonies/100 ml, respectively. Fecal coliform densities in September followed a similar pattern seen during March. No significant differences in FC densities were observed among the creeks during September. Mean FC densities in September for Bay Springs Branch, Toby Tubby, and Burney Branch Creeks were 889, 2811, and 4688 colonies/100 ml, respectively. During winter (December), Toby Tubby Creek had significantly greater FC densities than Bay Springs Branch with Burney Branch intermediate between the two creeks. Mean winter FC densities were 383, 6850, and 3800 colonies/100 ml for Bay Springs Branch, Toby Tubby, and Burney Branch Creeks, respectively. Seasonal fluctuations observed in this study for Bay Springs Branch and Burney Branch Creeks are typical with peak coliform counts occurring during warmer periods and declining during fall and winter. Similar seasonal patterns of FC density changes have occurred in forested and agricultural watersheds (Niemi and Niemi 1991; Howell, Coyne, and Cornelius 1995). Cooper and Knight (1989) did not observed these same seasonal patterns and observed peak FC densities occurring during winter in two north Mississippi loess hill land streams, and this pattern was evident for Toby Tubby Creek in the present study.

Enterococci (a subgroup of fecal streptococci) is considered a valuable indicator for ascertaining the extent of fecal contamination in surface

waters and is the most efficient bacterial indicator of water quality (American Public Health Association 1992). Mean and median enterococci densities for Bay Springs Branch, Toby Tubby and Burney Branch Creeks are shown in Figure 2. The reference stream, Bay Springs Branch, had significantly lower overall median enterococci densities than Burney Branch (urban land-use stream) and Toby Tubby Creek had overall enterococci counts intermediate of the two creeks. Median densities were 500, 1600, and 2200 colonies/100 ml for Bay Springs Branch, Toby Tubby, and Burney Branch Creeks, repsectively. Relatively few studies reported enterococci counts and instead have focused on coliforms and fecal streptococci (Crane et al. 1983).

SUMMARY

Patterns of land-use have significant impacts on water quality and the need for a reference watershed is increasingly important in ascertaining baseline or pristine water quality conditions. Despite differences in watershed size between Bay Springs Branch Creek (8 km^2) and Toby Tubby (38 km^2) and Burney Branch (28 km^2) creeks, Bay Springs Branch Creek meets the criteria of a reference watershed in this study. Comparisons of the reference watershed (Bay Springs Branch Creek) with Demonstration Erosion Control (DEC) Project watersheds (Toby Tubby and Burney Branch Creeks) that are in various stages of rehabilitation allow us to determine the rate of progression among watersheds with different land-use patterns. Currently, Bay Springs Branch watershed had significantly better overall water quality than Burney Branch watershed (an urban land-use stream) and moderately better overall water quality than Toby Tubby watershed (a rural land-use stream). Primary differences in water quality among the creeks studied occurred for nutrients and bacterial contamination. Current watershed rehabilitation practices designed to control erosion, stabilize channel and banks, and mitigate soil loss also have the added benefit of improving overall water quality.

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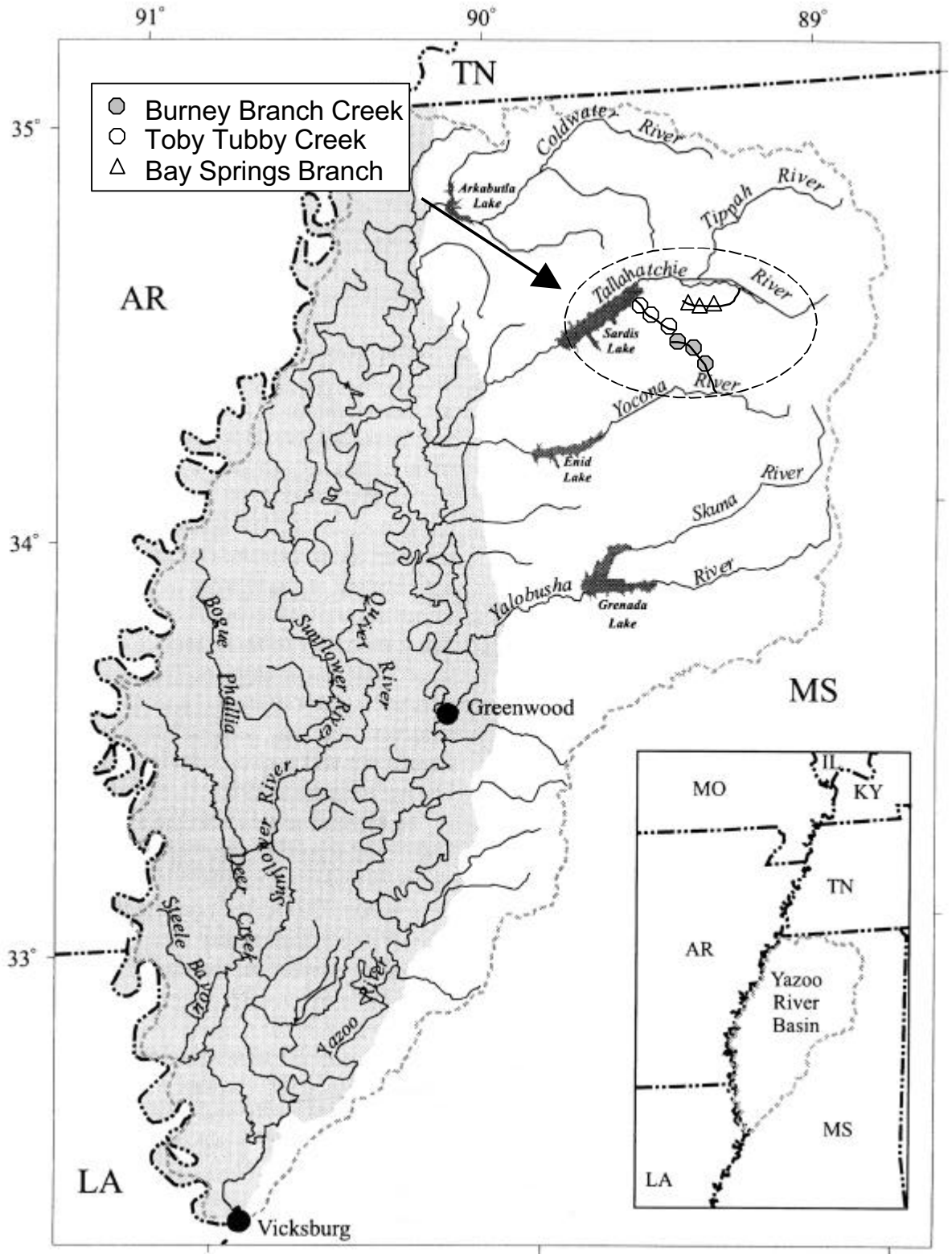

Figure 1. Sampling locations for Burney Branch, Toby Tubby, and Bay Springs Branch Creeks in north Mississippi.

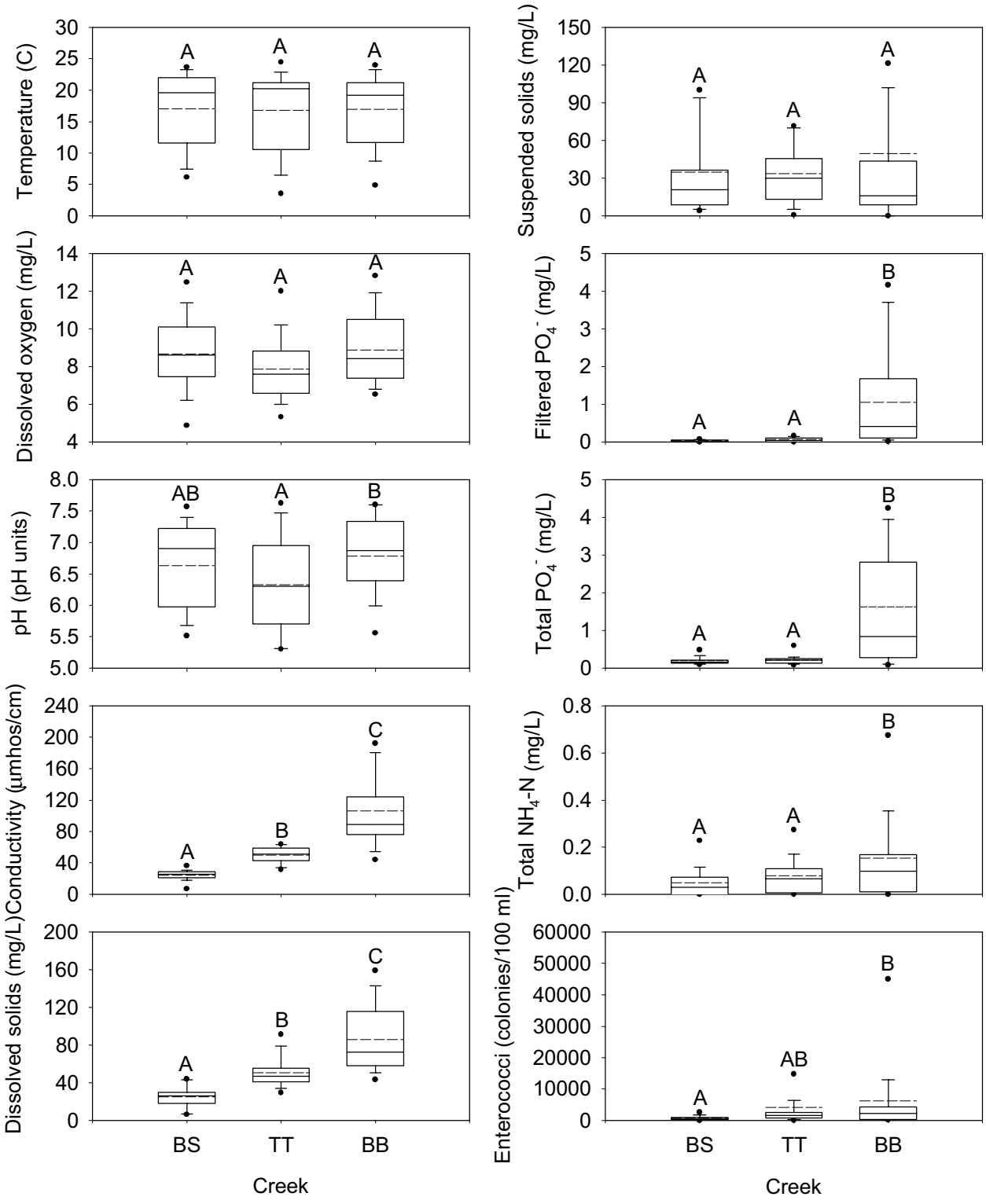

Figure 2. Box plots of water quality in Bay Springs Branch (BS), Toby Tubby (TT) and Burney Branch (BB) creeks from 1998-2000. Creeks with different letters are significantly different ($P < 0.05$) for that water quality parameter. Box = 25th-75th percentiles; whiskers = 10th-90th percentiles; points = 5th-95th percentiles; solid line = median value; dashed line = mean value.

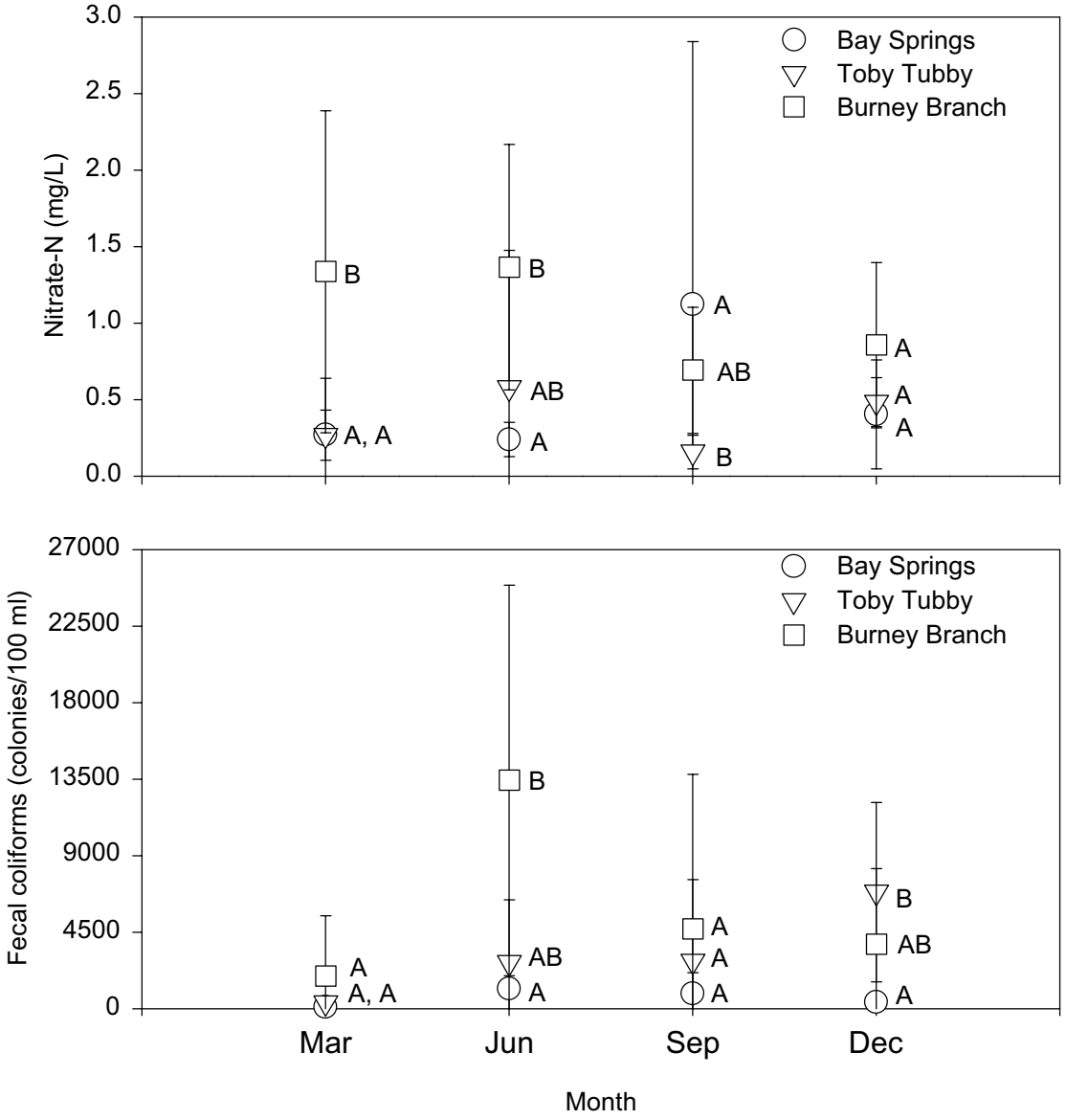

Figure 3. Seasonal differences in mean nitrate-N concentrations and fecal coliform counts in Bay Springs Branch, Toby Tubby and Burney Branch creeks from 1998-2000. Creeks with different letters are significantly different ($P < 0.05$) for that month.