Surface Water Quality Screening Assessment of the Tennessee River Basin-2003

Part II: Reservoir Tributary Embayments

Aquatic Assessment Unit – Field Operations Division
Alabama Department of Environmental Management

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Report Date: July 2005

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FINAL REPORT

Preface

This project was funded or partially funded by the Alabama Department of Environmental Management utilizing a Clean Water Act Section 319(h) nonpoint source demonstration grant provided by the U.S. Environmental Protection Agency - Region 4.

Comments or questions related to this report should be addressed to:

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EXECUTIVE SUMMARY

In 2003, intensive monitoring of reservoir tributary embayments in the Tennessee River basin was conducted in an effort to address nutrient effects and to assist in development of total maximum daily loads as required by Section 303(d) of the Clean Water Act. Objectives of this survey were to:

a) assess the water quality of tributary embayment locations in the Tennessee River Basin;
b) identify tributary embayments most impacted by point and nonpoint source (NPS) pollution; and,
c) assist the Nonpoint Source Unit of the ADEM in prioritization of subwatersheds by determining the water quality of tributary embayments.

Tributary embayment locations were targeted because embayments typically exhibit water quality characteristics that are more indicative of the tributary than of the mainstem reservoir. Water quality assessments were conducted at 28 embayments throughout the Tennessee River basin in Alabama at monthly intervals April-October.

Chemical, physical, and biological variables were measured at each location to determine water quality and trophic state. Water quality data selected for further discussion consist of the following:

a) total nitrogen (TN) and total phosphorus (TP), used as indicators of nutrient content in the waterbody;
b) algal growth potential tests (AGPT), used as a determinant of the total quantity of algal biomass supportable by test waters and of the limiting nutrient;
c) corrected chlorophyll *a* (chl. a), used as an indicator of algal biomass;
d) dissolved oxygen (DO) concentrations, used as a more direct indicator of water quality; and,
e) total suspended solids (TSS), used as an indicator of sediment inflow; and,
f) Carlson Trophic State Index (TSI), calculated from corrected chlorophyll *a* concentrations as a means of trophic state classification of a reservoir or embayment.

These variables were selected because of their relationship to the process of eutrophication and their interest to the regulatory and scientific communities that stems from this relationship.

<u>Guntersville Reservoir Tributaries</u>

Mean TN, TP, and TSS concentrations in Guntersville tributary embayments were among the lowest of any Tennessee basin tributaries (Figs. 6, 7 & 9). However, the highest mean chlorophyll *a* concentration of any Tennessee basin tributary was found in Roseberry Creek (Fig. 8).

AGPT results indicated that Crow, Raccoon, Big Spring, and Brown's Creeks were phosphorus limited, with mean maximum standing crop (MSC) values well below the maximum 5.0 mg/l level suggested to assure protection from nuisance algal blooms and fish-kills in southeastern lakes (Table 4). N. Sauty and Short Creeks were nitrogen limited while Roseberry, S. Sauty, and Town Creeks were co-limited. The MSC of both Town and Short Creeks exceeded suggested protection levels.

Dissolved oxygen concentrations were above the ADEM Water Criteria (ADEM Admin. Code R. 335-6-10-.09) limit of 5.0 mg/l for all stations in all months except for Raccoon Creek (June only) (Fig. 14). Heavy rains throughout the area in May caused all tributaries of Guntersville to be thoroughly mixed during the month (Fig. 12). In August, deoxygenation occurred in S. Sauty, Town, Short, Big Spring and Brown's Creek, representing 30-57% of the water column (Figs. 20-22). Other embayments showed deoxygenation at the bottom June-August (Figs. 18 & 19).

With the exception of Crow Creek which remained mesotrophic for most of the sampling season, trophic state index values for all of the remaining tributary embayments were within the eutrophic range (Fig. 17).

<u>Wheeler Reservoir Tributaries</u>

Mean TN and TP concentrations of the tributary embayments of Wheeler were similar to other Tennessee Basin embayments. Flint River had the third highest mean TN concentration of any Tennessee basin tributary (Fig. 6) and the highest mean TP of any Wheeler Reservoir embayment (Fig. 7). Dry Branch, Round Island, Spring, and Second Creeks were among the lowest mean TN and TP concentrations. Chlorophyll *a* concentrations of Dry Branch, Second

Creek, and Flint Creek were among the highest of the basin (Fig. 8). Flint Creek, Dry Branch, and Round Island Creek were among the highest mean TSS concentrations of any tributary of the basin, while Spring and Second Creeks were among the lowest (Fig. 9).

AGPT results indicated that Paint Rock and Flint River, Indian, and Limestone Creeks were phosphorus limited (Table 4). Dry Branch, Cotaco, Flint, and Round Island Creek were nitrogen limited while Spring and Second Creeks were co-limited. The MSC of Flint River and both Limestone and Indian Creeks well exceeded the maximum 5.0 mg/l level suggested to assure protection from nuisance algal blooms and fish-kills in southeastern lakes.

Dissolved oxygen concentrations were above the ADEM Water Criteria (ADEM Admin. Code R. 335-6-10-.09) limit of 5.0 mg/l for all stations in all months except for Indian Creek (May only) (Fig. 25). Heavy rains throughout the area may have caused the Indian Creek embayment to be thoroughly mixed and below 5.0 mg/l in the month of May (Fig. 13). DO profiles indicate deoxygenation of up to 49% of the water column occurred April-September in Spring Creek (Fig. 33). Other embayments contained adequate oxygen concentrations throughout most of the water column (Figs. 29-33).

TSI values for the upper tributary embayments of Wheeler were typically in the mesotrophic range (Fig. 28). The TSI values for all other tributary embayments fell in the eutrophic range for all months except May (Fig. 28).

Wilson Reservoir Tributaries

The second highest mean TN and highest mean TP concentrations in the basin were measured in the Big Nance Creek embayment of Wilson Reservoir (Figs. 6 & 7). The lowest mean chlorophyll *a* concentration was also measured in the Big Nance embayment (Fig. 8), with the second lowest mean TSS concentration measured in Shoal Creek (Fig. 9).

AGPT results indicated that Big Nance Creek was phosphorus limited (Table 4). Town and Shoal Creeks were nitrogen limited, and Bluewater Creek was co-limited. The MSC of Big Nance, Bluewater, and Town Creeks well exceeded the maximum 5.0 mg/l level suggested to assure protection from nuisance algal blooms and fish-kills in southeastern lakes.

Dissolved oxygen concentrations were above the ADEM Water Criteria (ADEM Admin. Code R. 335-6-10-.09) limit of 5.0 mg/l for all stations in all months except for Town Creek (June only) (Fig. 35). Heavy rains during sampling may have caused low DO and high TSS concentrations in the Town Creek embayment (Fig. 13). DO profiles indicated well-oxygenated water columns for all embayments, April-October (Figs. 37-39).

TSI values for Big Nance Creek remained mostly in the oligotrophic range while Bluewater Creek began in the oligotrophic range and gradually increased to eutrophic levels throughout the sampling season (Fig. 36). Town and Shoal Creeks remained in the euptrophic range for most months (Fig. 36).

Pickwick Tributaries

Water quality concerns for Pickwick Reservoir tributaries center primarily on Spring Creek. The highest mean TN, second highest mean TP, and highest mean TSS concentrations were measured in the Spring Creek embayment (Figs. 6, 7 & 9). The lowest mean chlorophyll *a* concentration was also measured in that embayment (Fig. 8). The mean TN, chlorophyll *a*, and TSS concentrations of Cypress, Cane and Second Creeks were low compared to other basin locations.

AGPT results indicated that Cypress, Spring, and Second Creeks were phosphorus limited and Cane Creek was co-limited (Table 4). The MSC of Cane Creek well exceeded the maximum 5.0 mg/l level suggested to assure protection from nuisance algal blooms and fish-kills in southeastern lakes.

All dissolved oxygen concentrations were above the ADEM Water Criteria (ADEM Admin. Code R. 335-6-10-.09) limit of 5.0 mg/l for all stations in all months (Fig 40). DO profiles show well-oxygenated water columns for all embayments, April-October (Figs. 42-43).

TSI values for Cypress Creek ranged from oligotrophic to eutrophic throughout the sampling season (Fig. 41). Spring Creek was in the oligotrophic range, Cane Creek in the mesotrophic range, and Second Creek in the eutrophic range throughout the sampling season (Fig. 41).

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INTRODUCTION

ADEM Reservoir Water Quality Monitoring Program

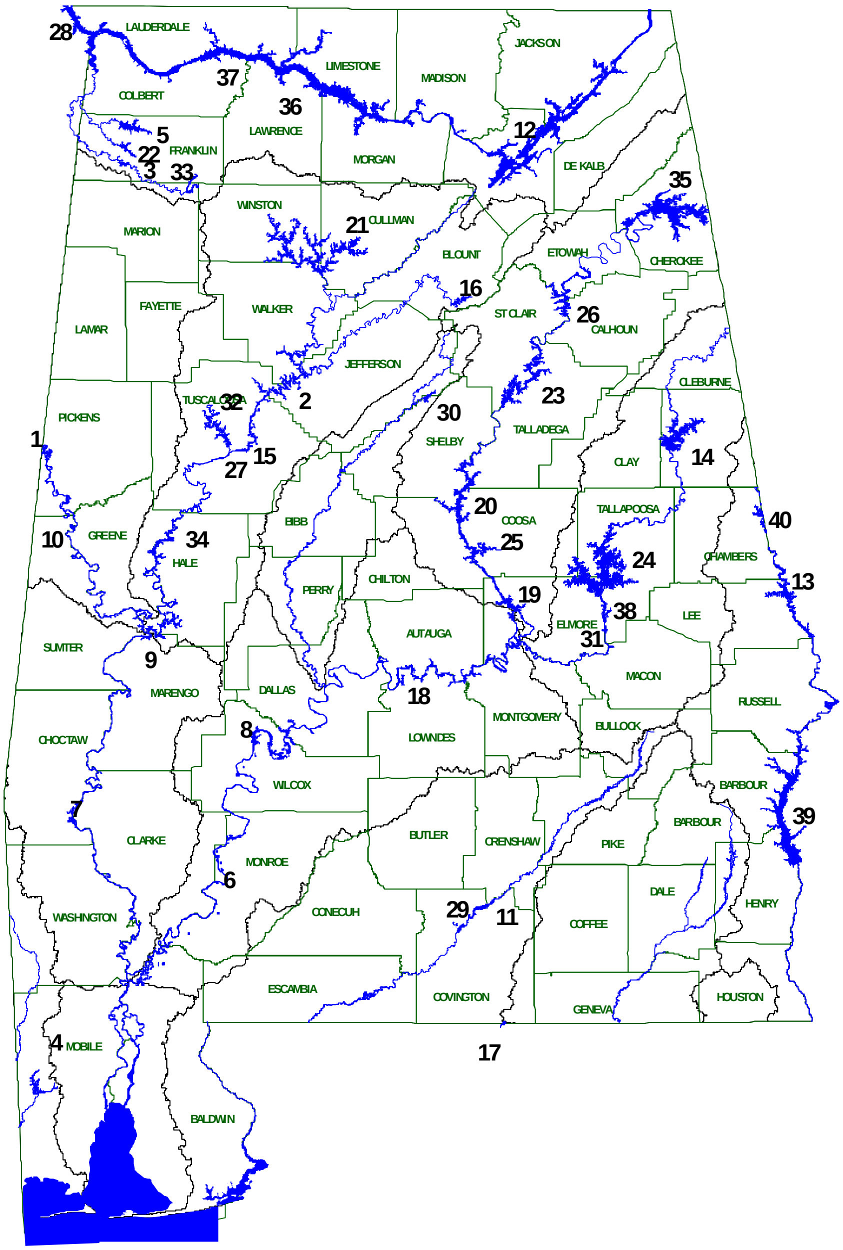
Section 314(a)(1) of the Water Quality Act of 1987 requires states to conduct assessments of the water quality of publicly-owned lakes and report the findings as part of their biennial 305(b) Water Quality Report To Congress. Prior to 1997, funding for the assessments was provided by Lake Water Quality Assessment (LWQA) grants administered through the Clean Lakes Program of the United States Environmental Protection Agency (EPA). Submittal to the EPA of approved lakes assessment information from states ensured continued eligibility for financial assistance under the Clean Lakes Program. With the discontinuance of Clean Lakes Program funding, water quality assessments are currently conducted using funding from a variety of sources, including Clean Water Act Section 319 funds.

The Alabama Department of Environmental Management (ADEM) has defined publicly-owned lakes/reservoirs as those that are of a multiple-use nature, publicly-accessible, and exhibit physical/chemical characteristics typical of impounded waters. Lakes designated strictly for water supply, privately owned lakes, or lakes managed by the Alabama Department of Conservation and Natural Resources (ADCNR) strictly for fish production are not included in this definition. Lakes meeting the above definition are listed in Figure 1.

In 1985, the need for information on the trophic state of Alabama's publicly-owned lakes led to an initial survey conducted by the ADEM with the assistance of the Environmental Protection Agency (EPA), Region IV. The survey established limited baseline information on the lakes and was used to rank them according to trophic condition.

In 1989, LWQA funds enabled the ADEM to conduct required water quality assessments of thirty-four publicly-owned lakes in the state and submit the collected information as part of the 1990 305(b) Water Quality Report to Congress (ADEM 1989). Trophic state index (TSI) values calculated from data gathered for the water quality assessments indicated potentially significant increases when compared to TSI values from the study conducted in 1985.

Figure 1.
Alabama Publicly Accessible Reservoirs



1) Aliceville
2) Bankhead
3) Bear Creek
4) Big Creek
5) Cedar Creek
6) Claiborne
7) Coffeeville
8) Dannelly
9) Demopolis
10) Gainesville
11) Gantt
12) Guntersville
13) Harding
14) Harris
15) Holt
16) Inland
17) Jackson
18) Jones Bluff
19) Jordan
20) Lay
21) Lewis Smith
22) Little Bear Creek
23) Logan-Martin
24) Martin
25) Mitchell
26) Neely Henry
27) Oliver
28) Pickwick
29) Point A
30) Purdy
31) Thurlow
32) Tuscaloosa
33) Upper Bear Creek
34) Warrior
35) Weiss
36) Wheeler
37) Wilson
38) Yates
39) W. F. George
40) West Point

In 1990, the Reservoir Water Quality Monitoring (RWQM) Program was initiated by the Special Studies Section of the Field Operations Division of the ADEM. Objectives of the program are as follows:

a) to develop an adequate water quality database for all publicly-owned lakes in the state;

b) to establish trends in lake trophic status that can only be established through long-term monitoring efforts; and,

c) to satisfy the requirement of Section 314(a)(1) of the Water Quality Act of 1987 that states conduct assessments of the water quality of publicly-owned lakes and report the findings as part of their biennial Water Quality Report to Congress.

Acquiring this information enables the ADEM to determine lake water quality and identify those in which water quality may be deteriorating. Should deterioration in lake water quality be indicated by collected data, more intensive study of the lake can be instituted to establish causes and extent of the deterioration.

Thirty-one publicly-owned lakes in the state were monitored at least once during the three-year period 1990-1992. In 1991, additional funding received through the Clean Lakes Program enabled the expansion of the RWQM Program to include all of the 31 publicly-owned lakes in the state, with the exception of those in the Tennessee River system. Expansion of the program allowed more extensive monitoring of certain lakes for which water quality concerns were greatest and the inclusion of Alabama/Georgia border lakes that were not included in earlier water quality assessments.

Beginning in 1994, the frequency of reservoir monitoring in the RWQM Program was increased to a minimum of once every two years so that the water quality database and trends in trophic status could be developed more rapidly. Lakes indicated to be use-threatened or impaired from previously collected data continued to be monitored annually. Realignment of the reservoir sampling schedule was also begun in 1994 so that reservoir sampling by basin could be instituted.

In 1996, the Nonpoint Source Unit (NPSU) of the Office of Education and Outreach of ADEM adopted a watershed assessment strategy. The intent of the watershed management approach is to synchronize water quality monitoring, assessment, and implementation of control activities on a geographic basis. In Alabama, the major drainage basins are monitored on a 5-year rotation basis. Concentrating monitoring efforts within one basin provides the NPSU with a framework for more centralized management and implementation of control efforts and provides consistent and integrated decision making for awarding Clean Water Act Section 319 NPS funds.

During 1997, intensive monitoring of reservoirs by basin was initiated with Coosa and Tallapoosa reservoirs sampled to gather water quality data prior to proposed water diversions in Georgia. Intensive monitoring consists of monthly sampling of mainstem and tributary embayment sites through the algal growing season (April through October). Basins sampled to date are as follows:

a) 1997 - Coosa and Tallapoosa River basins;

b) 1998 - Warrior River basin;

c) 1999 - Chattahoochee and Conecuh River basins;

d) 2000 - Coosa, Tallapoosa, and Alabama River basins;

e) 2001 – Escatawpa and Tombigbee River basins; and,

f) 2002 - Warrior River basin.

During 2003, tributary embayments located on Guntersville, Wheeler, Wilson, and Pickwick Reservoirs of the Tennessee River basin were intensively monitored. Water quality monitoring of the mainstem reservoirs of the Tennessee River system is conducted by the Tennessee Valley Authority (TVA) through its Reservoir Vital Signs Monitoring Program. Objectives of the program are to provide basic information on the "health" or integrity of the aquatic ecosystem in each TVA reservoir and to provide screening level information for describing how well each reservoir meets the "fishable" and "swimmable" goals of the Clean Water Act. Sampling activities involve examination of appropriate physical, chemical, and biological indicators in the forebay, mid-region, and headwaters areas of each reservoir. Initiated in 1990, the TVA program provides results of monitoring activities to ADEM on an annual basis through program reports.

Data collected through these monitoring efforts will be used to develop lake-specific nutrient criteria, and to assist in development of total maximum daily loads as required by Section 303(d) of the Clean Water Act.

MATERIALS AND METHODS

Sampling Locations. Embayments sampled during 2003 appear in Table 1. Locations of sampling sites appear in Table 2 and Figures 2 - 5. Multiple tributaries were sampled at each reservoir. Water quality measurements and water sample collections were conducted from boats positioned at the deepest point of the channel at each sampling site. Mainstem reservoir stations were sampled through the TVA Reservoir Vital Signs Monitoring Program.

Sample Collection. Intensive monitoring of embayments consisted of monthly sampling of all stations from April through October in the Tennessee basin. All stations were sampled within a one-week period to reduce weather-related variability in water quality conditions.

Monitoring and analyses were conducted in accordance with appropriate standard operating procedures. Water quality variables measured during 2003 appear in Table 3.

At each sampling site temperature, dissolved oxygen, specific conductance, and pH were measured in situ at multiple depths in the water column with Hydrolab III and 4a instruments.

A standard, 20 cm diameter Secchi disk with attenuating black and white quadrants was used to measure visibility. Photic zone depth determinations were made by measuring the vertical illumination of the water column using an underwater photometer. The depth at which one percent of the surface illumination was measured by the photometer was considered the photic zone depth. A composite water sample of twenty liters was collected from the photic zone. The sample was collected by raising and lowering a plastic submersible pump and hose apparatus repeatedly through the photic zone while collecting the sample in a plastic container. Withdrawal of individual samples from the composite water sample occurred in the order presented in the following paragraphs.

Chlorophyll *a* samples were collected by filtering a minimum of 500 ml of the composite photic zone sample through glass fiber filters immediately after collection of the composite sample. Immediately after filtering, each filter was folded once and placed in a 50 mm petri dish. Each petri dish was wrapped in aluminum foil, sealed in a ziploc bag, and placed on ice for shipment to the Field Operations Division to be frozen until analyzed. Corrected chlorophyll a concentrations were used in calculating Carlson's trophic state index (TSI) for lakes. A more detailed discussion of Carlson's TSI appears later in this section.

Table 1. Embayments sampled during the Surface Water Quality Screening Assessment of the Tennessee River Basin, 2003.

Reservoir	Embayment	Surface Area (acres)	Drainage Area (mi^2)
Guntersville		67,900	24,450
	Crow Creek		110
	Raccoon Creek		96
	Mud Creek		105
	Roseberry Creek		102
	North Sauty Creek		84
	South Sauty Creek		126
	Town Creek		250
	Short Creek		113
	Big Spring Creek		72
	Brown's Creek		73
Wheeler		67,070	29,590
	Paint Rock River		416
	Flint River		439
	Indian Creek		198
	Cotaco Creek		276
	Limestone Creek		219
	Flint Creek		465
	Dry Branch		29
	Round Island Creek		116
	Spring Creek		31
	Second Creek		80
Wilson		15,500	30,750
	Big Nance Creek		200
	Bluewater Creek		89
	Town Creek		250
	Shoal Creek		118
Pickwick		43,100	32,820
	Cypress Creek		150
	Spring Creek		107
	Cane Creek		142
	Second Creek		47

Table 2. Monitoring sites for the Surface Water Quality Screening Assessment of the Tennessee River Basin 2003.

Basin	Reservoir	Station #	Latitude	Longitude	Description
Tennessee					
	Guntersville	1	34.83665	-85.82496	Deepest point, main creek channel, Crow Creek embayment, approximately 0.5 mile downstream of US Hwy 72 bridge.
		2	34.75049	-85.83659	Deepest point, main creek channel, Racoon Creek embayment, Approximately 2 miles upstream of lake confluence.
		3	34.76665	-85.90149	Deepest point, main creek channel, Mud Creek embayment, immediately upstream of Hwy. 72 bridge at powerline crossing.
		4	34.63230	-86.01811	Deepest point, main creek channel, Roseberry Creek embayment, 0.5 mile downstream of Jackson County Park.
		5	34.59346	-86.09137	Deepest point, main creek channel, North Sauty Creek embayment, immediately upstream of AL Hwy 79 bridge.
		6	34.51905	-86.10391	Deepest point, main creek channel, South Sauty Creek embayment, immediately upstream of CR 67 bridge.
		7	34.40581	-86.18317	Deepest point, main creek channel, Town Creek embayment, approximately 0.5 miles downstream of AL Hwy 227 bridge.
		8	34.36859	-86.21950	Deepest point, main creek channel, Short Creek embayment, immediately upstream of AL Hwy 227 bridge.
		9	34.34551	-86.29182	Deepest point, main creek channel, Big Spring Creek embayment, immediately upstream of AL Hwy 227 bridge.
		10	34.34463	-86.33057	Deepest point, main creek channel, Brown's Creek embayment, approximately 1.0 mile upstream of AL Hwy 69 bridge.
	Wheeler	1	34.48325	-86.4551	Deepest point, main river channel, Paint Rock River, approximately 1 mile upstream of confluence with Tennessee River.
		2	34.51073	86.5141	Deepest point, main river channel, Flint River, approximately 1 mile upstream of confluence with Tennessee River.
		3	34.58431	86.7291	Deepest point, main creek channel, Indian Creek embayment, 1 mile upstream of lake confluence.
		4	34.54297	-86.7263	Deepest point, main creek channel, Cotaco Creek embayment, immediately upstream of Sharps Ford Bridge.

Table 2 cont'd. Monitoring sites for the Surface Water Quality Screening Assessment of the Tennessee River Basin, 2003

Basin	Reservoir	Station #	Latitude	Longitude	Description
Tennessee	Wheeler	5	34.59322	-86.8902	Deepest point, main creek channel, Limestone Creek embayment, approximately 1 mile upstream of lake confluence.
		6	34.55947	-86.9333	Deepest point, main creek channel, Flint Creek embayment, 1 mile downstream of CR 67 bridge at public access area.
		7	34.62081	-87.0006	Deepest point, main creek channel, Dry Branch embayment, immediately downstream of Alt. Hwy. 72 bridge.
		8	34.69864	-87.0507	Deepest point, main creek channel, Round Island Creek embayment, approximately 1.5 miles upstream of lake confluence.
		9	34.72263	-87.2805	Deepest point, main creek channel, Spring Creek embayment, approximately 0.5 mile upstream of CR 400 bridge.
		10	34.83745	-87.3715	Deepest point, main creek channel, Second Creek embayment, approximately 0.5 mile downstream of Hwy. 72 bridge.
	Wilson	1	34.77935	-87.3932	Deepest point, main creek channel, Big Nance Creek embayment, immediately upstream of AL Hwy. 101 bridge.
		2	34.82273	-87.4089	Deepest point, main creek channel, Bluewater Creek embayment, approximately one mile upstream of lake confluence.
		3	34.77307	-87.4303	Deepest point, main creek channel, Town Creek embayment, approximately one mile downstream of CR 314 bridge.
		4	34.85183	-87.5693	Deepest point, main creek channel, Shoal Creek embayment, immediately upstream of US Hwy 72 bridge.
	Pickwick	1	34.78814	-87.6971	Deepest point, main creek channel, Cypress Creek embayment, approximately 0.5 miles upstream of AL Hwy. 20.
		2	34.73944	-87.7309	Deepest point, main creek channel, Spring Creek embayment, approximately 1 mile upstream of lake confluence.
		3	34.74689	-87.8638	Deepest point, main creek channel, Cane Creek embayment, approximately one mile upstream of lake confluence.
		4	34.92624	-88.0468	Deepest point, main creek channel, Second Creek embayment, approximately one mile upstream of CR 14 bridge.

Figure 2. Guntersville Reservoir with 2003 sampling locations.

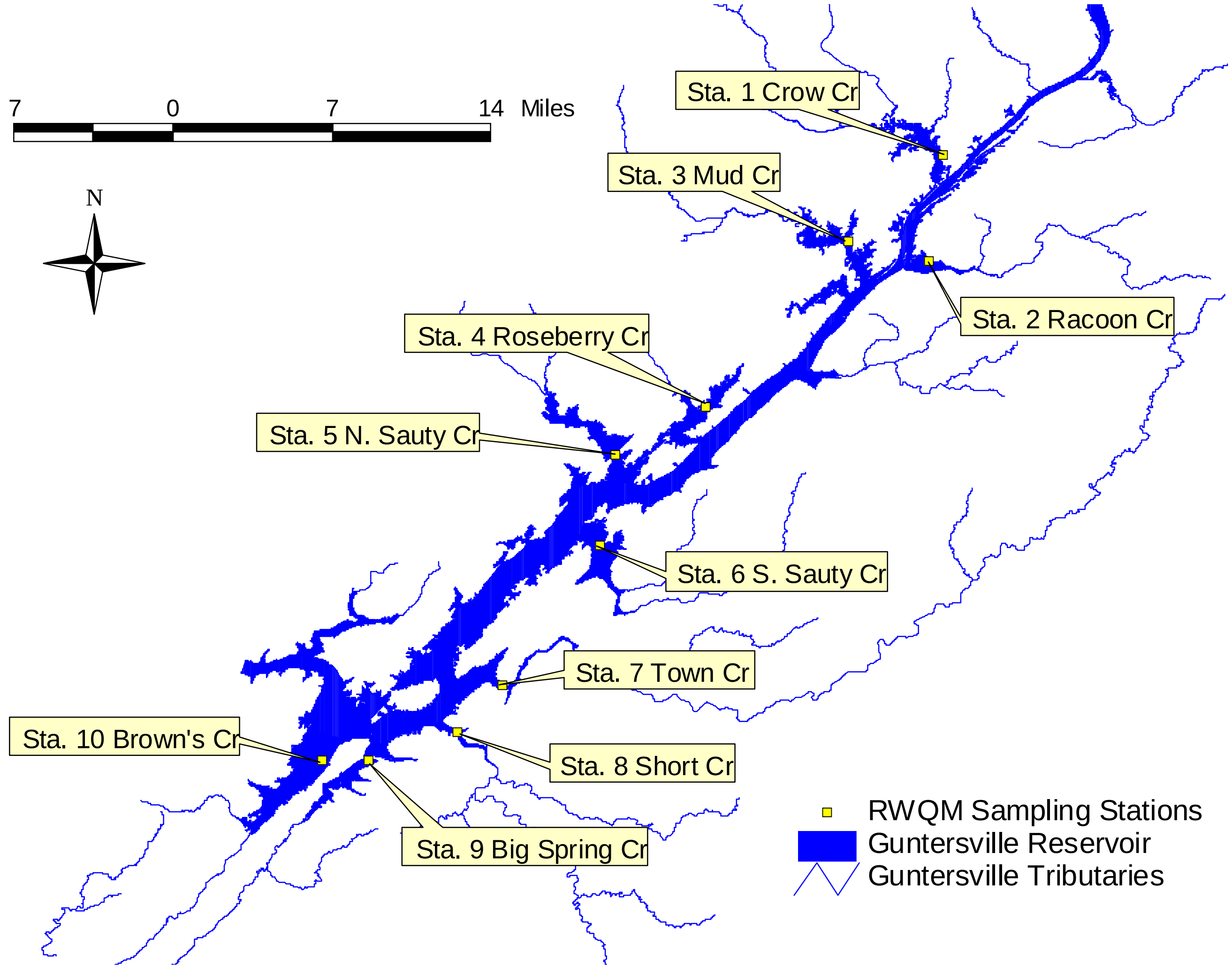


Figure 3. Wheeler Reservoir with 2003 sampling locations.

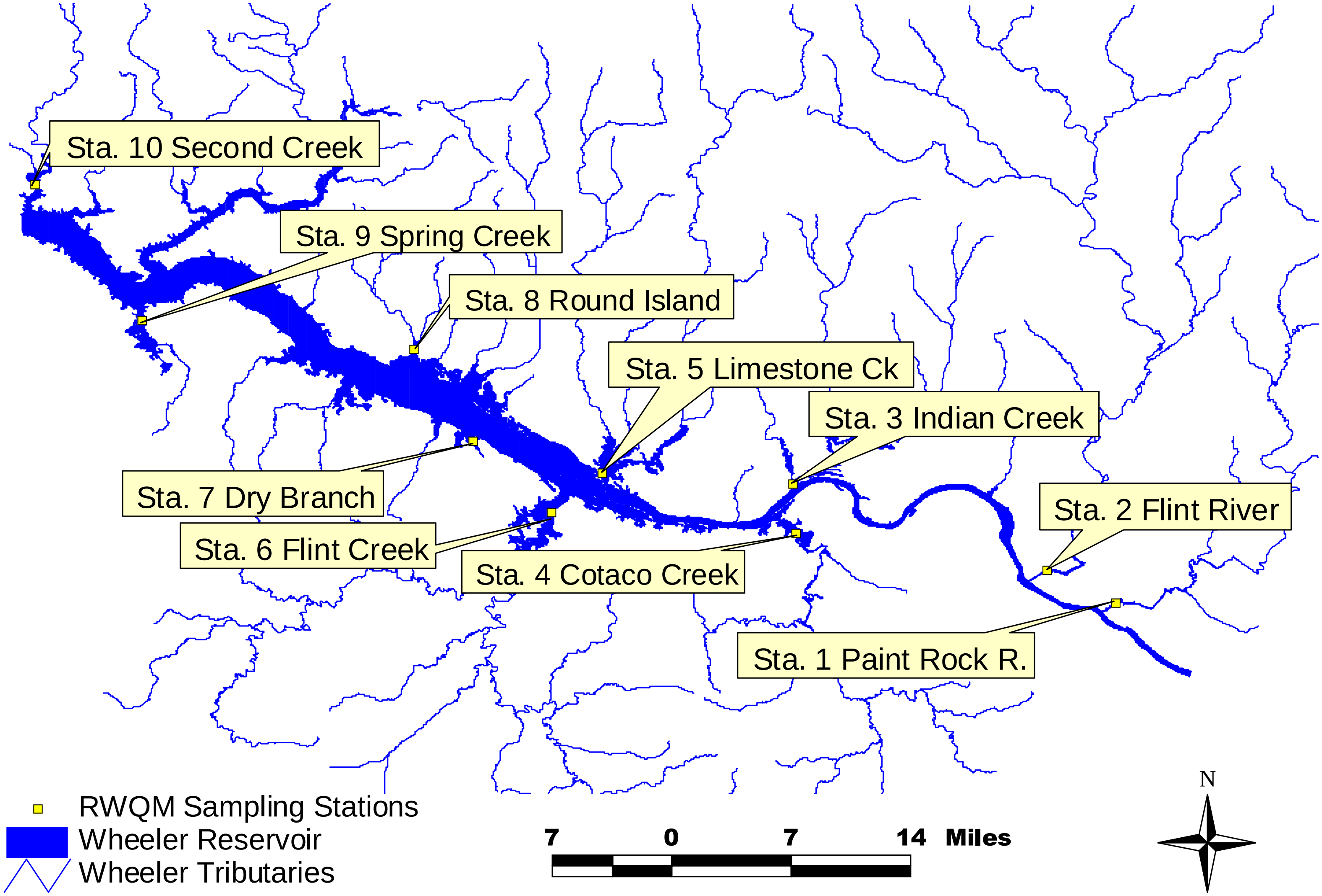


Figure 4. Wilson Reservoir with 2003 sampling locations.

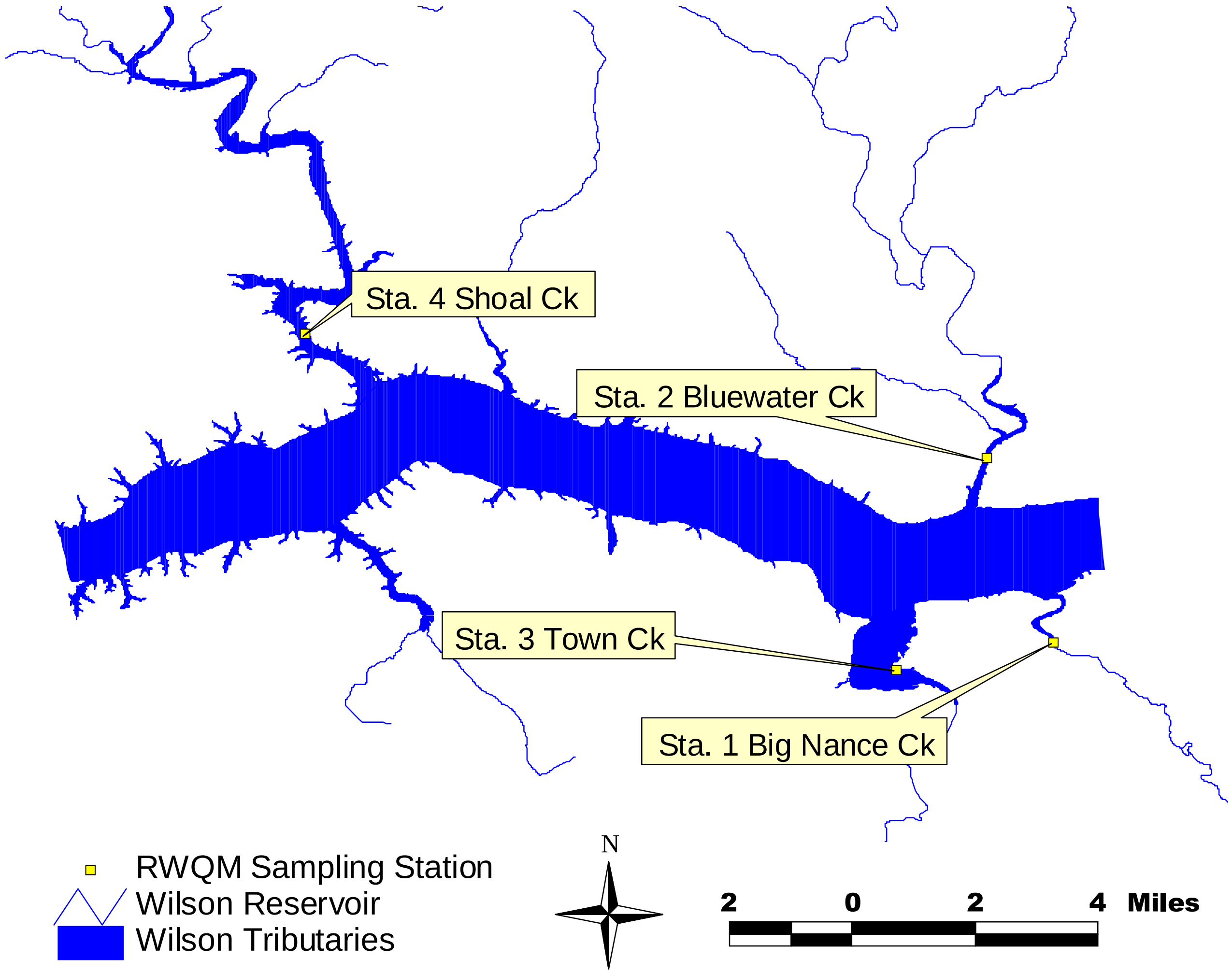


Figure 5. Pickwick Reservoir with 2003 sampling locations.

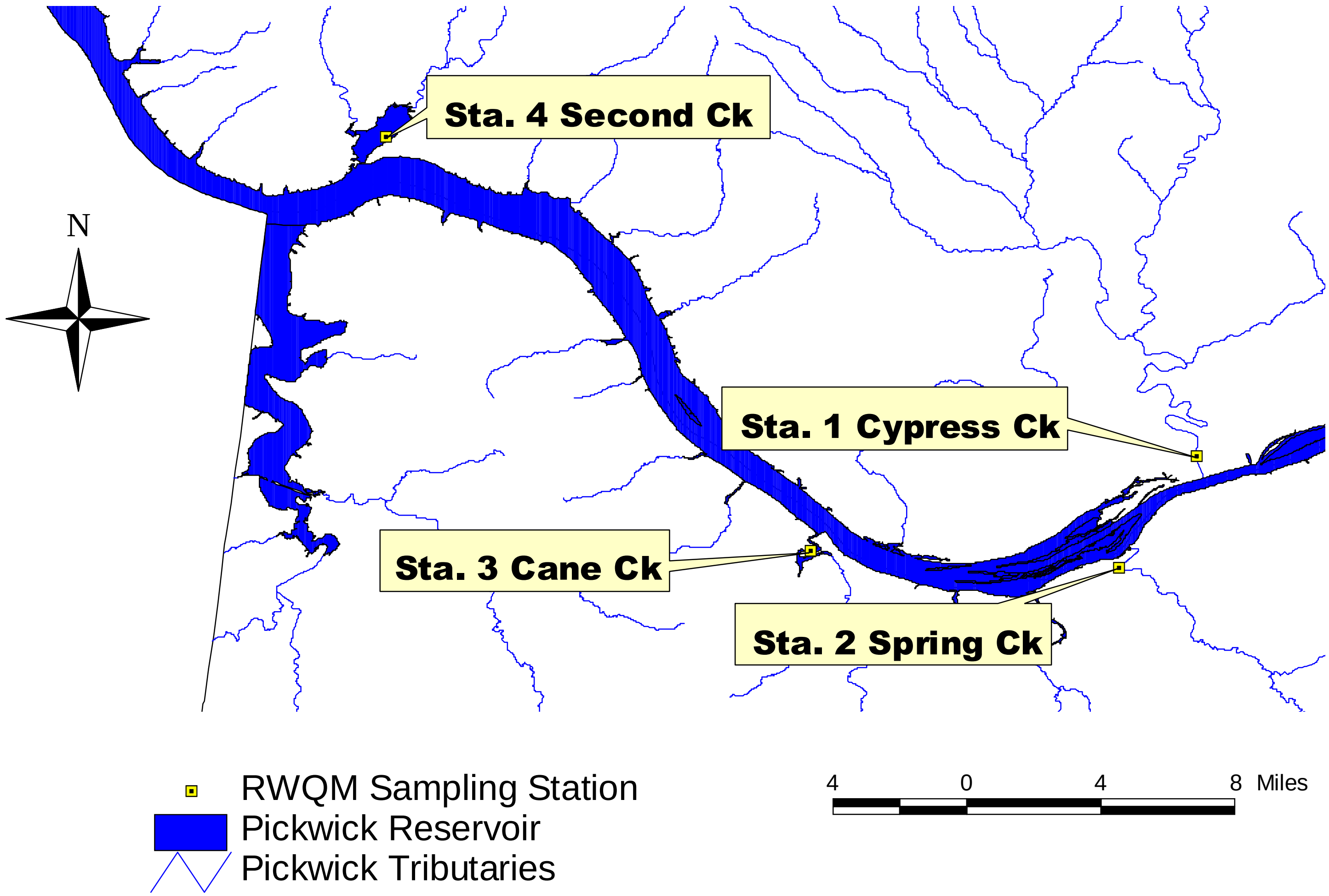


Table 3. Water quality variables measured during the Surface Water Quality Screening Assessment of the Tennessee River Basin, 2003.

Variable	Method	Reference	Detection Limit
Physical			
Vertical illumination	Photometer, Secchi disk	Lind, 1979	---
Temperature	Thermistor	APHA et al. 1998	---
Turbidity	Nephelometer	APHA et al. 1998	---
Total dissolved solids	Filtration, drying	EPA-600/4-79-020	1 mg/l
Total suspended solids	Filtration, drying	EPA-600/4-79-020	1 mg/l
Specific conductance	Wheatstone bridge	APHA et al. 1998	---
Hardness	Titrametric, EDTA	EPA-600/4-79-020	1 mg/l
Alkalinity	Potentiometric titration	EPA-600/4-79-020	1 mg/l
Chemical			
Dissolved oxygen	Membrane electrode	APHA et al. 1998	---
pH	Glass electrode	APHA et al. 1998	---
Ammonia	Automated phenate	EPA-600/4-79-020	0.015 mg/l
Nitrate + Nitrite	Cadmium reduction	EPA-600/4-79-020	0.003 mg/l
Total Kjeldahl Nitrogen	Automated colorimetric	EPA-600/4-79-020	0.15 mg/l
Dissolved reactive phosphorus	Automated single reagent	EPA-600/4-79-020	0.004 mg/l
Total phosphorus	Persulfate digestion	EPA-600/4-79-020	0.004 mg/l
Total organic carbon	Persulfate-ultraviolet	EPA-600/4-79-020	0.50 mg/l
Biological			
Chlorophyll *a*	Spectrophotometeric	APHA et al. 1998	0.1 μg/l
Algal growth potential test *	Printz Algal Assay Test	ADEM 1993	---

* August only.

Dissolved reactive phosphorus samples were collected by vacuum filtering approximately 125 ml of the composite sample through a disposable filtering apparatus containing a 0.45 micron membrane filter. The detachable base flask containing collected filtrate served as the sample container.

Finally, two half-gallon portions of the composite sample were collected in plastic containers and properly preserved for laboratory analysis of water quality variables.

During August, samples for Algal Growth Potential Tests (AGPT) were collected from the composite photic zone sample by filling a properly prepared plastic container and preserving on ice. A more detailed discussion of AGPT appears later in this section.

All samples were preserved, stored, and transported according to procedures in the ADEM Field Operations Division Standard Operating Procedures and Quality Control Assurance Manual Volume I Physical/Chemical (2000a).

Quality Control / Quality Assurance. For quality control/quality assurance purposes, field duplicates of each sample type were collected at five percent of the sampling sites. Field duplicates were true duplicates of the complete collection process. Blanks were collected at the same frequency as duplicates by processing distilled water through the collection and filtration equipment in the same manner as regular samples. Measurements of water temperature, dissolved oxygen, specific conductance, and pH were replicated at sampling sites where duplicate samples were collected.

Trophic State Index. Corrected chlorophyll a concentrations were used in calculating Carlson's trophic state index (TSI) for lakes (Carlson 1977). Carlson's TSI provides limnologists and the public with a single number that serves as an indicator of a lake's trophic status. Corrected chlorophyll a is the parameter used in the RWQM Program to calculate TSI because it is considered to give the best estimate of the biotic response of lakes to nutrient enrichment when algae is the dominant plant community.

The trophic state classification scale used is as follows:

Oligotrophic: TSI < 40

Mesotrophic: TSI 40 – 49

Eutrophic: TSI 50 – 69

Hypereutrophic: TSI > 70

Algal Growth Potential Tests. The Algal Growth Potential Test (AGPT) determines the total quantity of algal biomass supportable by the test waters and provides a reliable estimate of the bioavailable and limiting nutrients (Raschke and Schultz 1987). In control samples, maximum algal standing crop (MSC) dry weights below 5.0 mg/l are thought to assure protection from nuisance algal blooms and fish-kills in southeastern lakes, with the exception of lakes in Florida (Raschke and Schultz 1987). In most freshwater lakes, phosphorus is the essential plant nutrient that limits growth and productivity of plankton algae (Wetzel 1983). Nitrogen usually becomes the limiting nutrient when bioavailable phosphorus increases relative to nitrogen, as in the case of waters receiving quantities of treated municipal waste (Raschke and Schultz 1987). The AGPT is helpful in identifying these common growth limiting nutrients.

RESULTS

Data Selection. Material in this section is presented by reservoir. Results are graphically displayed. Water quality data selected for display consist of the following:

a) total nitrogen (TN) and total phosphorus (TP), used as indicators of nutrient content in the waterbody;

b) algal growth potential tests (AGPT), used as a determinant of the total quantity of algal biomass supportable by test waters and of the limiting nutrient;

c) corrected chlorophyll a (chl. *a*), used as an indicator of algal biomass;

d) total suspended solids (TSS) concentrations, used as an indicator of water clarity;

e) dissolved oxygen (DO) concentrations, used as a more direct indicator of water quality because severe depletion can damage aquatic vertebrate and macroinvertebrate communities and interfere with water supply and recreational uses; and,

f) Carlson Trophic State Index (TSI), calculated from corrected chlorophyll a concentrations as a means of trophic state classification of the reservoir.

These data were selected because of their relationship to the process of eutrophication and their interest to the regulatory and scientific communities that stems from this relationship. Stream water quality assessments, land-use information, point sources, and potential non-point sources can be found in "Surface Water Quality Screening Assessment of the Tennessee River Basin-2003 Part I" (2005).

Graphs. Bar graphs consist of means of the variables for all months depicted in the line graphs. Line graphs for each tributary depict the monthly changes in the variables. Nutrients were plotted vs. discharge when available. Daily rainfall graphs were included since 2003 total rainfall was above average in most months and USGS gages available for only 5 creeks/rivers across the sampling area. Rain gauges were selected throughout the basin to show regional differences in rainfall amounts. These graphs show the amount of rainfall per day alongside the sampling events in order to give an idea of flow conditions in streams without gages.

Line graphs of DO concentrations consist of measurements conducted at a depth of five feet, unless otherwise noted, because ADEM Water Quality Criteria pertaining to reservoir waters require a DO concentration of 5.0 mg/l at this depth (ADEM Admin. Code R. 335-6-10-

.09). Under extreme natural conditions such as drought, the DO concentration may be as low as 4.0 mg/l. When depth was at least 3m deep, a profile graph of the sampling station was also included. Profile graphs indicate if the waterbody was thermally and/or chemically stratified.

Eutrophication. For those unfamiliar with the process of eutrophication, it may be useful to discuss the relationship of the topics to the process and how the process affects the water quality of lakes and reservoirs. Eutrophication is the process by which water bodies become more productive through increased input of nutrients, primarily nitrogen and phosphorus (Welch 1992). Normally, increased plant (algae and/or macrophyte) productivity and biomass are considered part of the eutrophication process though nutrients can increase without an increase in plant growth if available light in the water column is limited by high concentrations of suspended solids.

The classical trophic succession sequence that occurs in natural lakes is as follows:

Oligotrophy: nutrient-poor, biologically unproductive;

Mesotrophy: intermediate nutrient availability and productivity;

Eutrophy: nutrient-rich, highly productive;

Hypereutrophic: the extreme end of the eutrophic stage.

Depending on the nature of the watershed however, eutrophication of natural lakes may take thousands of years or they may never become eutrophic.

All waterbodies monitored during the intensive survey are reservoir embayments rather than natural lakes. Trophic succession in these waterbodies does not occur in the classical form as in natural lakes. After filling of the reservoir basin, trophic upsurge occurs, resulting in high productivity of algae and fish. The trophic upsurge is fueled by nutrient inputs from the watershed, leaching of nutrients from the flooded soils of the basin, and decomposition of terrestrial vegetation and litter. Eventually a trophic depression takes place with a decline in the productivity of algae and fish as these initially available nutrient sources decline. In time, a less productive but more stable trophic state is established. The trophic state that the reservoir eventually settles into (oligotrophic, mesotrophic, or eutrophic) is determined by the combination of the natural fertility of the watershed and the effects of the point and nonpoint sources of pollution within the watershed.

The concern about eutrophication from a water quality standpoint is more likely due to cultural eutrophication. Cultural eutrophication can be defined as eutrophication brought about by the increase of nutrient, soil, and /or organic matter loads to a lake or reservoir as a result of anthropogenic activities (EPA 1990). Activities that contribute to cultural eutrophication include wastewater treatment discharges, agricultural and silvicultural activities, residential and urban development, and road building. Increased eutrophication in a waterbody occurring over a period of 10 to 50 years usually indicates cultural eutrophication (Welch 1992).

The effects of cultural eutrophication to a reservoir that is highly productive, or eutrophic, can lead to hypereutrophic conditions. Hypereutrophic conditions are characterized by the following:

a) dense algal populations;

b) low dissolved oxygen concentrations;

c) increased likelihood of fish kills; and,

d) interference with public water supply and recreational uses.

Regardless of whether a reservoir embayment is oligotrophic, mesotrophic, or eutrophic, cultural eutrophication negatively affects biological communities of these waterbodies through sedimentation and changes in water quality variables such as dissolved oxygen, pH, water temperature, and light availability.

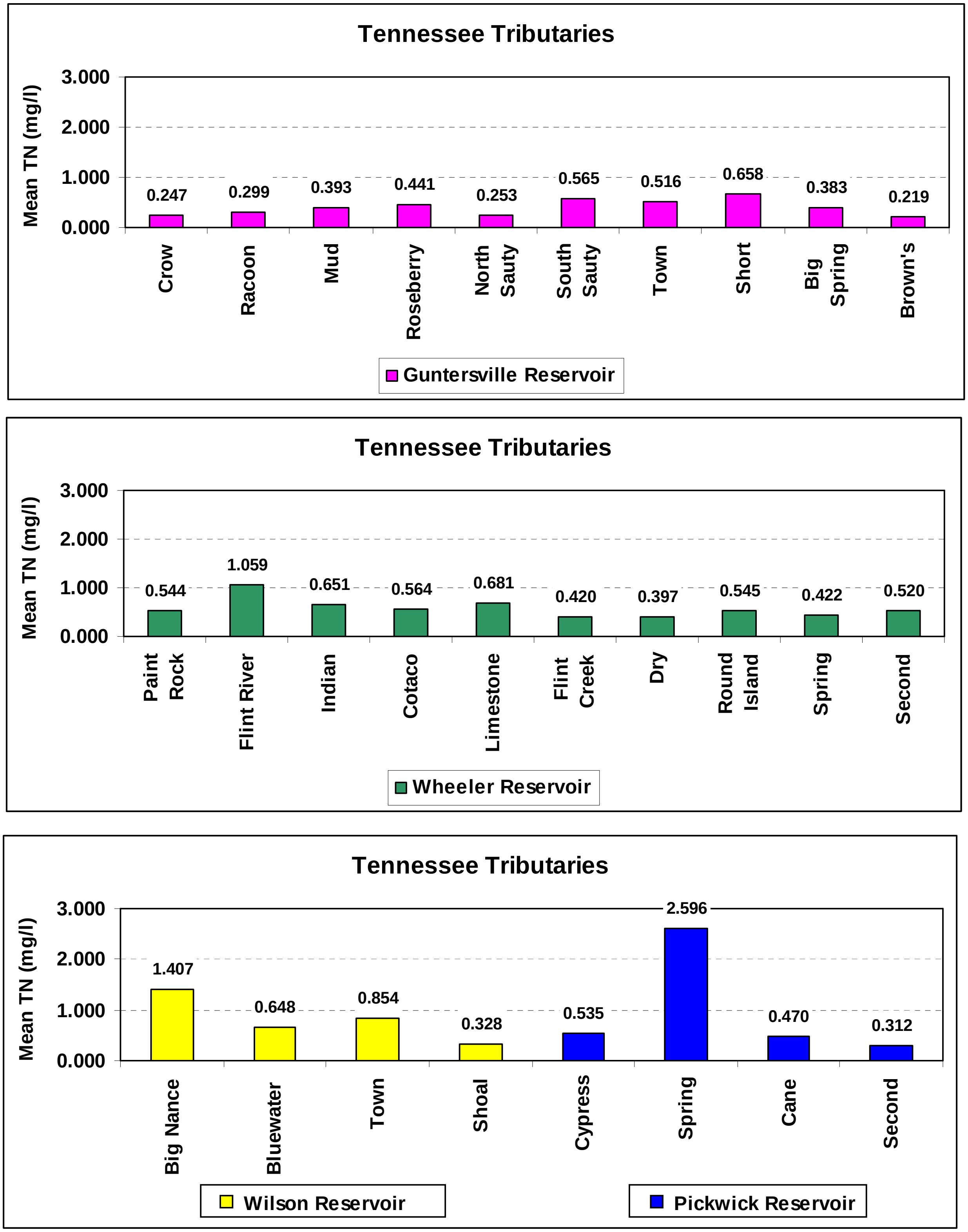


Figure 6. Mean total nitrogen (TN) concentrations of Tennessee Tributary locations, April-October 2003.

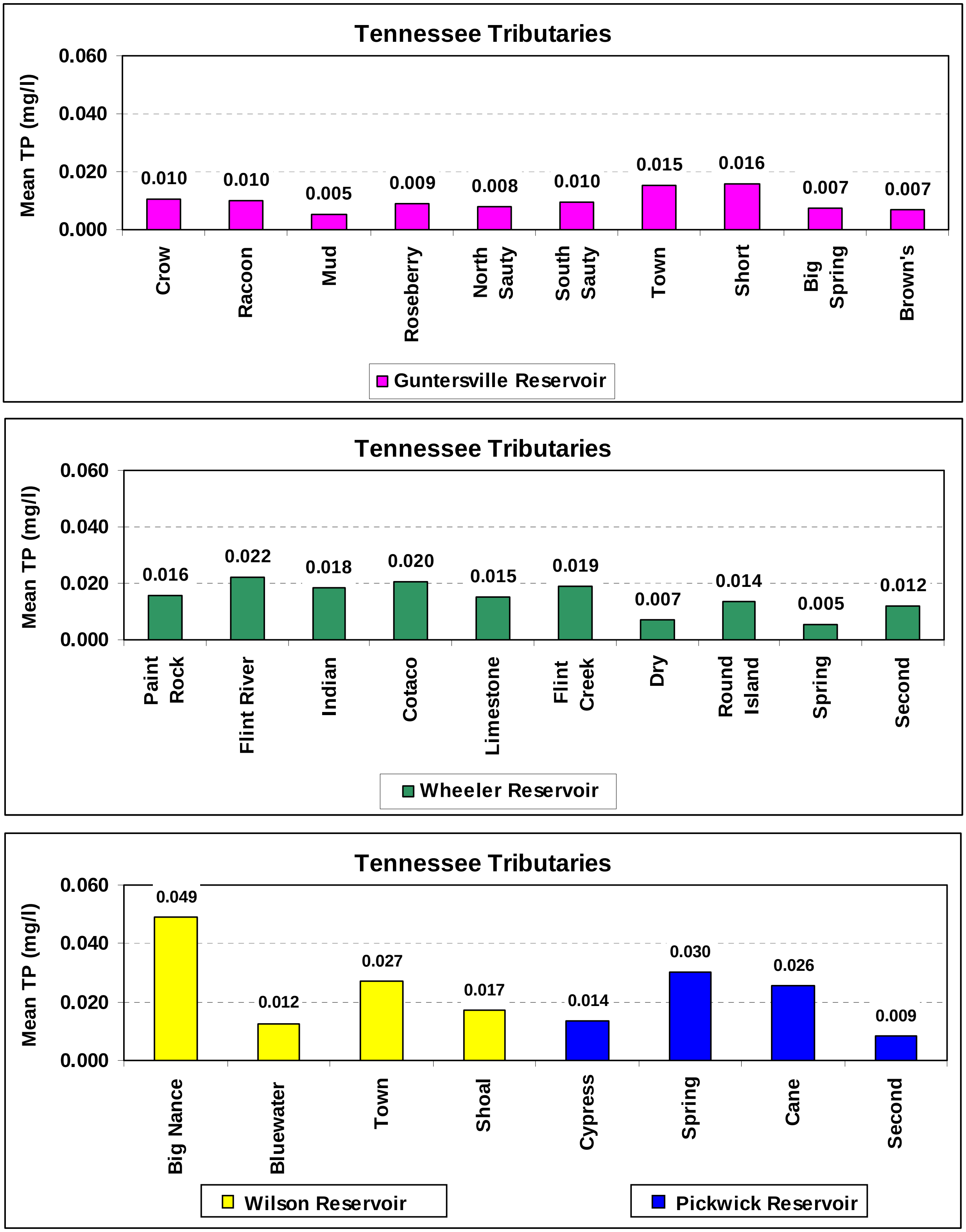


Figure 7. Mean total phosphorus (TP) concentrations of Tennessee Tributary locations April-October 2003.

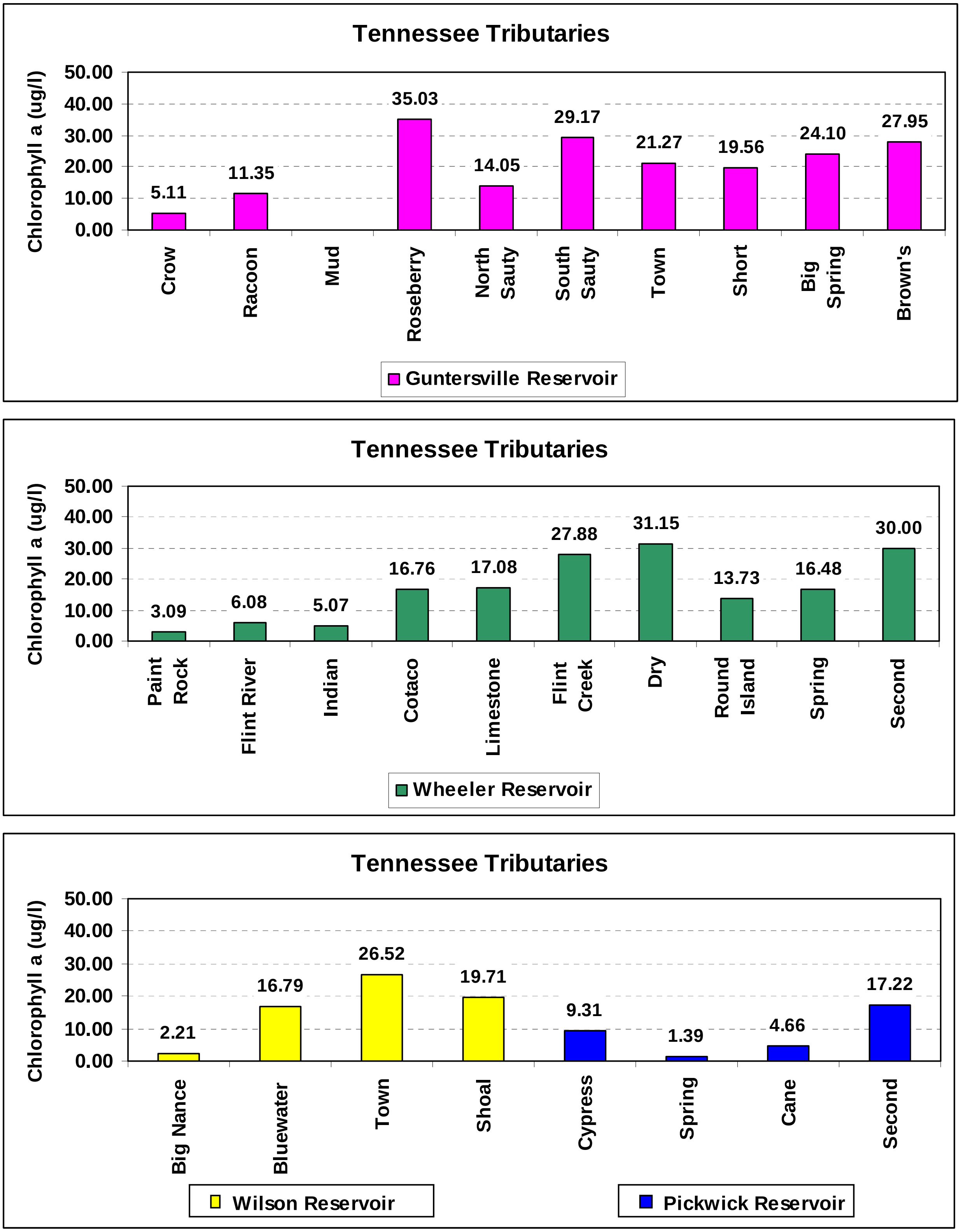


Figure 8. Mean chlorophyll *a* concentrations of Tennessee tributary embayment locations April-October 2003.

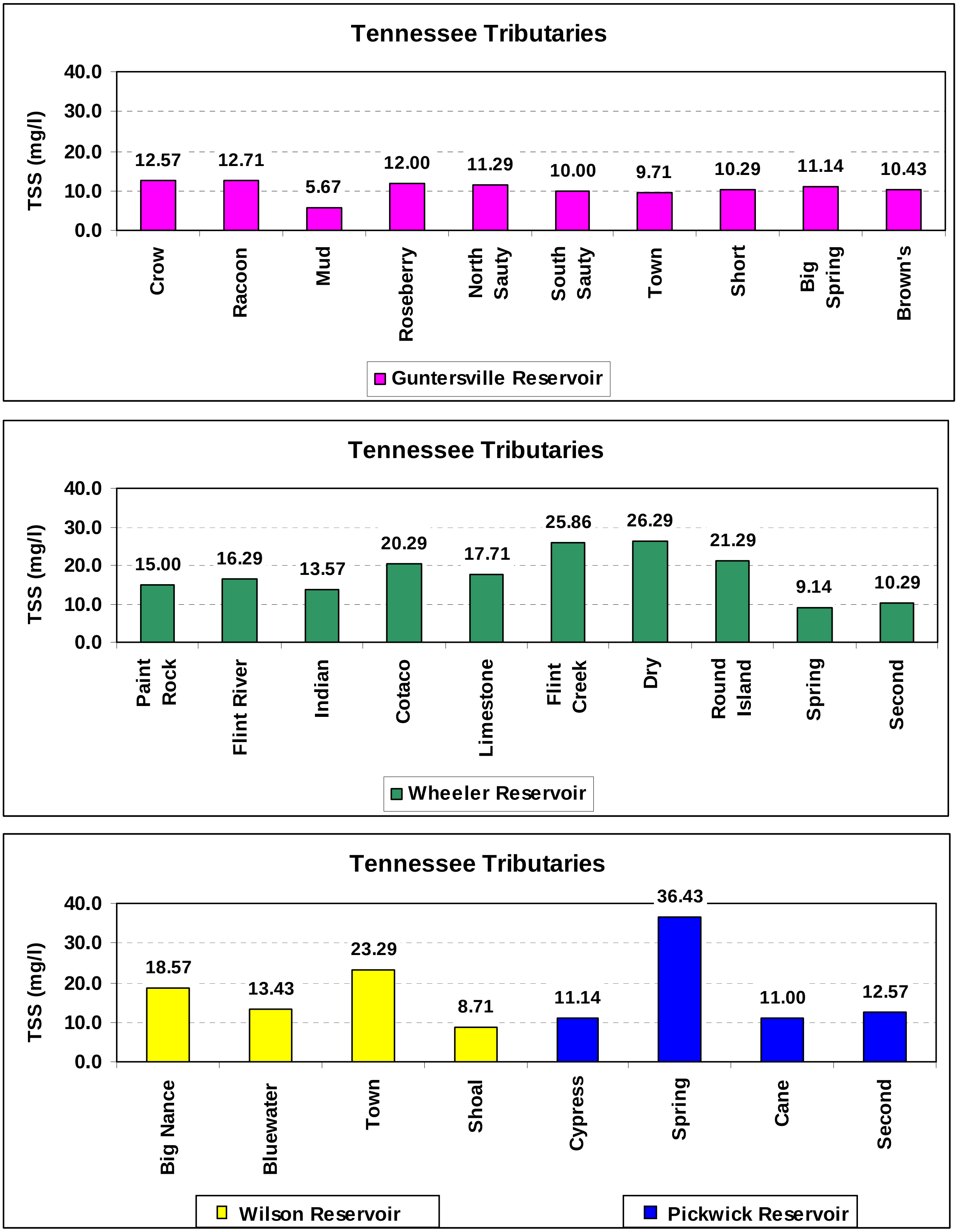


Figure 9. Mean total suspended solids (TSS) concentrations of Tennessee tributary embayment locations, April-October 2003.

Table 4. Algal growth potential testing (AGPT) of Tennessee River Embayments, August 2003

Reservoir	Station	Collection Date	Mean MSC (mg/l) C	C+N	C+P	Limiting Nutrient
Guntersville	Crow Creek	08/19/2003	0.98	0.87	**4.24**	Phosphorus
	Raccoon Creek	08/19/2003	2.89	3.06	**4.25**	Phosphorus
	Roseberry Creek	08/19/2003	4.71	**5.01**	**7.42**	Co-Limiting
	North Sauty Creek	08/19/2003	2.14	**3.26**	2.16	Nitrogen
	South Sauty Creek	08/19/2003	2.93	**3.14**	**3.83**	Co-Limiting
	Town Creek	08/20/2003	9.33	**12.14**	**10.90**	Co-Limiting
	Short Creek	08/20/2003	9.32	**51.09**	9.05	Nitrogen
	Big Spring Creek	08/20/2003	4.23	4.66	**8.83**	Phosphorus
	Brown's Creek	08/20/2003	3.75	3.98	**6.56**	Phosphorus
Wheeler	Paint Rock River	08/19/2003	1.22	1.07	**14.28**	Phosphorus
	Flint River	08/19/2003	8.28	7.59	**34.32**	Phosphorus
	Indian Creek	08/19/2003	10.13	10.48	**14.55**	Phosphorus
	Cotaco Creek	08/19/2003	5.01	**9.75**	5.24	Nitrogen
	Limestone	08/19/2003	7.04	6.74	**9.84**	Phosphorus
	Flint Creek	08/19/2003	3.09	**9.64**	2.57	Nitrogen
	Dry Branch	08/20/2003	5.52	**25.46**	5.52	Nitrogen
	Round Island Creek	08/20/2003	5.20	**10.82**	5.58	Nitrogen
	Spring Creek	08/20/2003	2.24	**2.79**	**3.28**	Co-Limiting
	Second Creek	08/20/2003	5.86	**10.51**	**7.04**	Co-Limiting
Wilson	Big Nance Creek	08/20/2003	9.09	9.32	**124.15**	Phosphorus
	Bluewater Creek	08/20/2003	29.80	**42.03**	**35.30**	Co-Limiting
	Town Creek	08/20/2003	19.00	**32.60**	21.72	Nitrogen
	Shoal Creek	08/20/2003	4.99	**20.16**	5.44	Nitrogen
Pickwick	Cypress Creek	08/19/2003	7.24	6.69	**35.48**	Phosphorus
	Spring Creek	08/19/2003	1.16	1.32	**9.68**	Phosphorus
	Cane Creek	08/19/2003	18.60	**22.79**	**20.73**	Co-Limiting
	Second Creek	08/19/2003	3.31	3.97	**4.89**	Phosphorus

MSC = Maximum Standing Crop
C = Control; C+N = Control + Nitrogen; C+P = Control + Phosphorus
Values in **bold** print are significantly different from control.

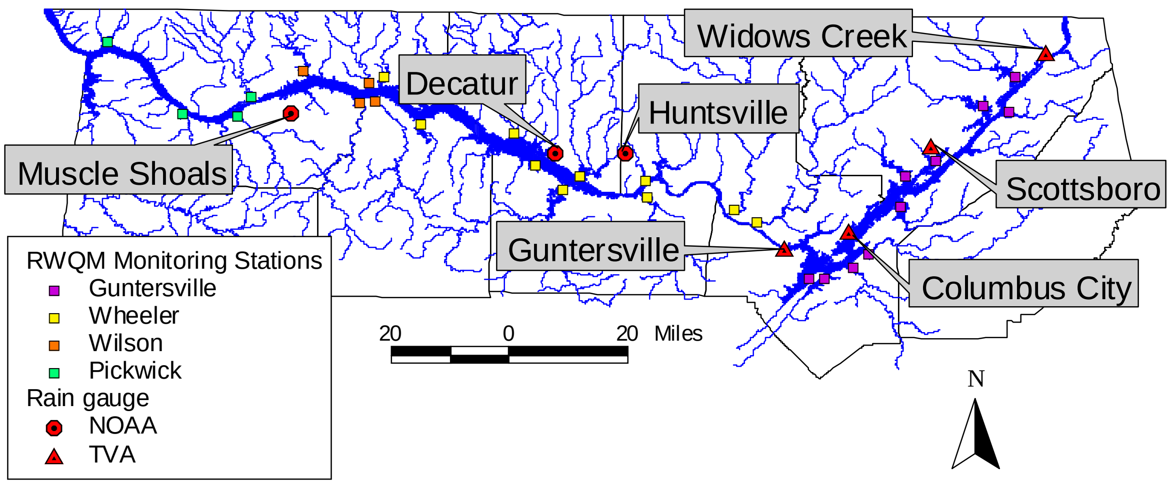


Figure 10. Map of rain gauge stations and their proximity to RWQM monitoring stations.

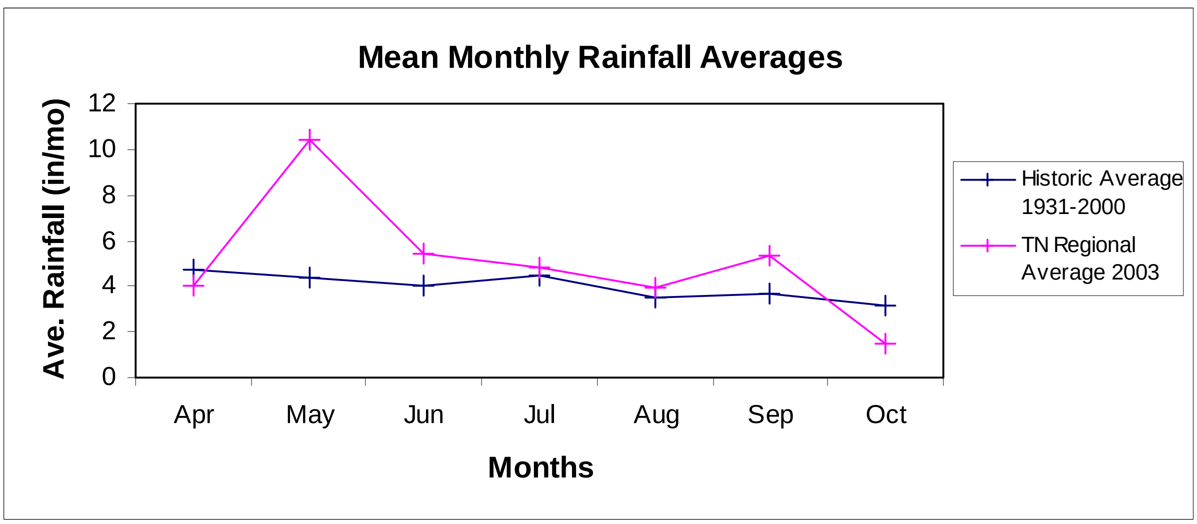
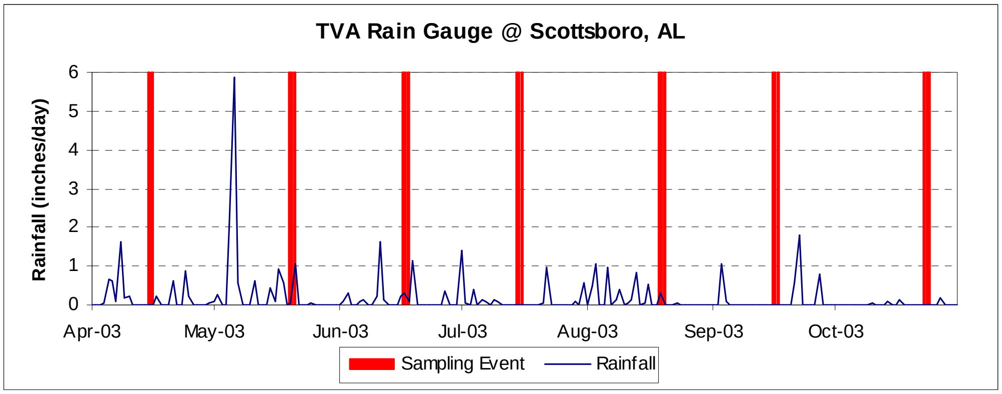
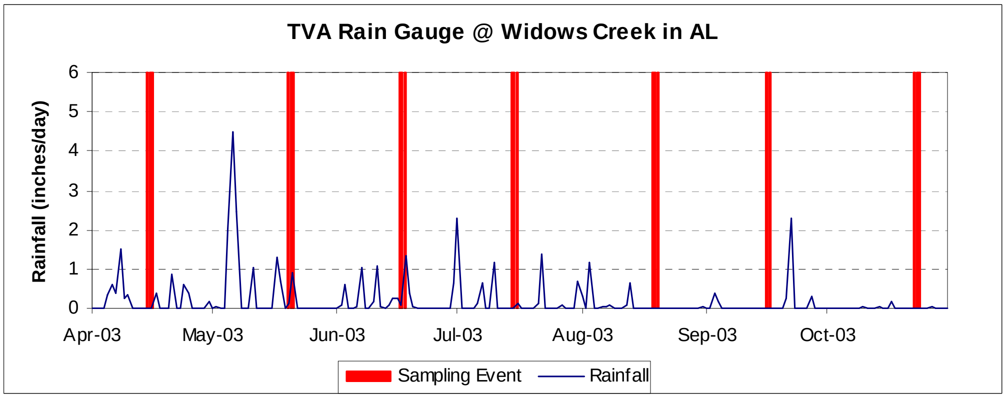
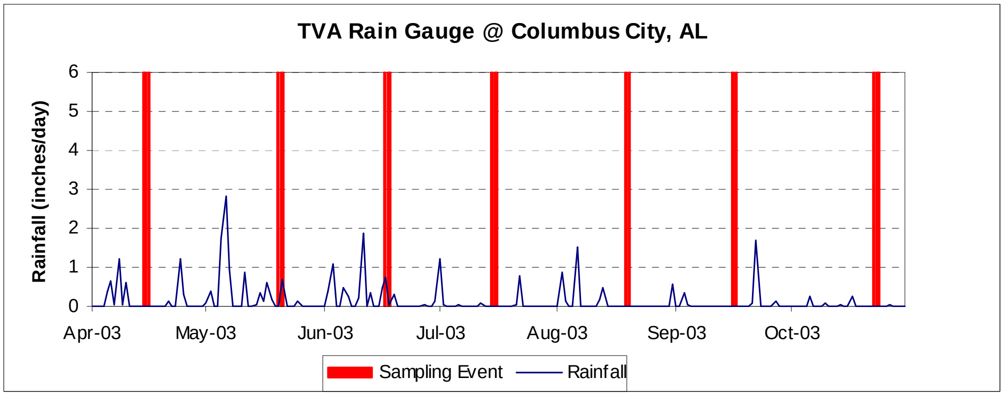


Figure 11. Mean monthly rainfall of the Tennessee basin, historic (1931-2000) vs. 2003.







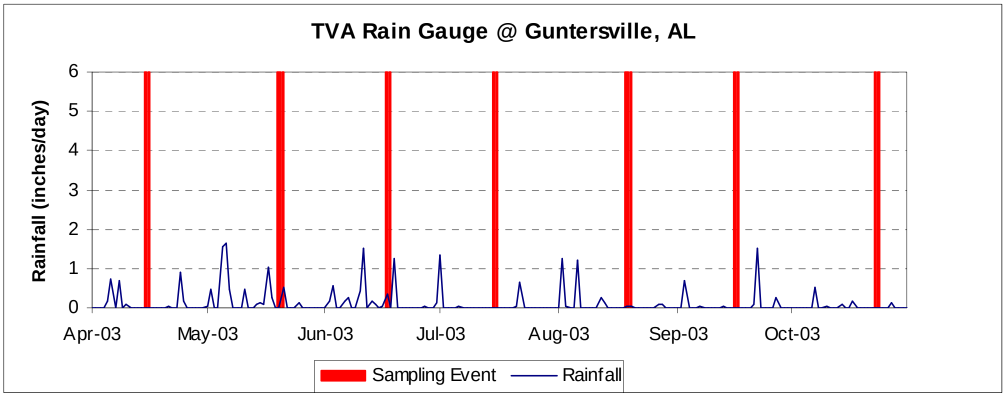


Figure 12. Daily rainfall at select TVA rain gauge stations across the Tennessee River basin, April-October 2003.

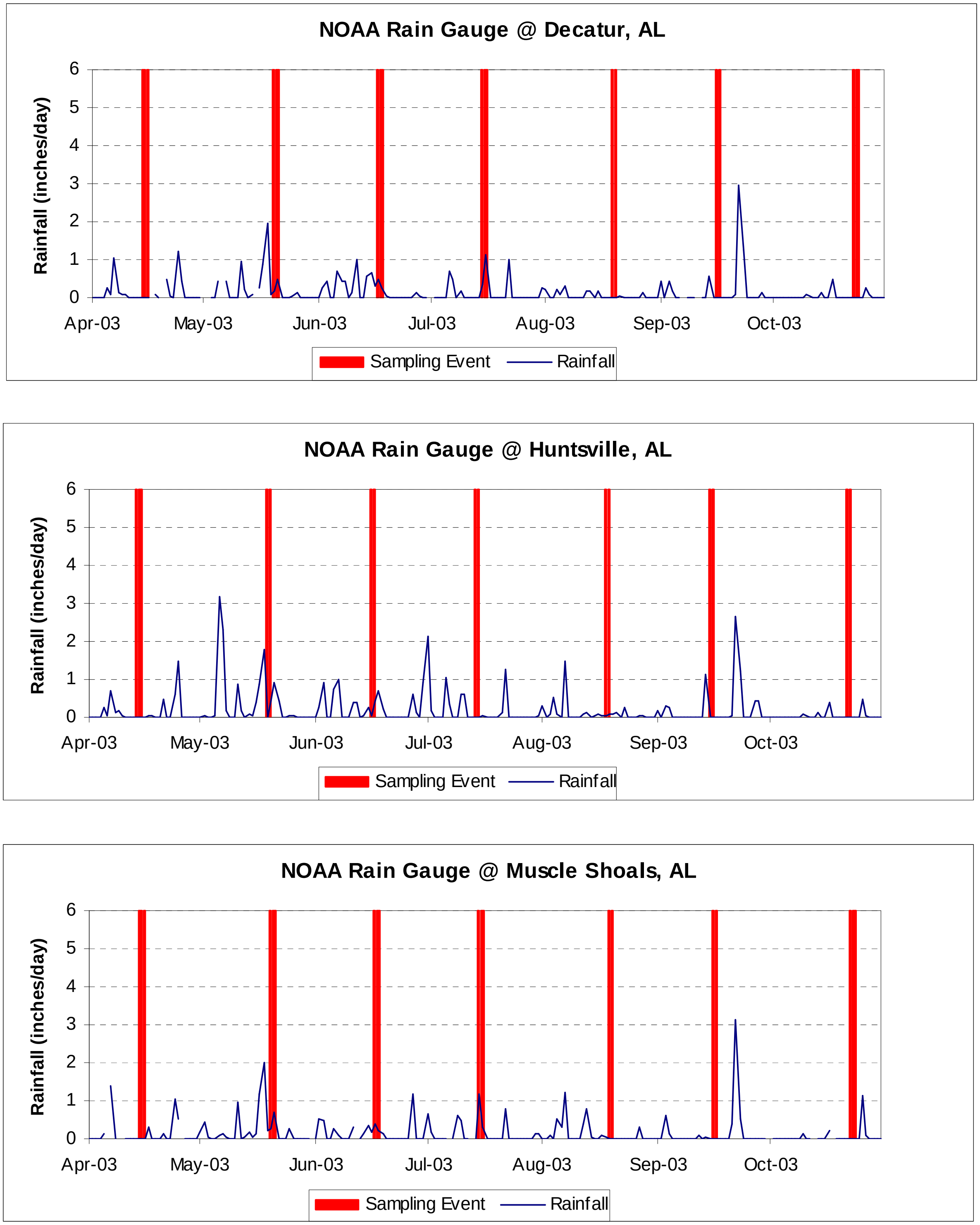


Figure 13. Daily rainfall at select NOAA rain gauge stations across the Tennessee River basin, April-October 2003.

Guntersville Reservoir Tributary Embayments

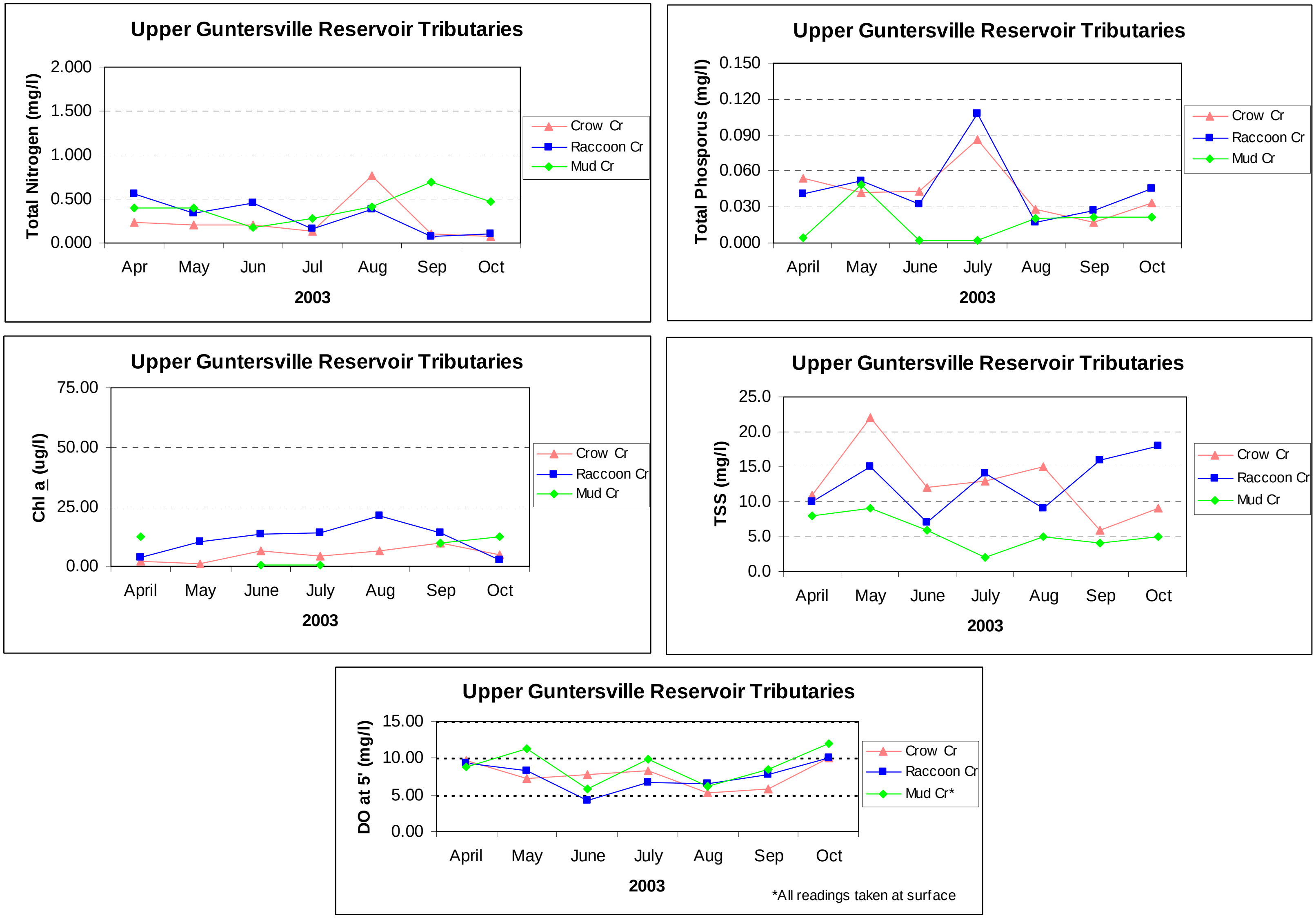


Figure 14. Total nitrogen, total phosphorus, chlorophyll *a* (chl a), total suspended solids (TSS), and dissolved oxygen (DO) in Upper Guntersville Reservoir Tributaries, April-October 2003.

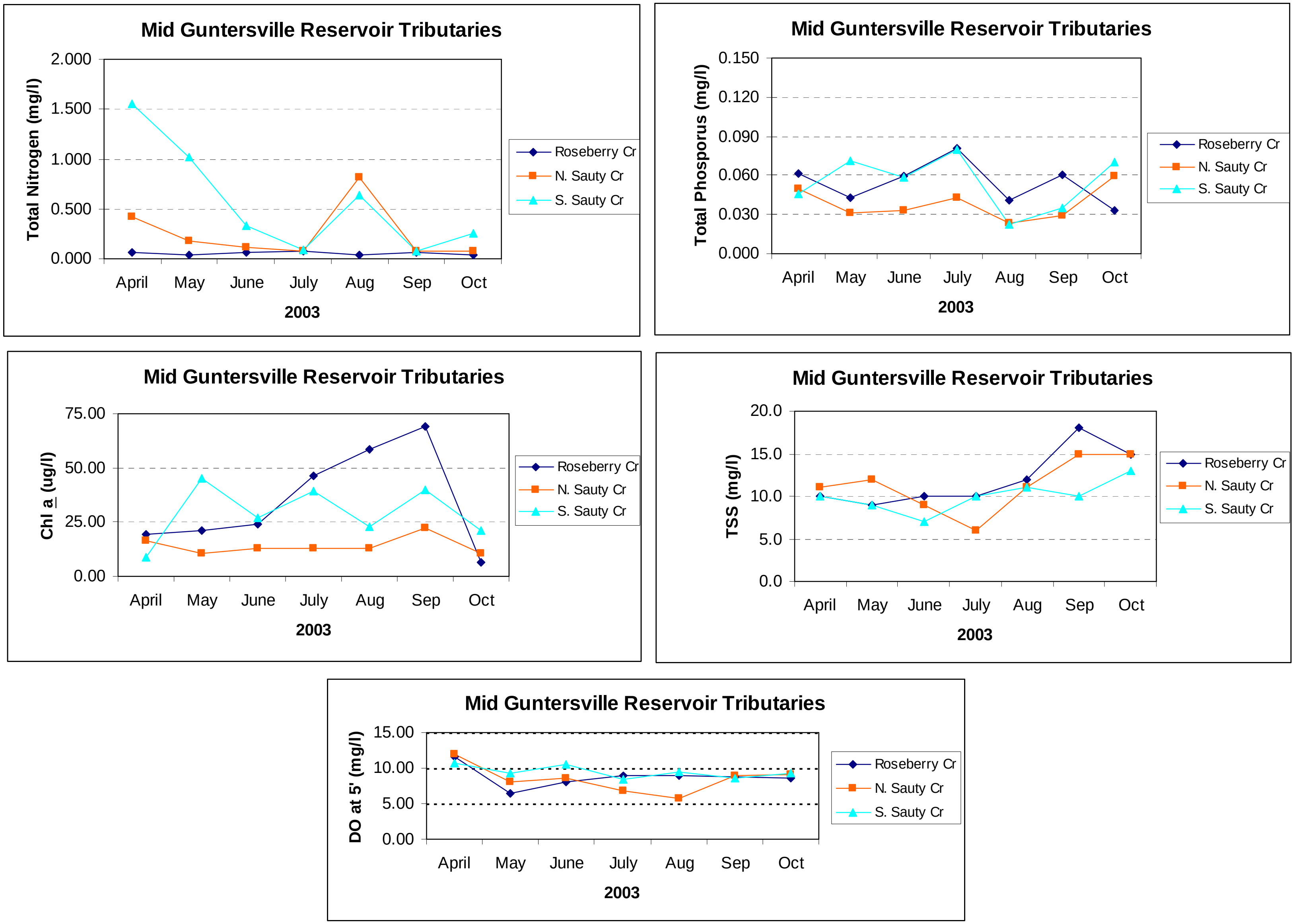


Figure 15. Total nitrogen, total phosphorus, chlorophyll *a* (chl a), total suspended solids (TSS), and dissolved oxygen (DO) in Mid Guntersville Reservoir Tributaries, April-October 2003.

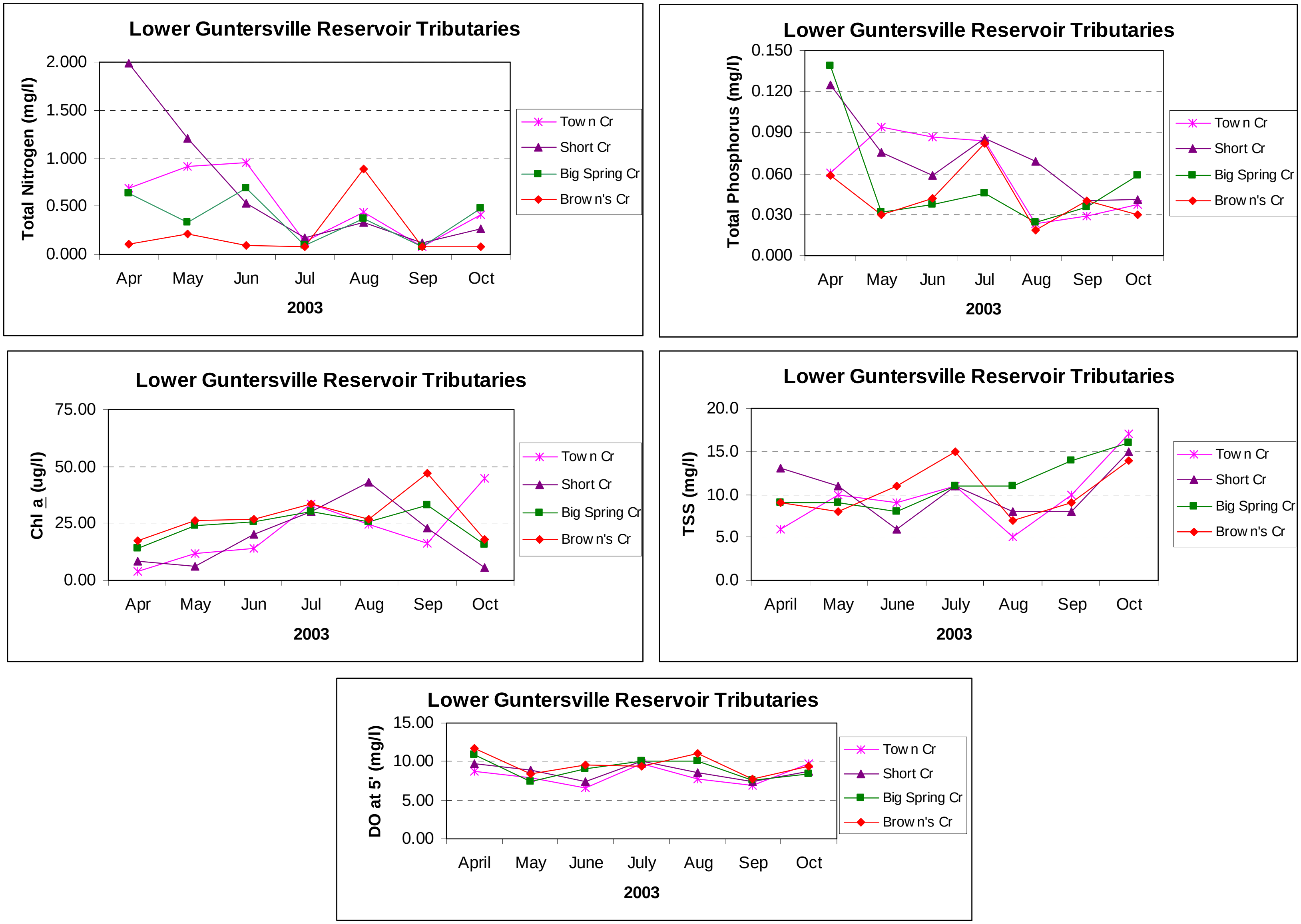


Figure 16. Total nitrogen, total phosphorus, chlorophyll *a* (chl a), total suspended solids (TSS), and dissolved oxygen (DO) in Lower Guntersville Reservoir Tributaries, April-October 2003.

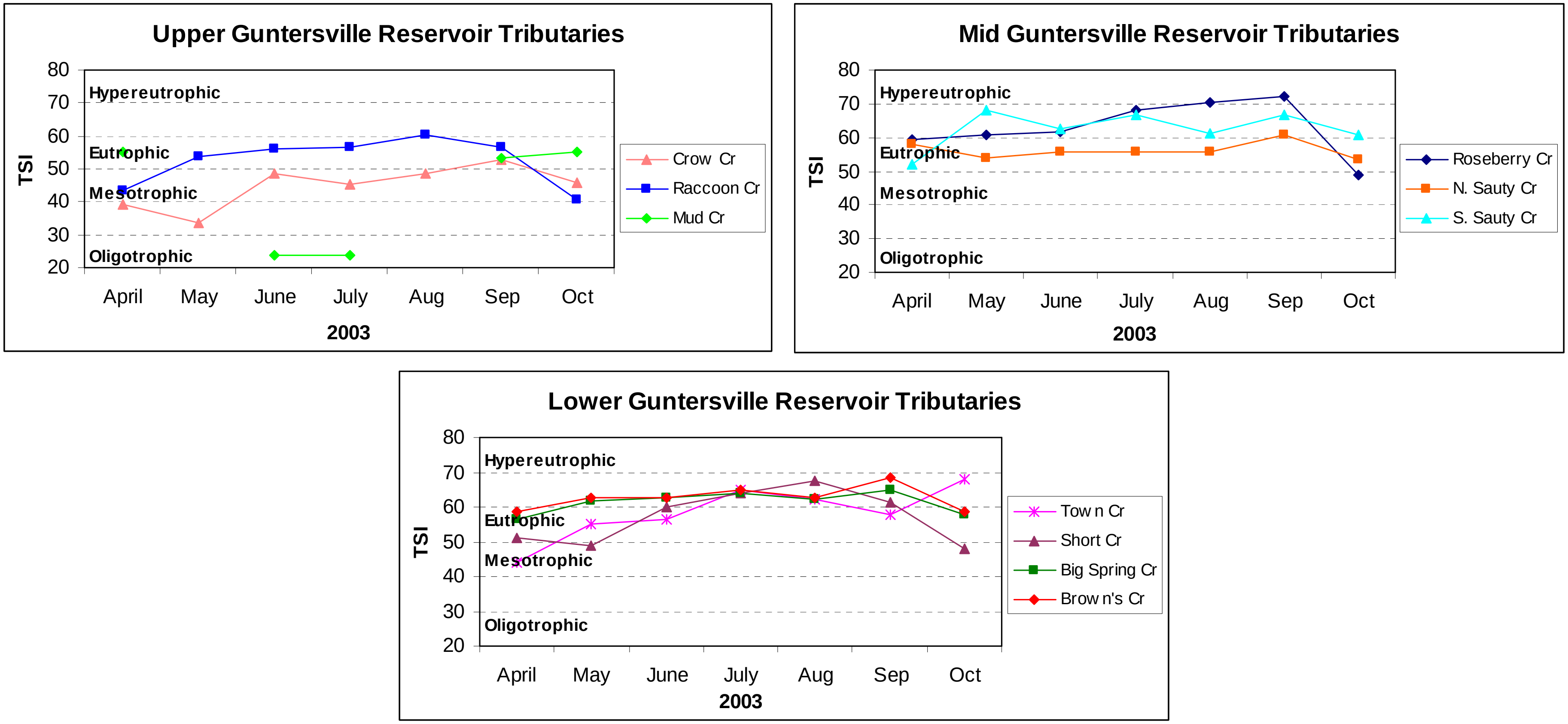


Figure 17. Trophic state index (TSI) for Guntersville Reservoir Tributaries, April-October 2003.

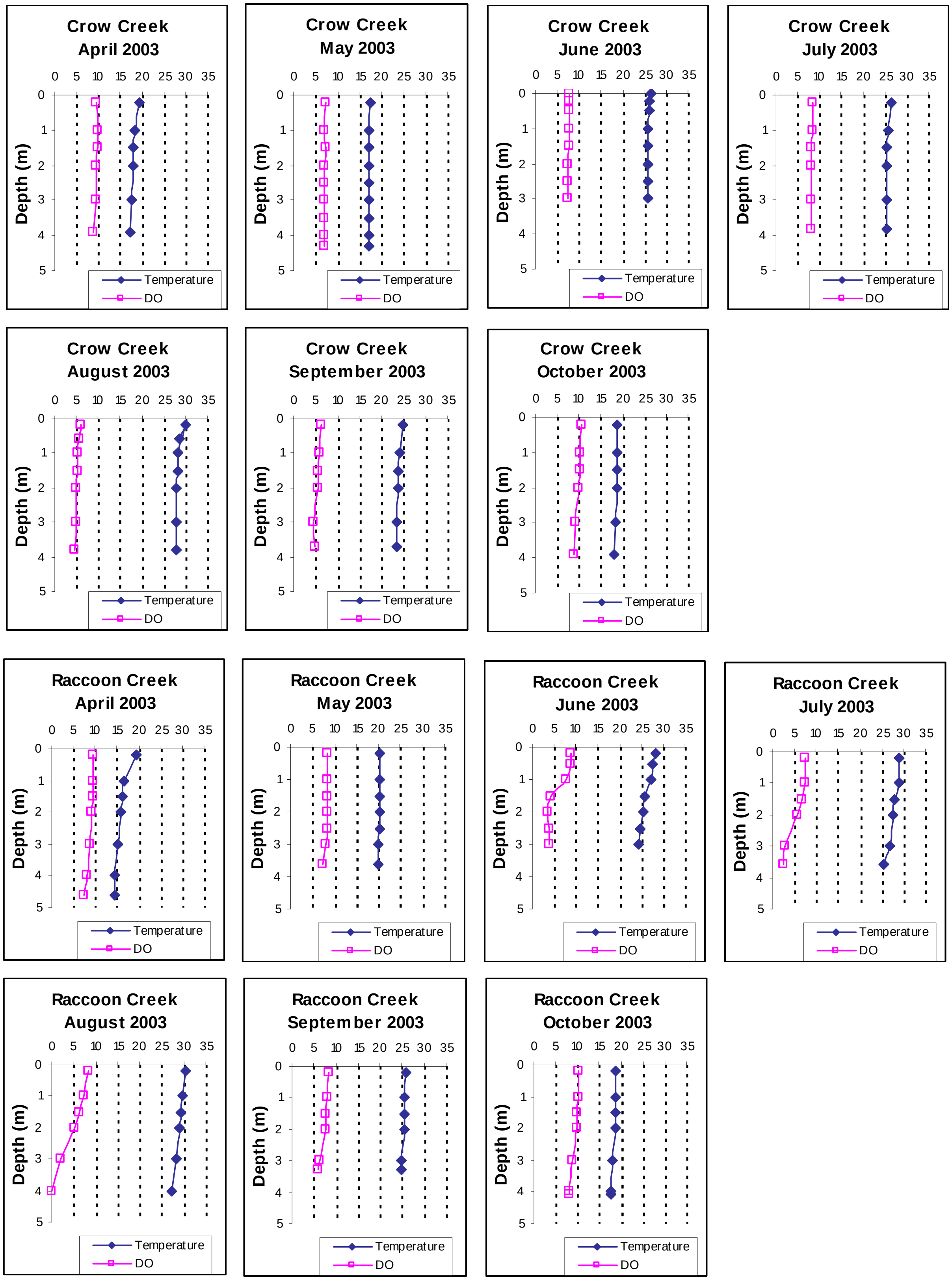


Figure 18. Depth profiles of dissolved oxygen (DO) and temperature in Crow and Raccoon Creeks, tributaries of Guntersville Reservoir, April-October 2003.

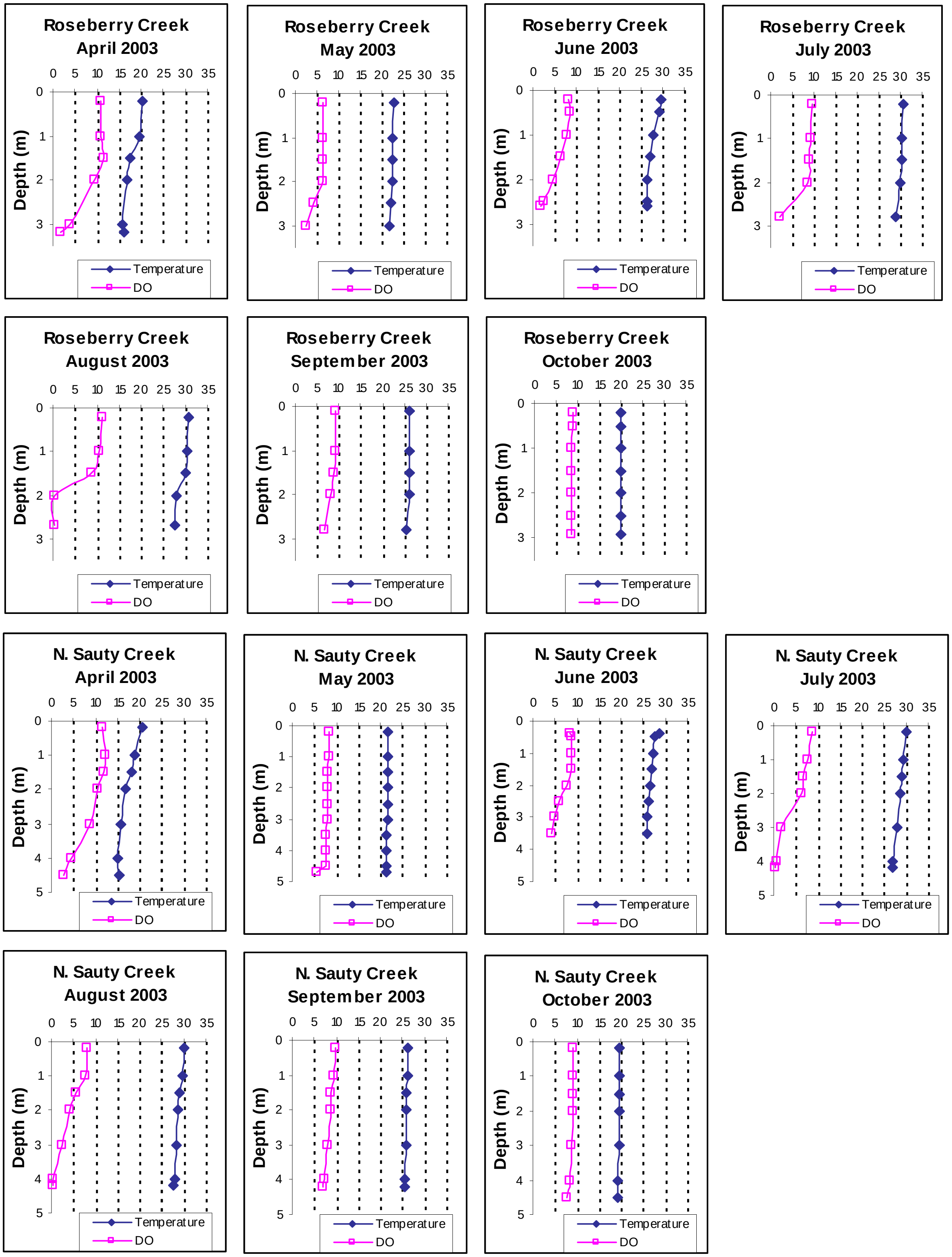


Figure 19. Depth profiles of dissolved oxygen (DO) and temperature in Roseberry and North Sauty Creeks, tributaries of Guntersville Reservoir, April-October 2003.

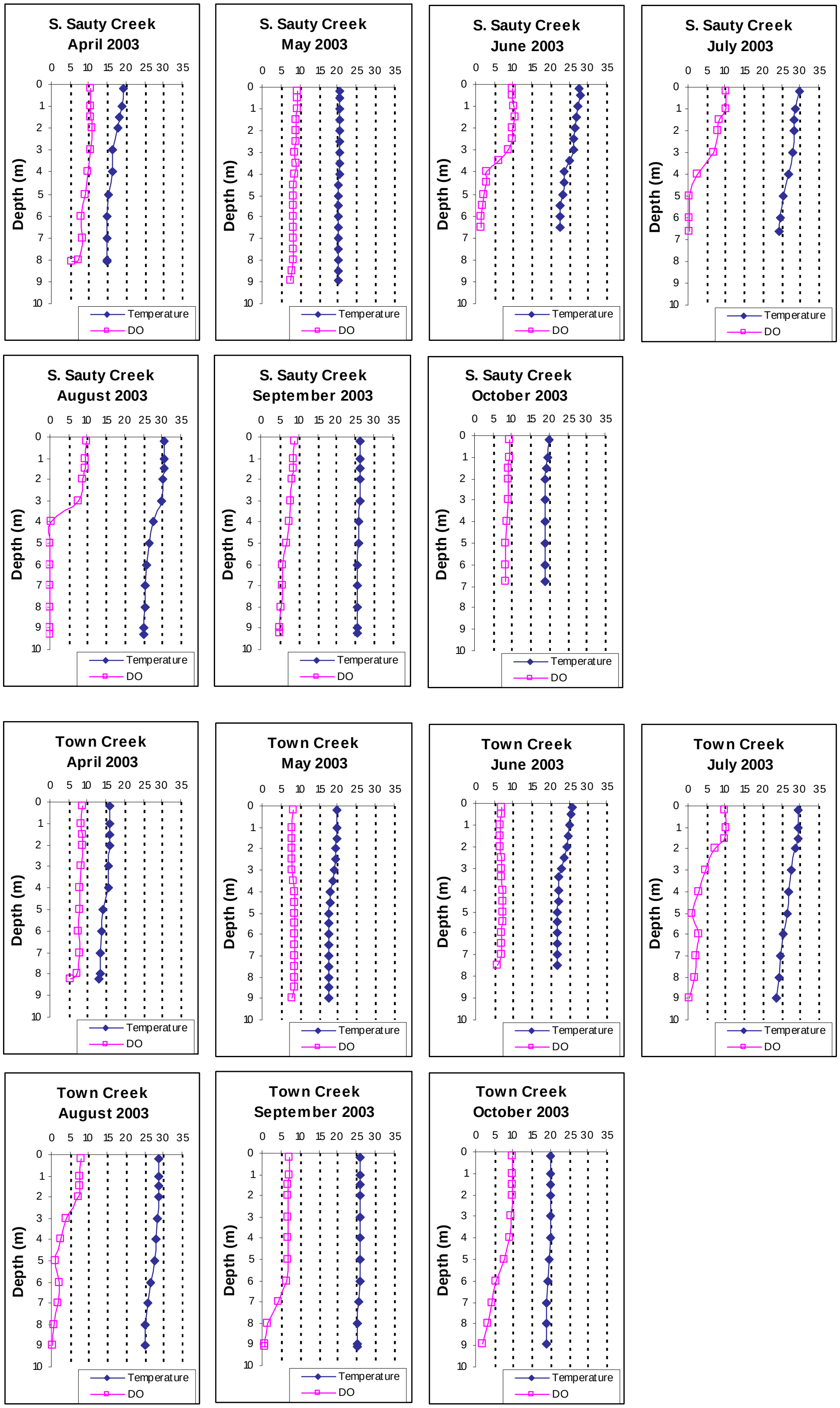


Figure 20. Depth profiles of dissolved oxygen (DO) and temperature in South Sauty and Town Creeks, tributaries of Guntersville Reservoir, April-October 2003.

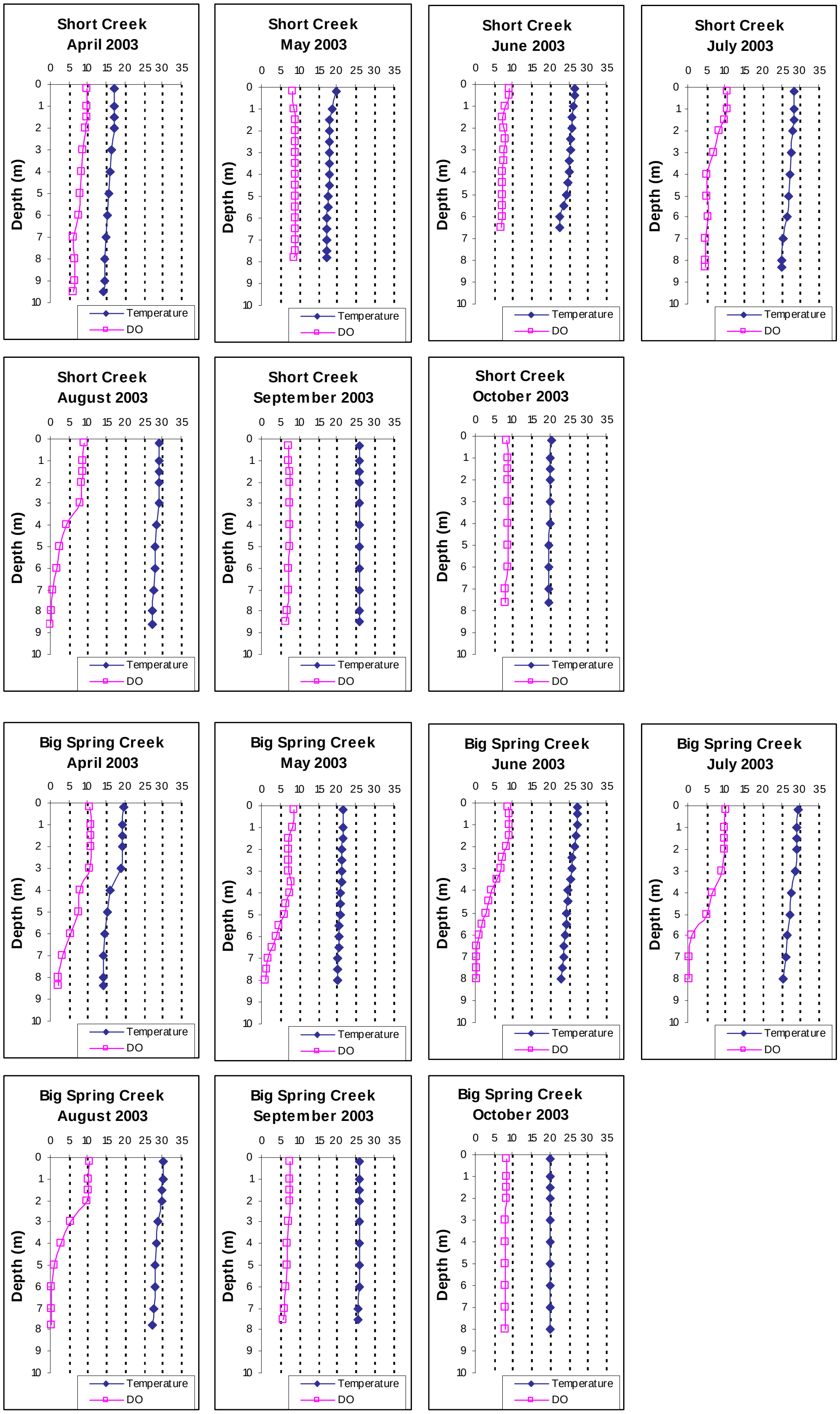


Figure 21. Depth profiles of dissolved oxygen (DO) and temperature in Short and Big Spring Creeks, tributaries of Guntersville Reservoir, April-October 2003.

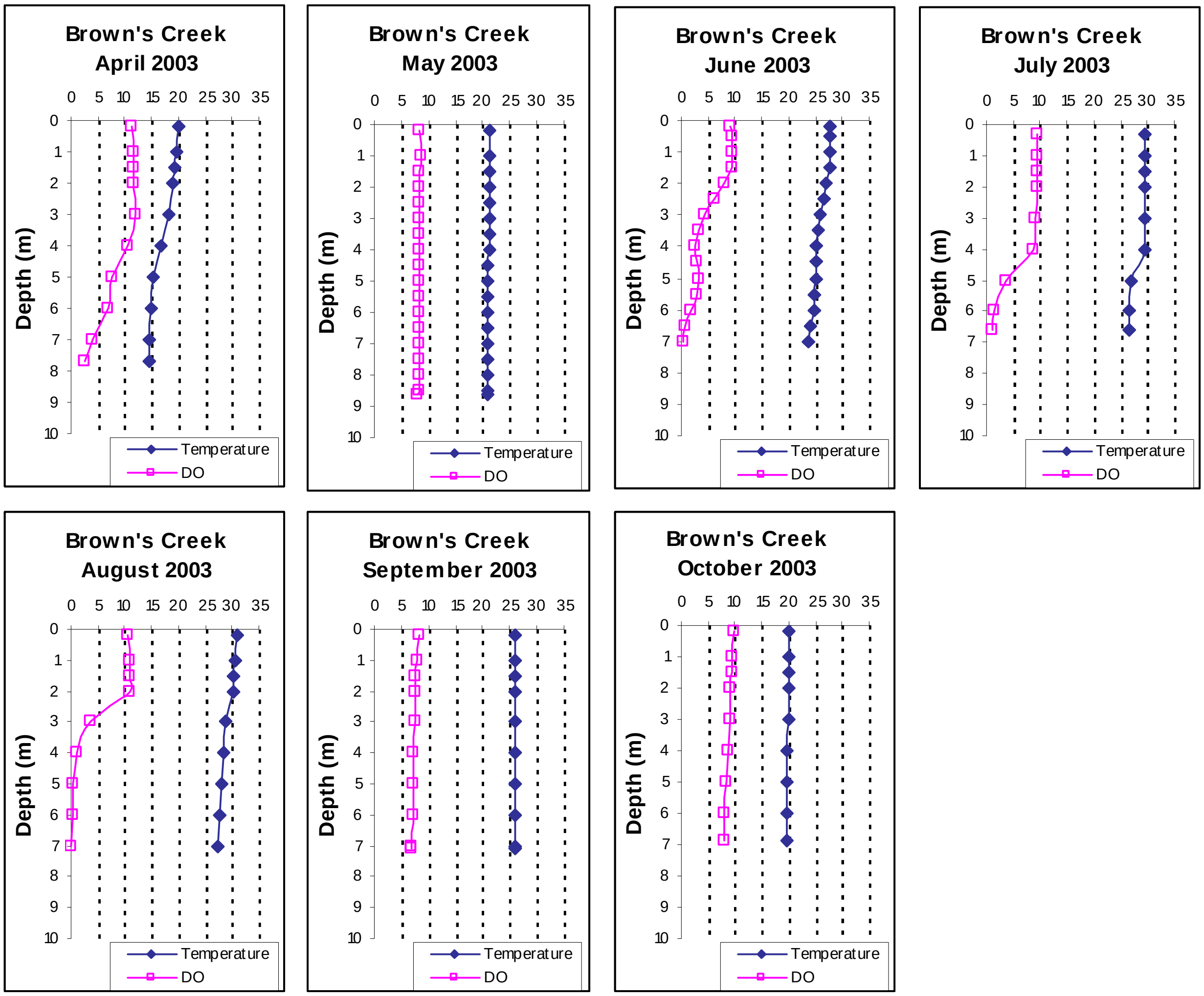


Figure 22. Depth profiles of dissolved oxygen (DO) and temperature in Brown's Creek, a tributary of Guntersville Reservoir, April-October 2003.

Wheeler Reservoir Tributary Embayments

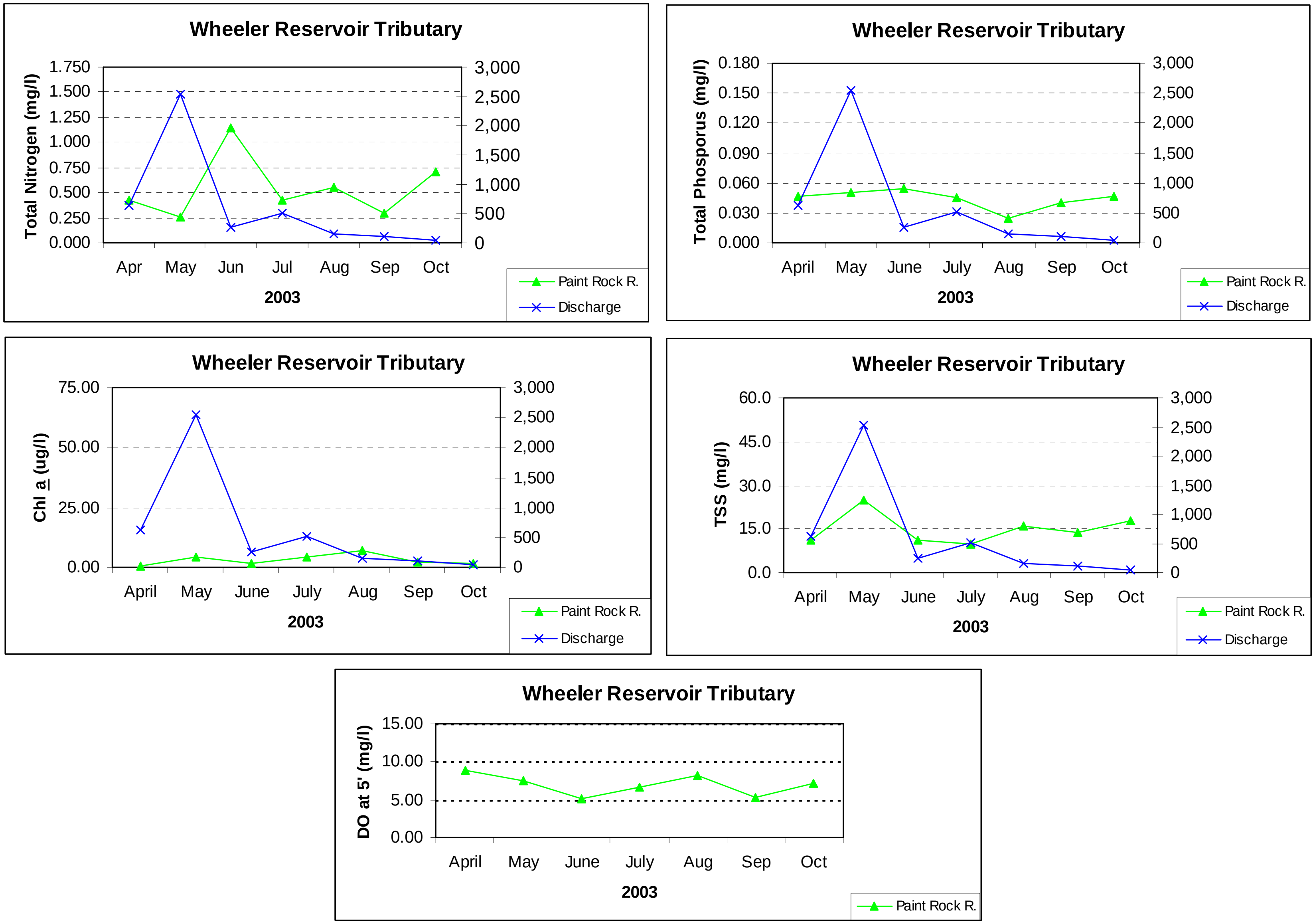


Figure 23. Total nitrogen, total phosphorus, chlorophyll a (chl a), total suspended solids (TSS), and dissolved oxygen (DO) in Paint Rock River, a tributary of Wheeler Reservoir, April-October 2003.

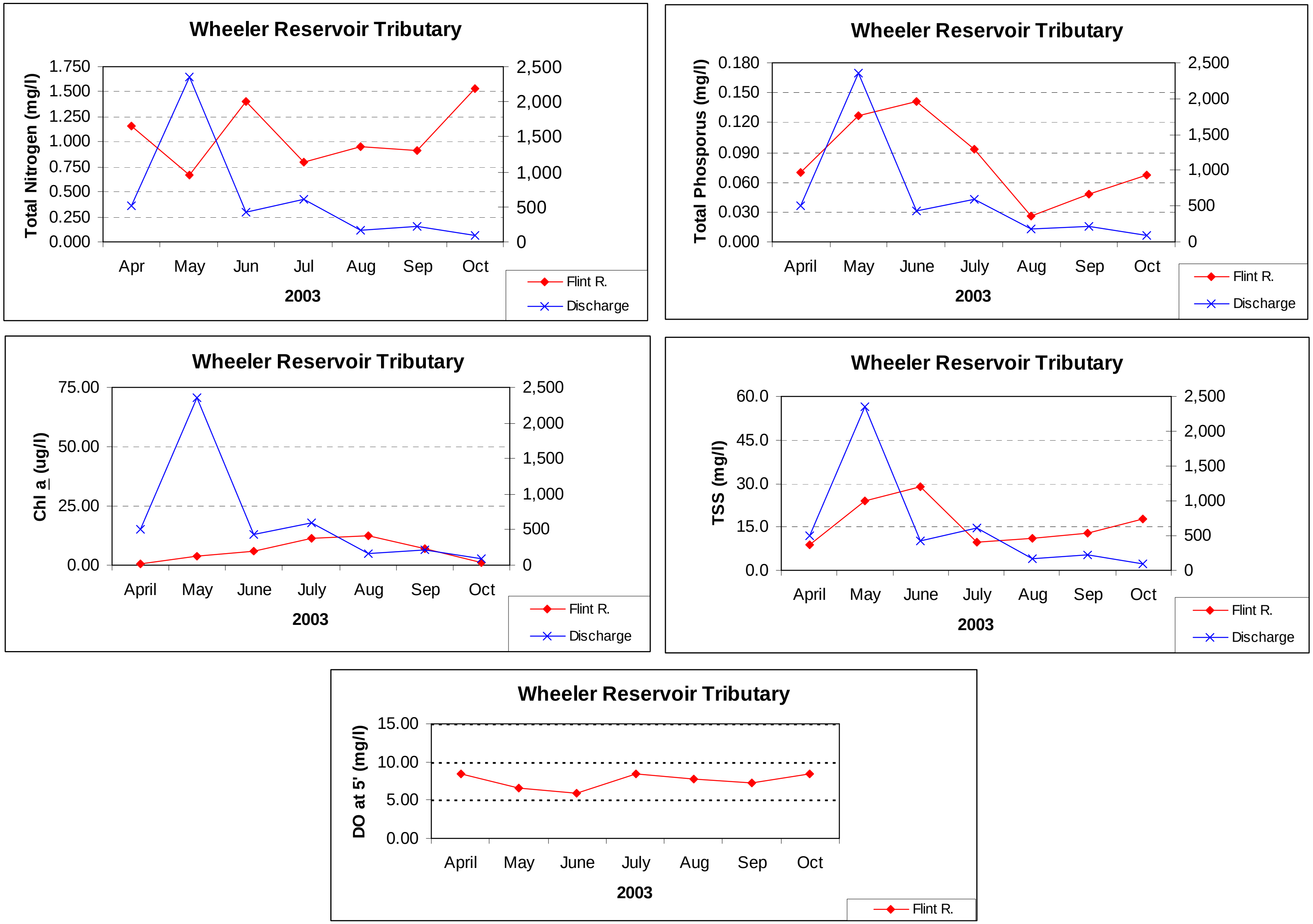


Figure 24. Total nitrogen, total phosphorus, chlorophyll *a* (chl a), total suspended solids (TSS), and dissolved oxygen (DO) for Flint River, a tributary of Wheeler Reservoir, April-October 2003.

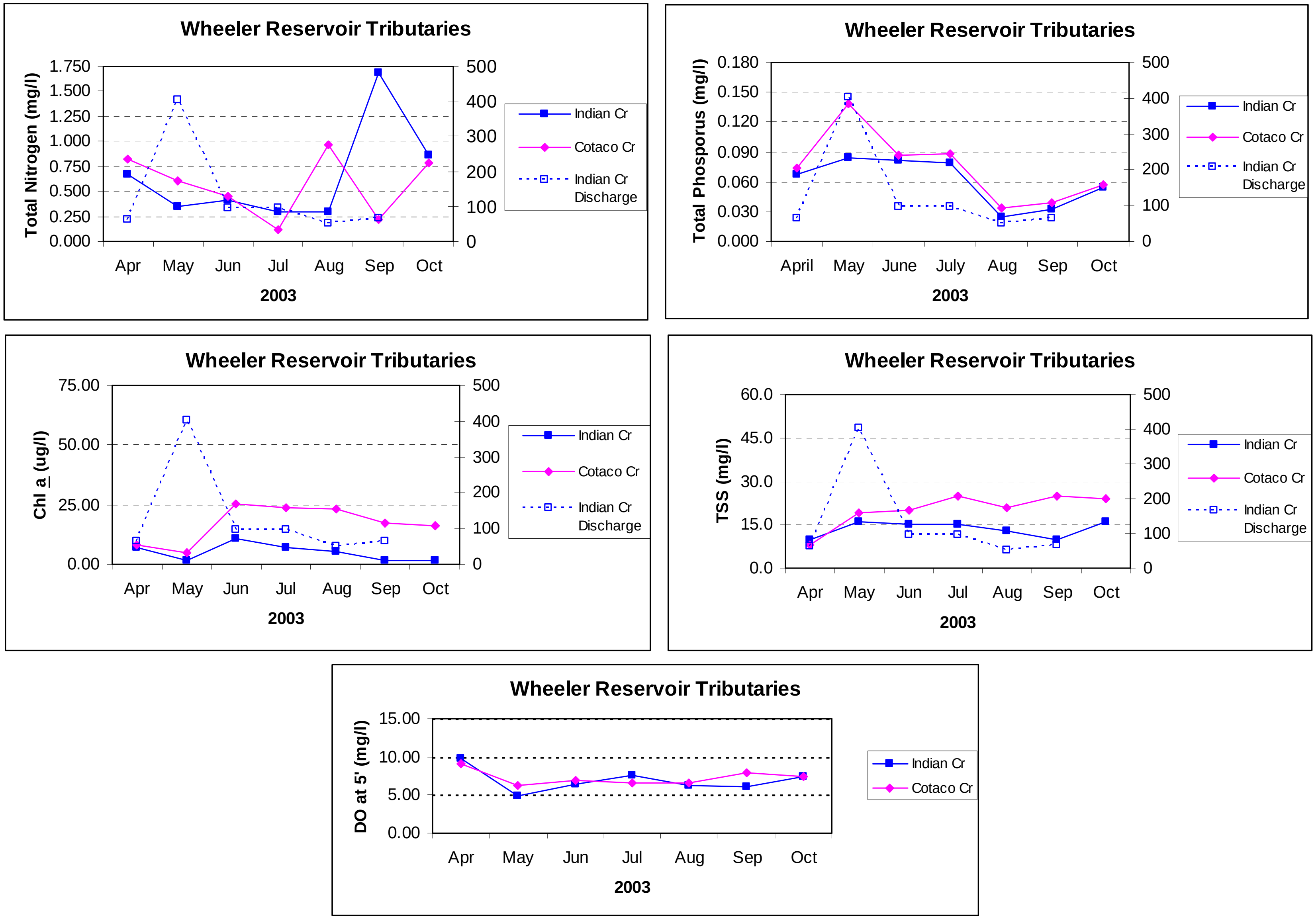


Figure 25. Total nitrogen, total phosphorus, chlorophyll *a* (chl a), total suspended solids (TSS), and dissolved oxygen (DO) for Indian and Cotaco Creeks, tributaries of Wheeler Reservoir, April-October 2003.

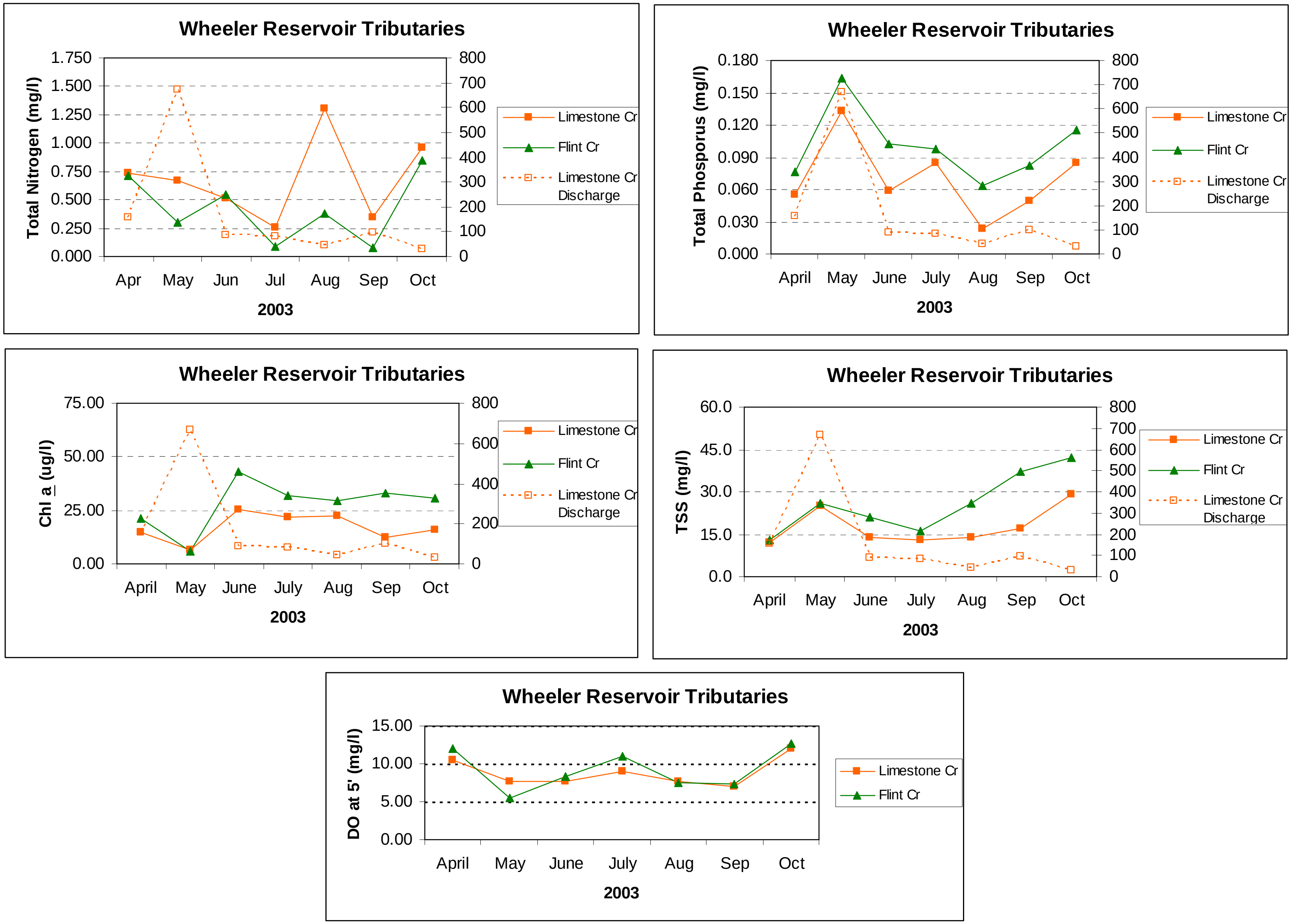


Figure 26. Total nitrogen, total phosphorus, chlorophyll *a* (chl a), total suspended solids (TSS), and dissolved oxygen (DO) for Limestone and Flint Creeks, tributaries of Wheeler Reservoir, April-October 2003.

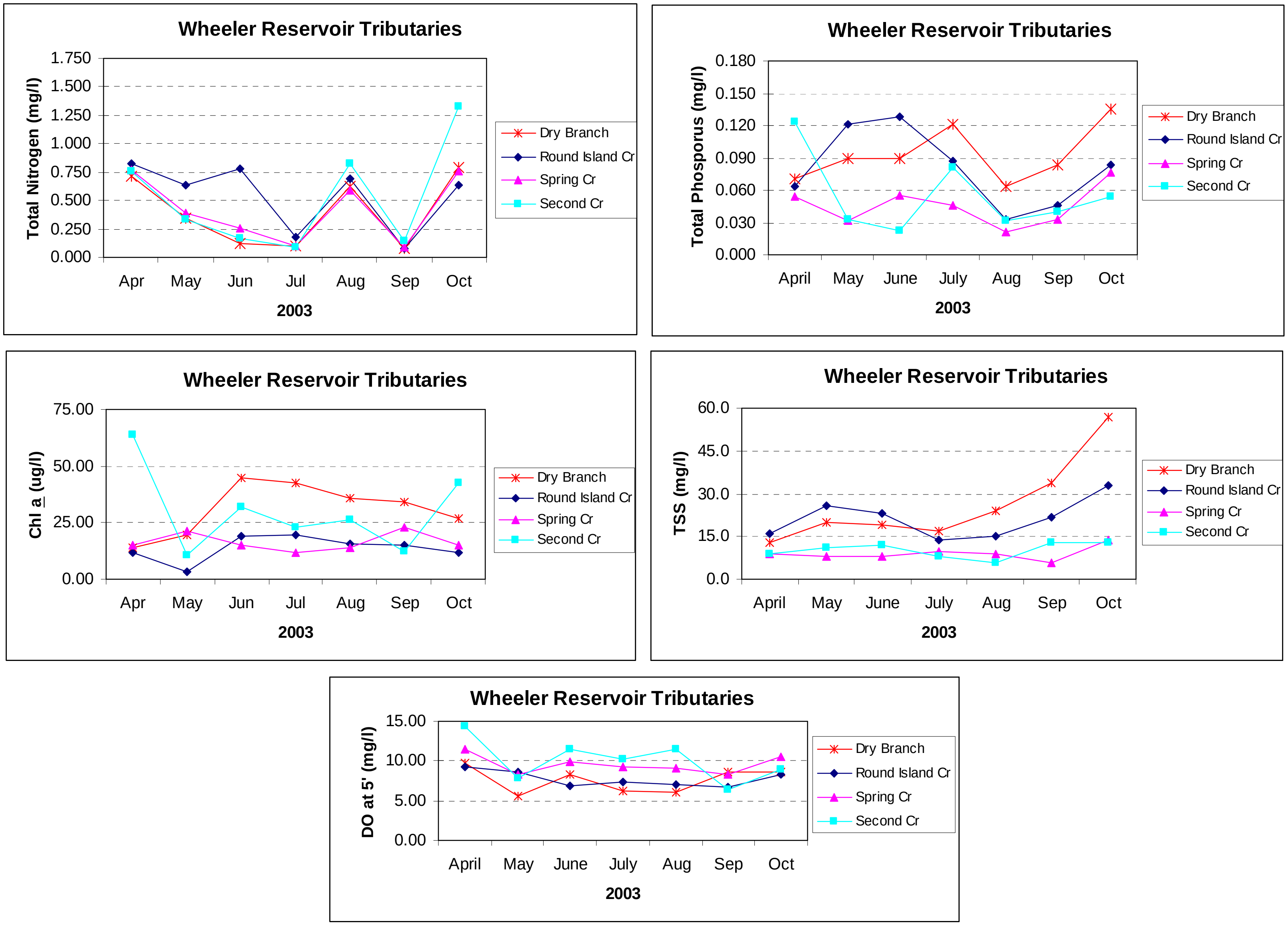


Figure 27. Total nitrogen, total phosphorus, chlorophyll *a* (chl a), total suspended solids (TSS), and dissolved oxygen (DO) for Dry Branch, Round Island, Spring, and Second Creeks, tributaries of Wheeler Reservoir, April-October 2003.

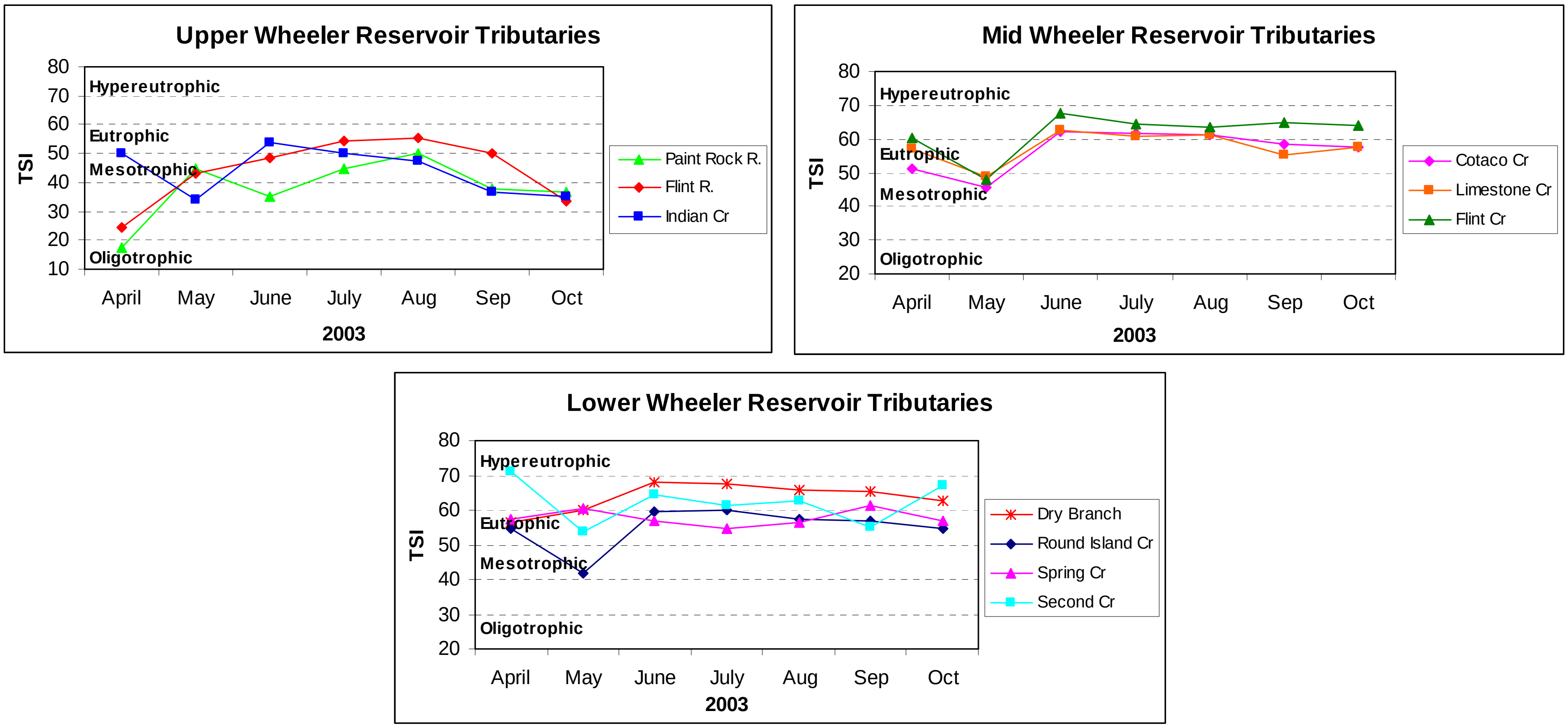


Figure 28. Trophic state index (TSI) for Wheeler Reservoir tributaries, April-October 2003.

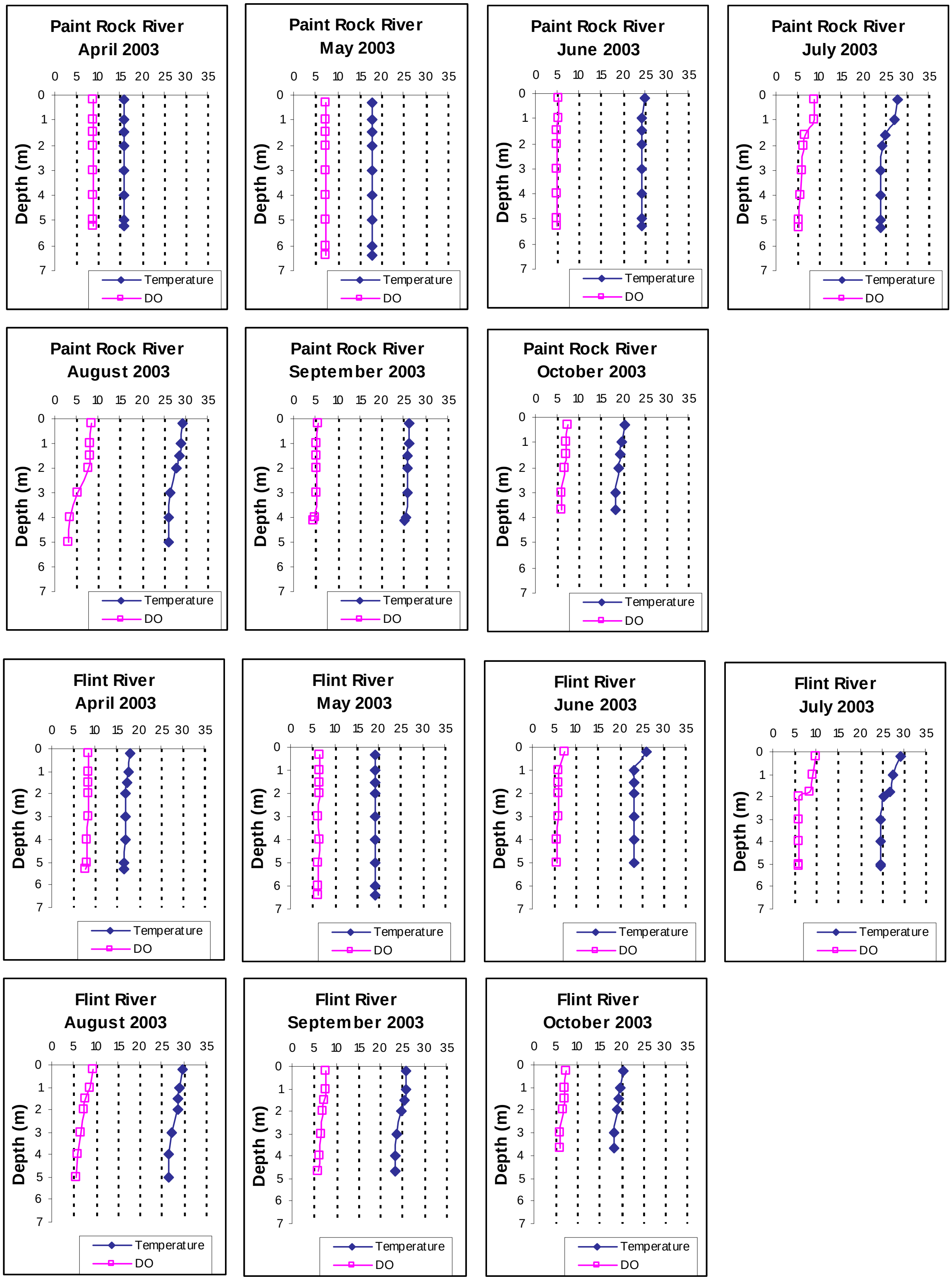


Figure 29. Depth profiles of dissolved oxygen (DO) and temperature of Paint Rock and Flint Rivers, tributaries of Wheeler Reservoir, April-October 2003.

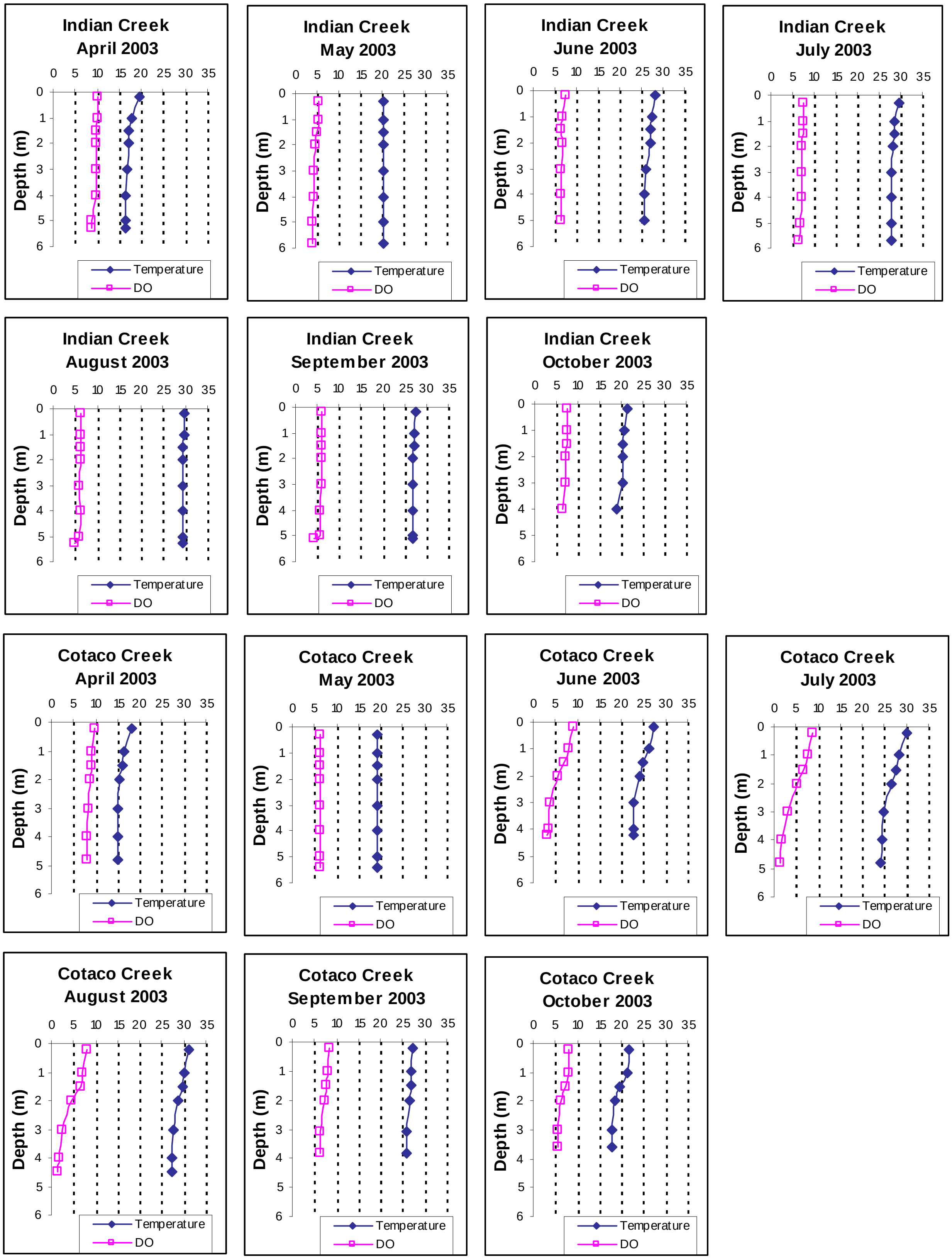


Figure 30. Depth profiles of dissolved oxygen (DO) and temperature of Indian and Cotaco Creeks, tributaries of Wheeler Reservoir, April-October 2003.

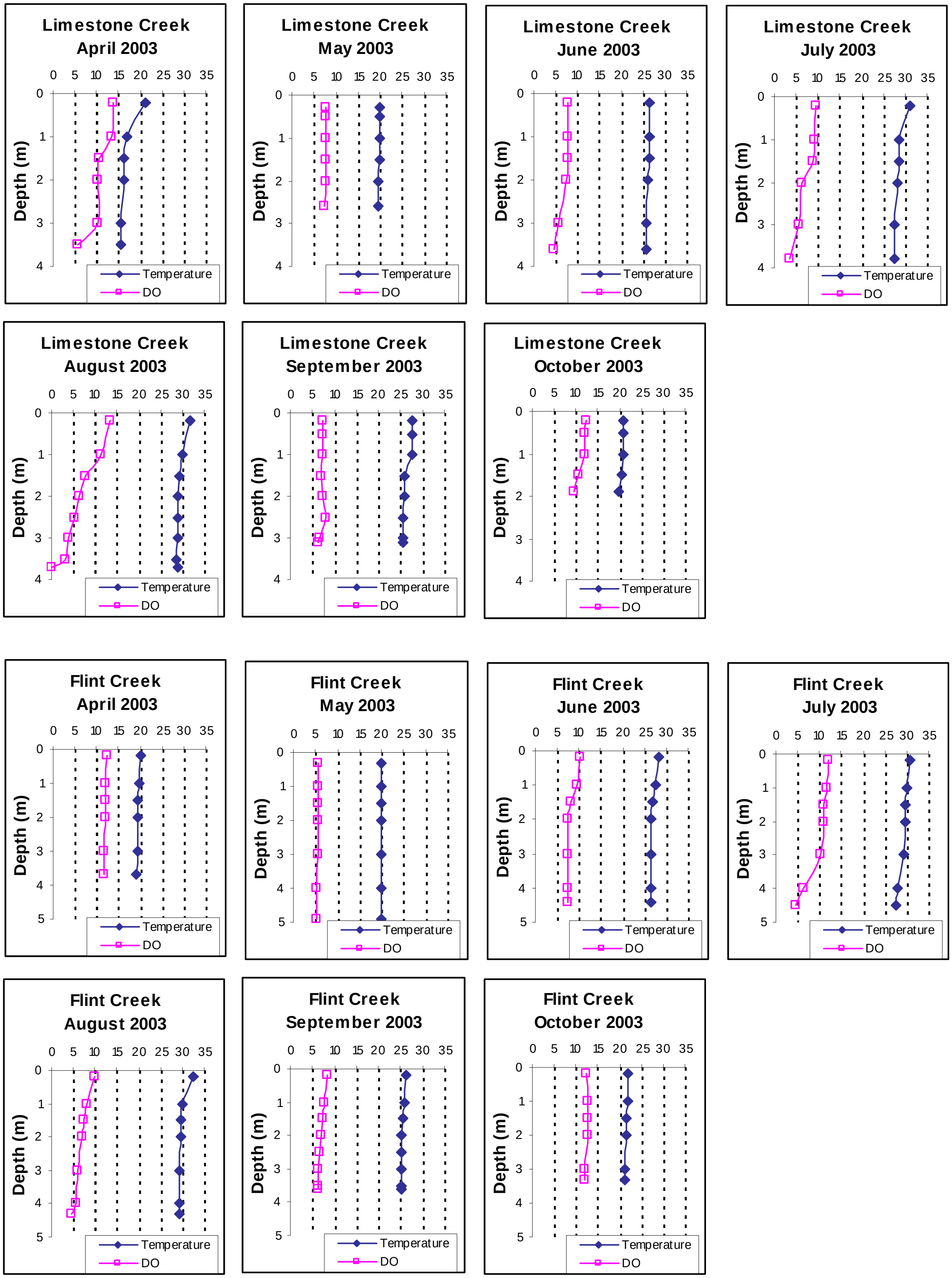


Figure 31. Depth profiles of dissolved oxygen (DO) and temperature of Limestone and Flint Creeks, tributaries of Wheeler Reservoir, April-October 2003.

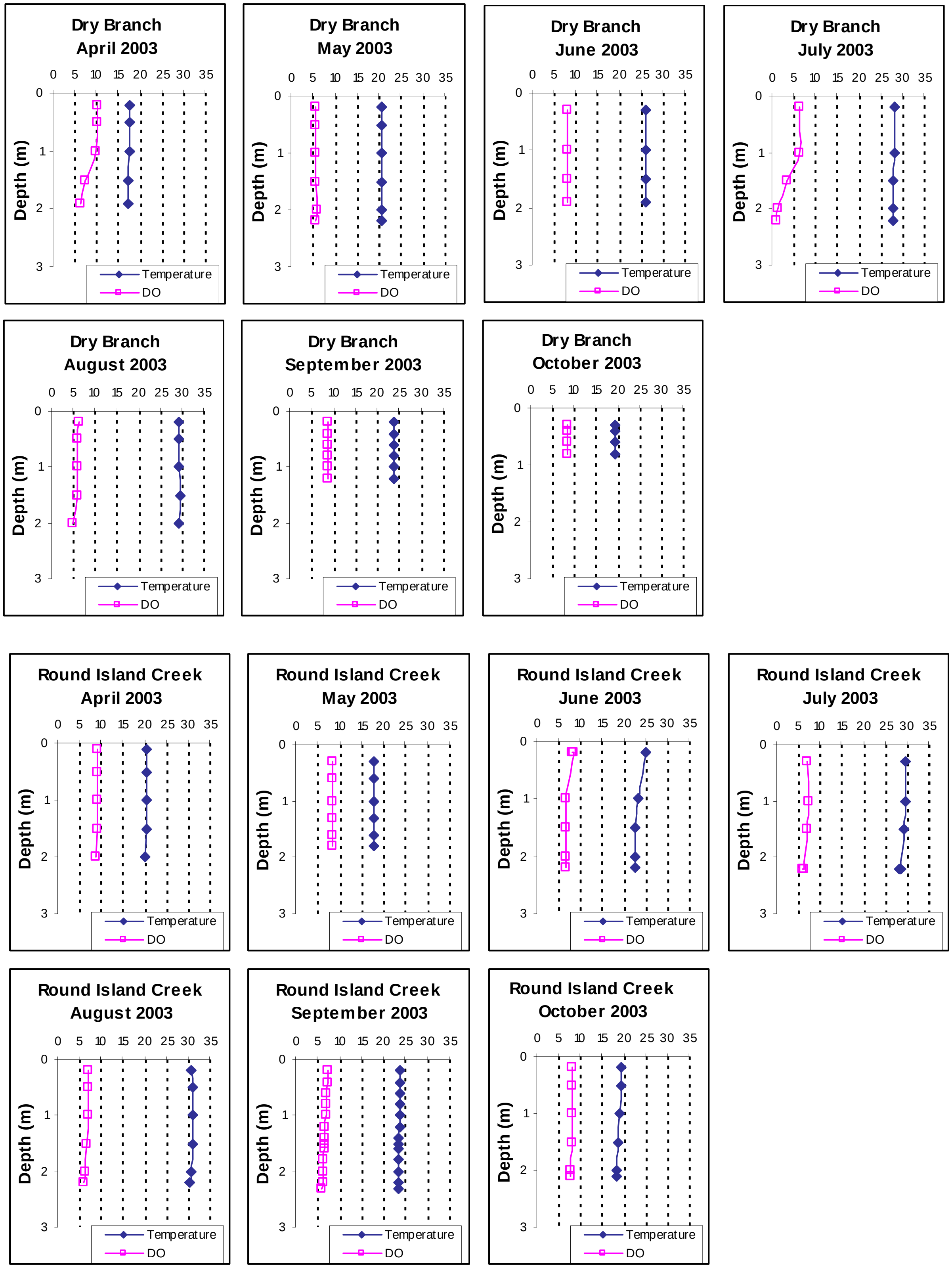


Figure 32. Depth profiles of dissolved oxygen (DO) and temperature of Dry Branch and Round Island Creek, tributaries of Wheeler Reservoir, April-October 2003.

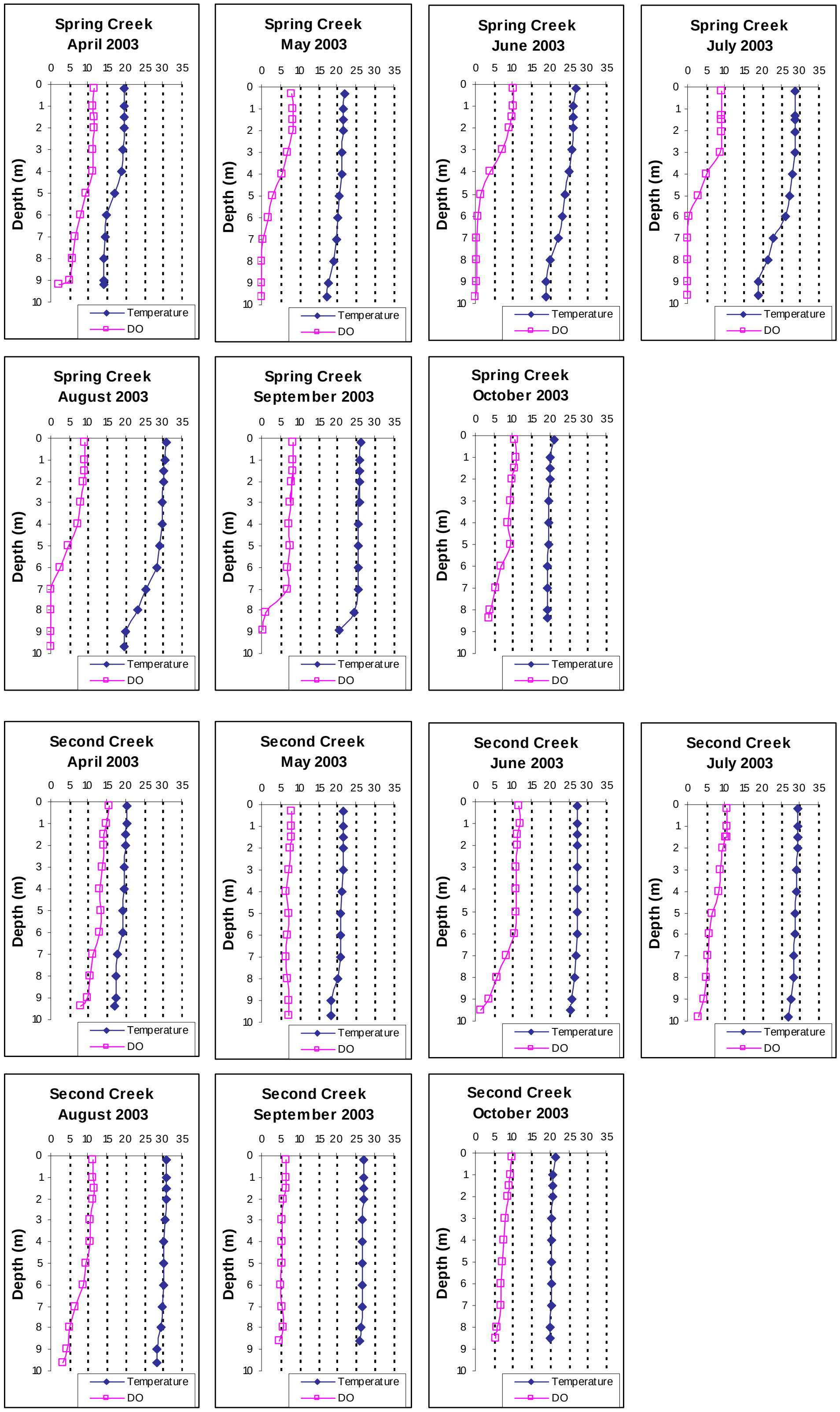


Figure 33. Depth profiles of dissolved oxygen (DO) and temperature of Spring and Second Creeks, tributaries of Wheeler Reservoir, April-October 2003.

Wilson Reservoir Tributary Embayments

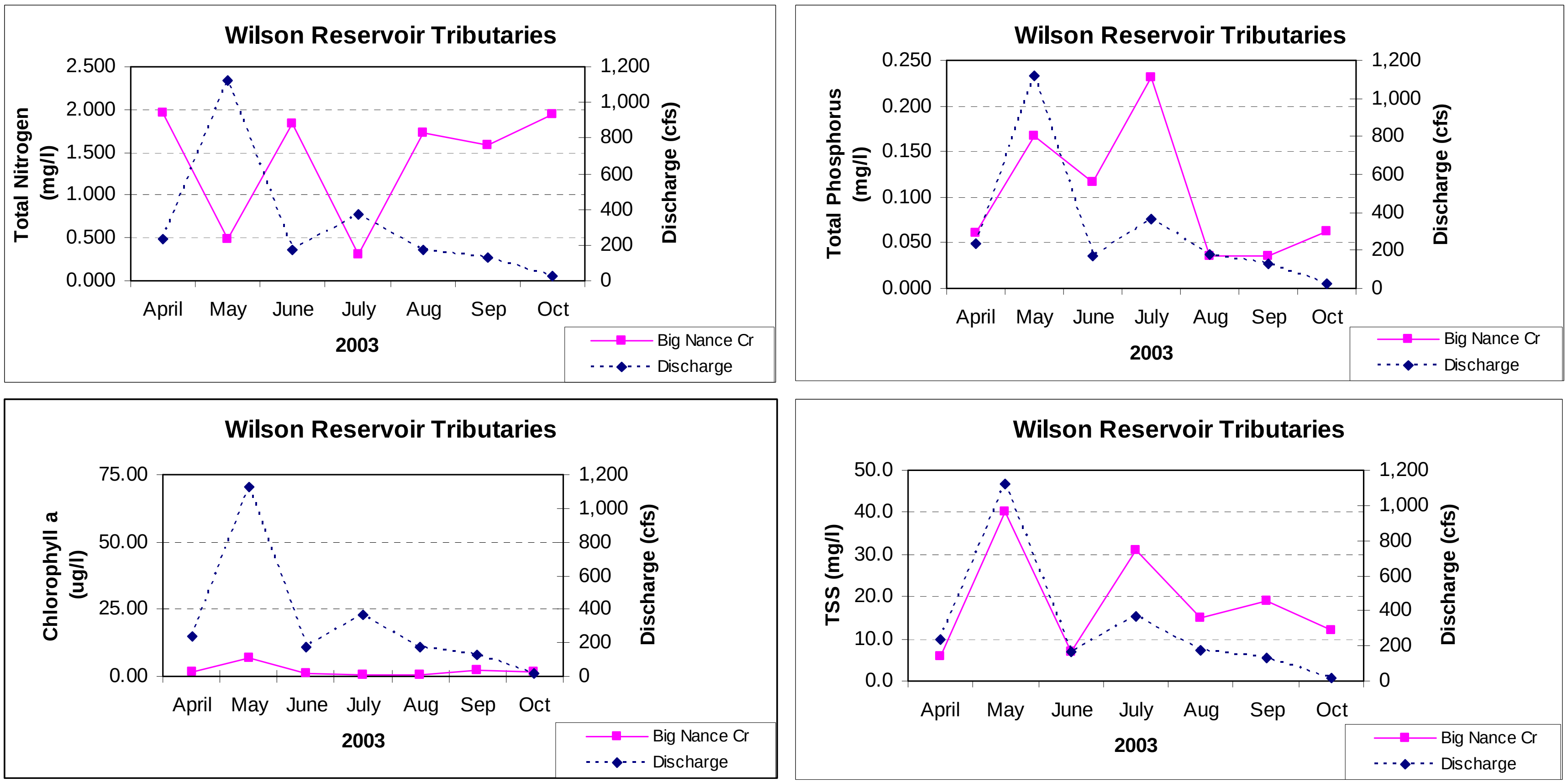


Figure 34. Total nitrogen, total phosphorus, chlorophyll *a*, and total suspended solids (TSS) of Wilson Reservoir Tributaries, April-October 2003.

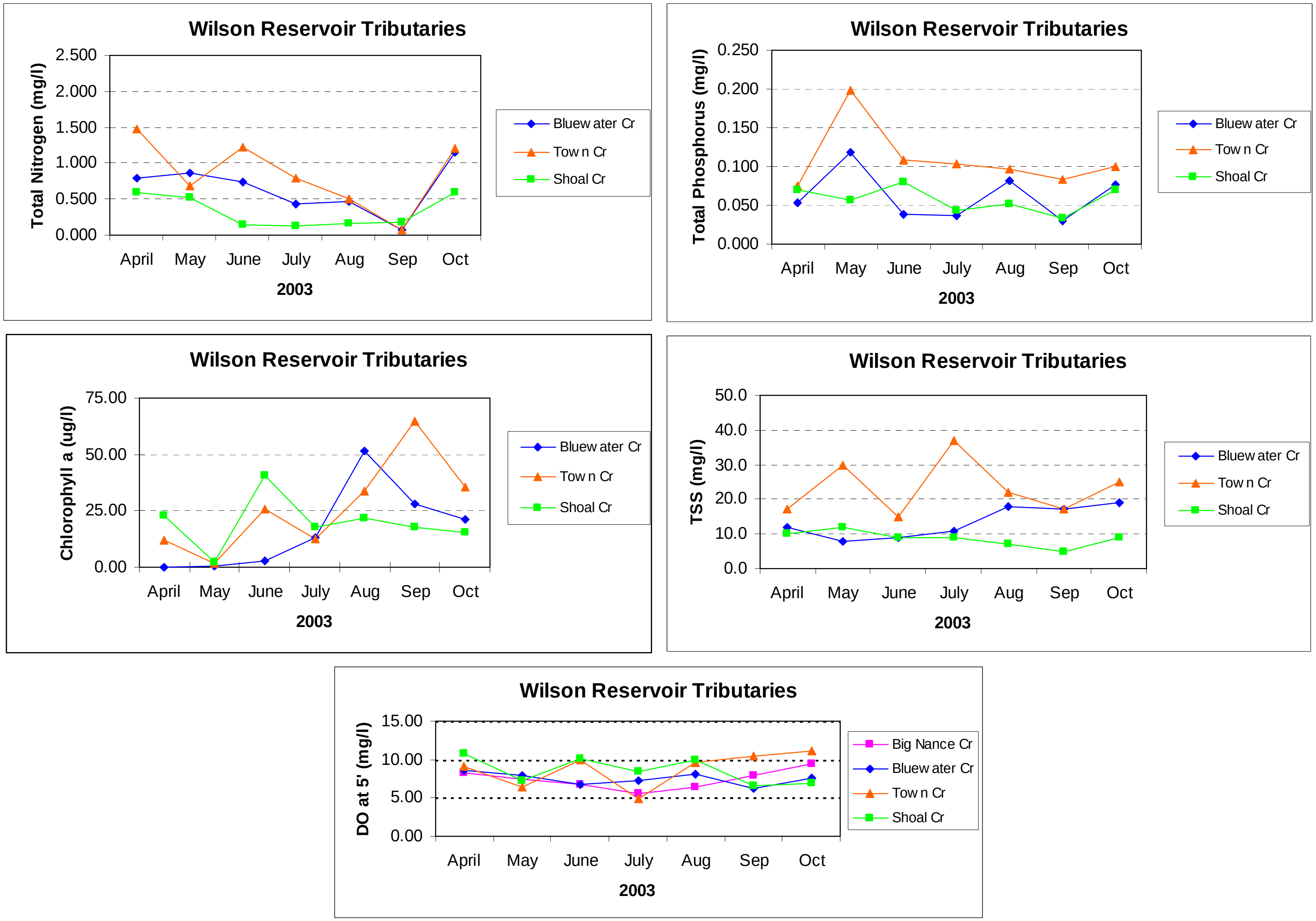


Figure 35. Total nitrogen, total phosphorus, chlorophyll *a*, total suspended solids (TSS), and dissolved oxygen (DO) of Wilson Reservoir Tributaries, April-October 2003.

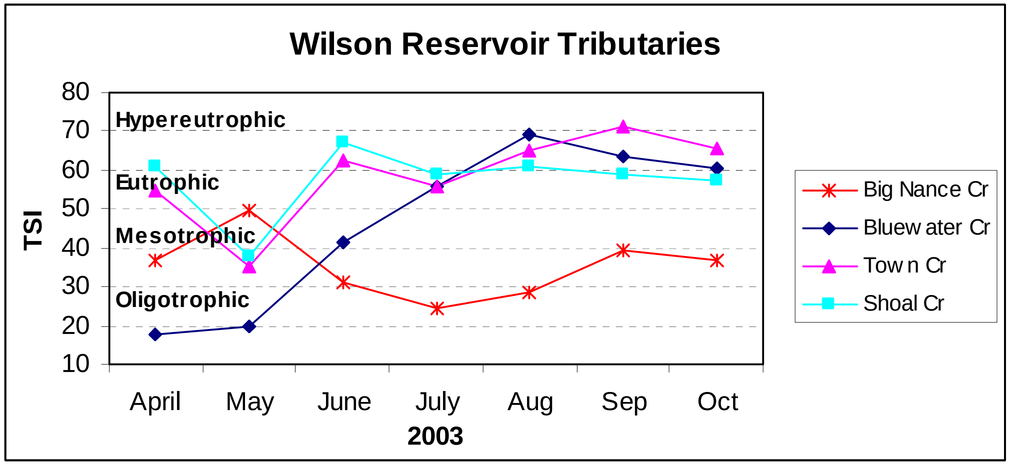


Figure 36. Trophic state index (TSI) for Wilson Reservoir tributaries, April-October 2003.

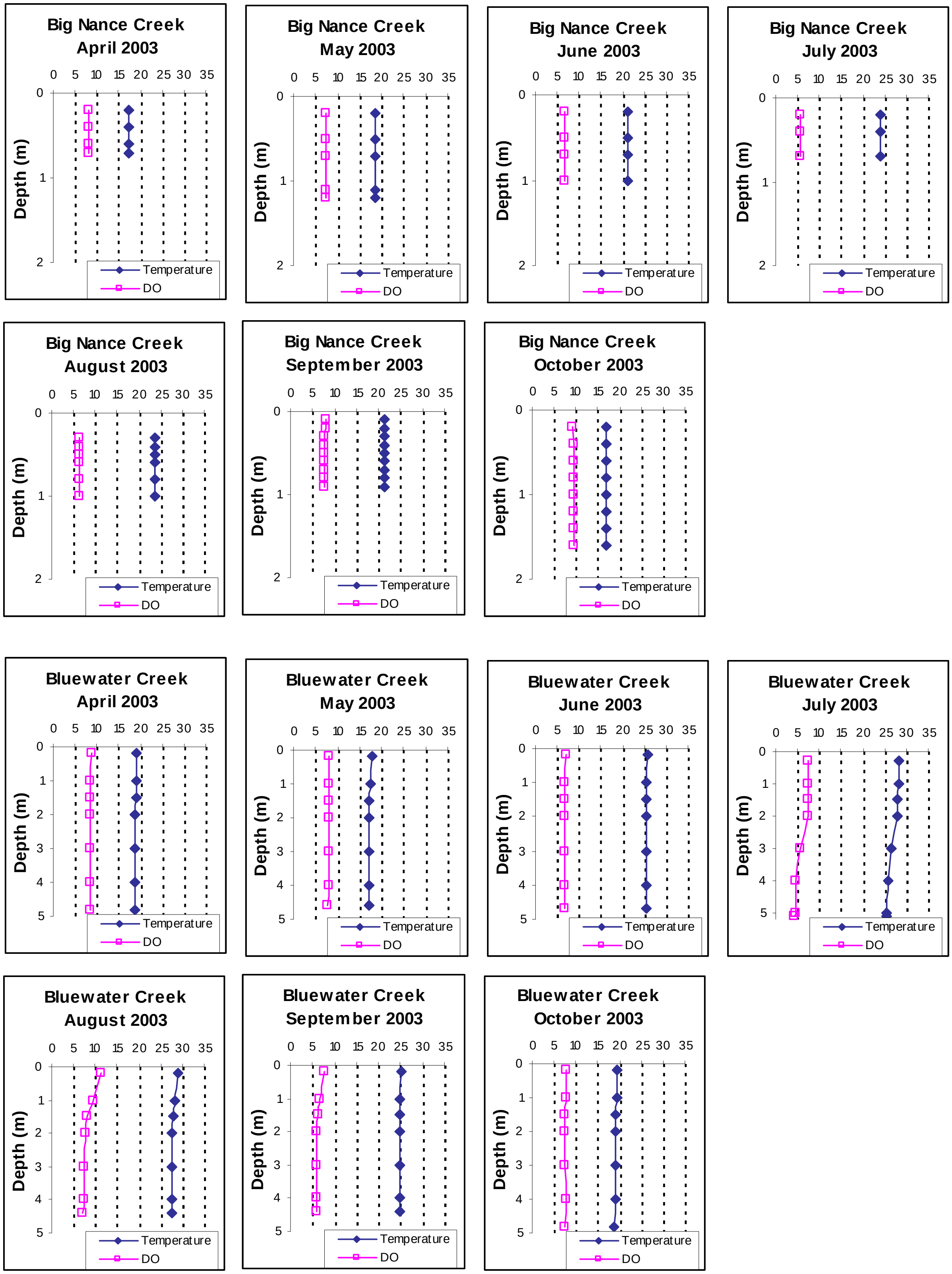


Figure 37. Depth profiles of dissolved oxygen (DO) and temperature for Big Nance and Bluewater Creeks, tributaries of Wilson Reservoir, April-October 2003.

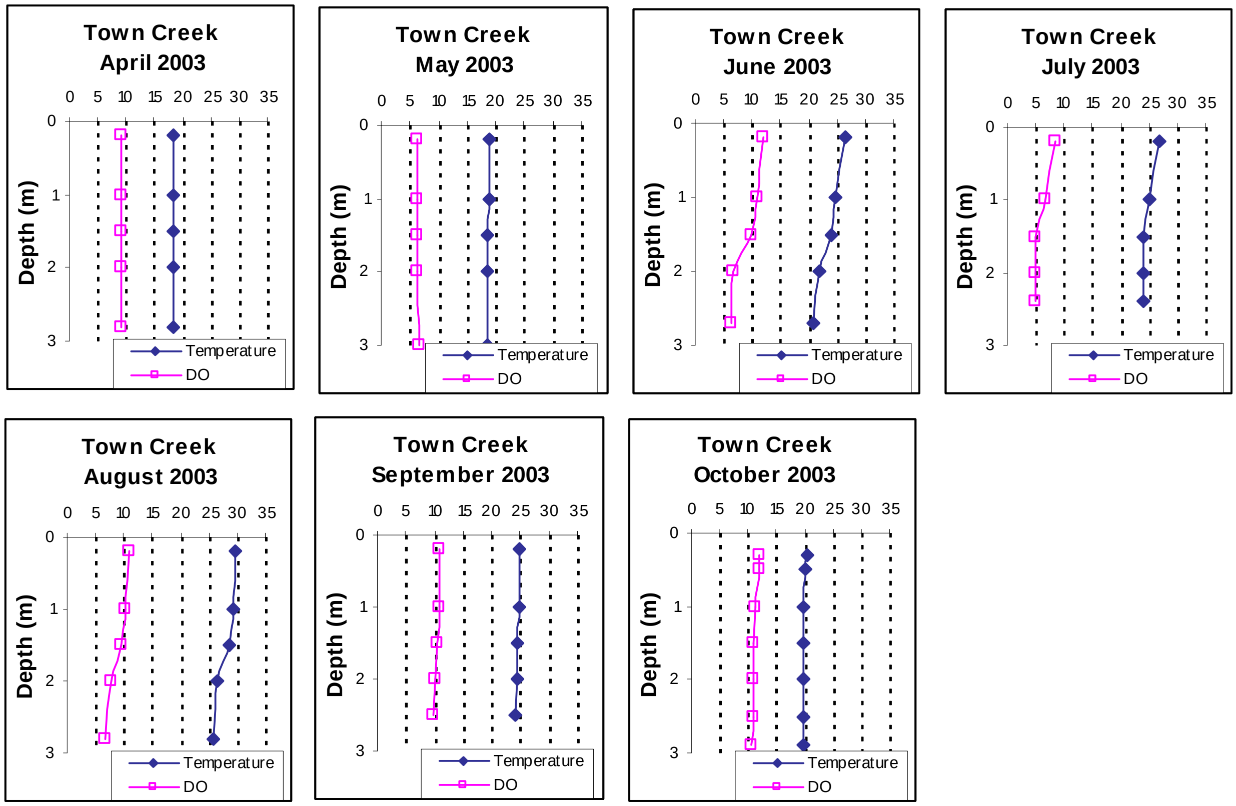


Figure 38. Depth profiles of dissolved oxygen (DO) and temperature in Town Creek, tributary of Wilson Reservoir, April-October 2003.

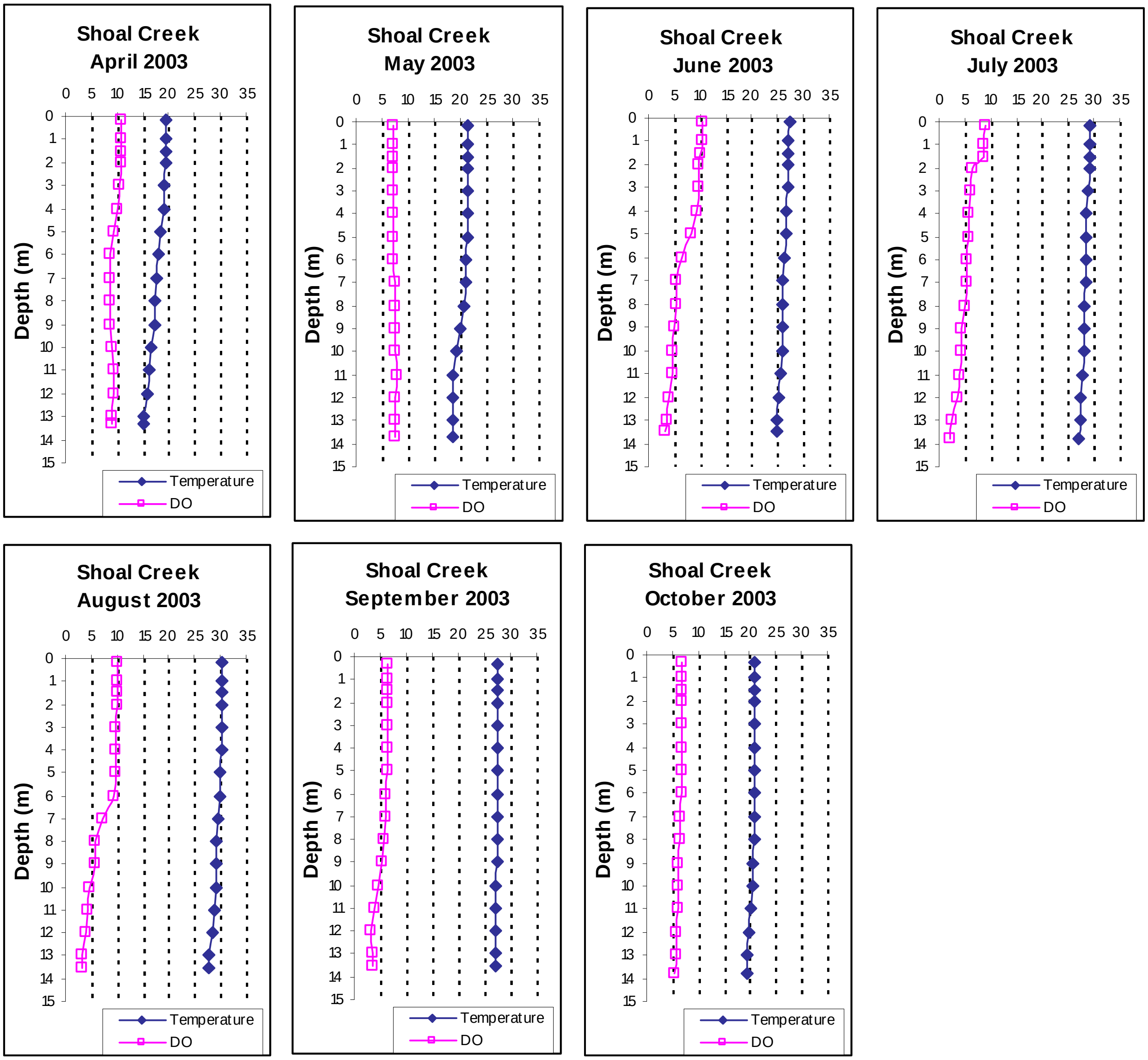


Figure 39. Depth profiles of dissolved oxygen (DO) and temperature in Shoal Creek, tributary of Wilson Reservoir, April-October 2003.

Pickwick Reservoir Tributary Embayments

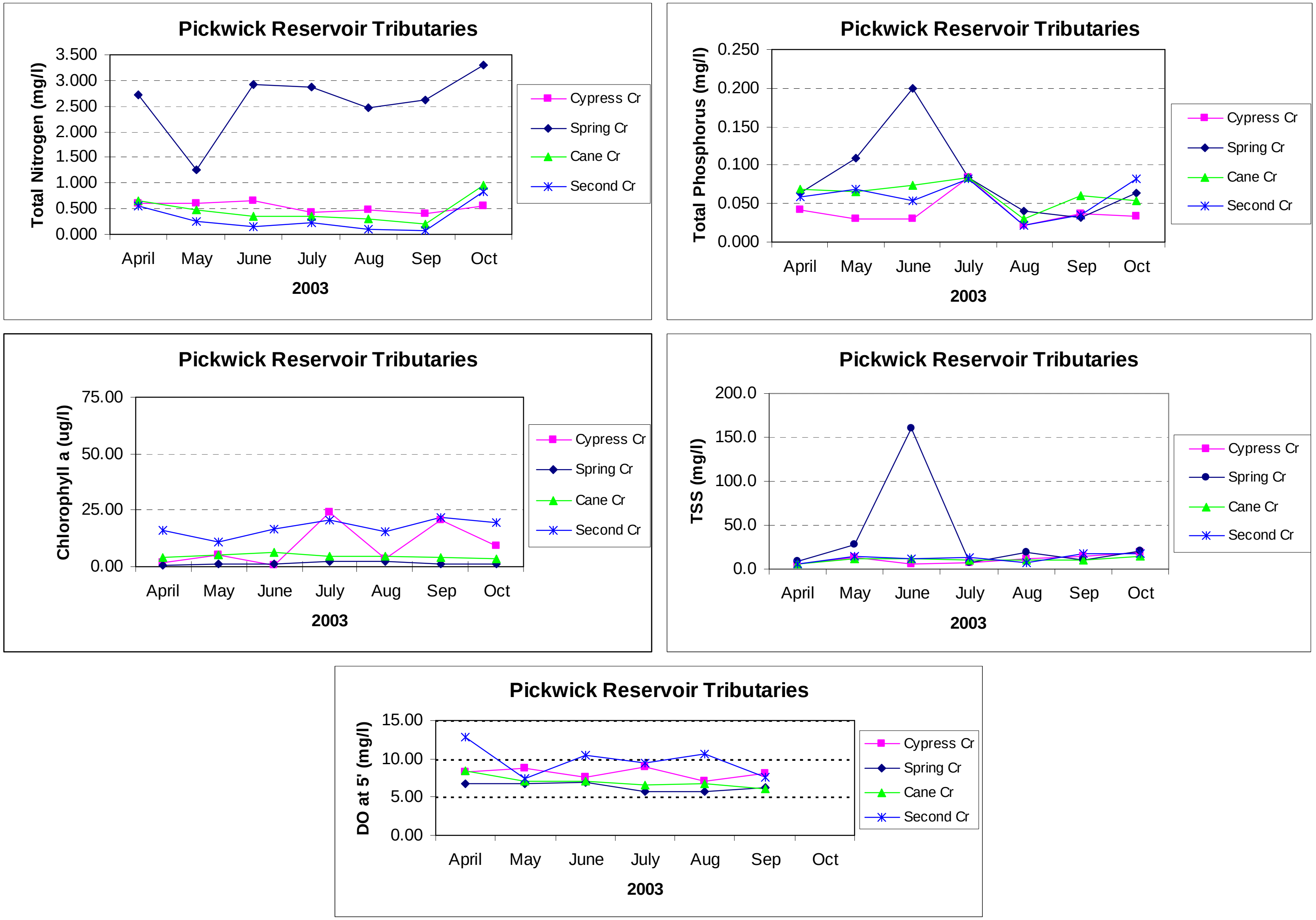


Figure 40. Total nitrogen, total phosphorus, chlorophyll *a*, total suspended solids (TSS), and dissolved oxygen (DO) for Cypress, Spring, Cane, and Second Creeks, tributaries of Pickwick Reservoir, April-October 2003.

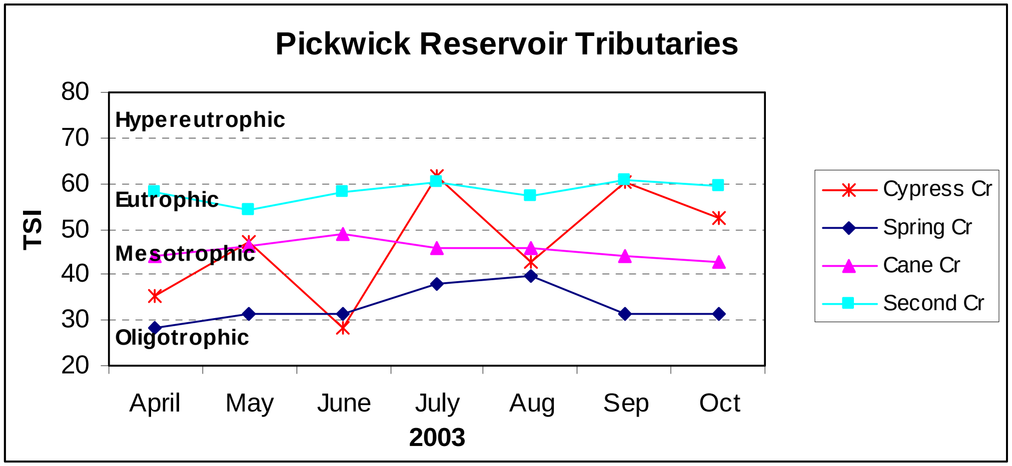


Figure 41. Trophic state index (TSI) for Pickwick Reservoir tributaries, April-October 2003.

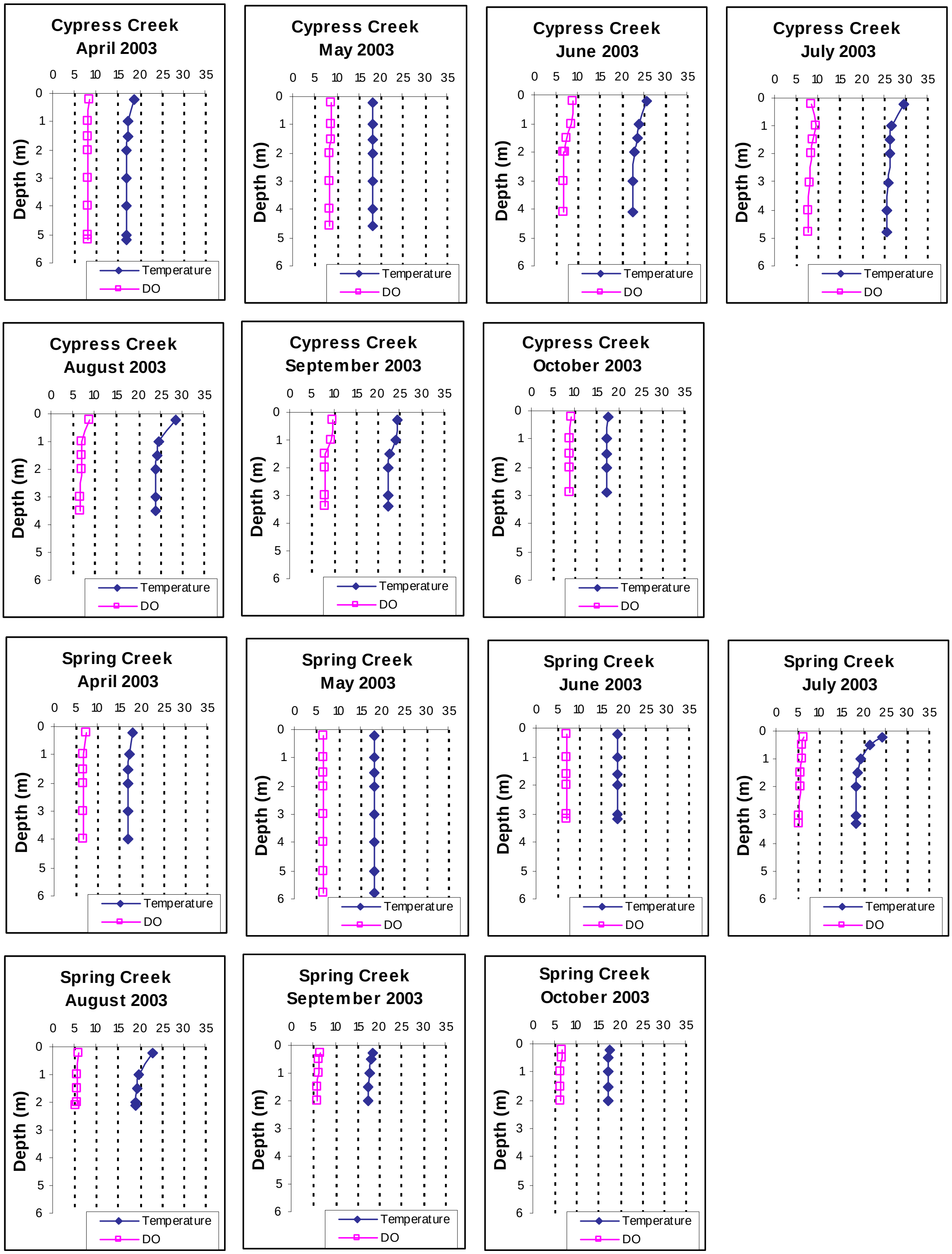


Figure 42. Depth profiles of dissolved oxygen (DO) and temperature in Cypress and Spring Creeks, tributaries of Pickwick Reservoir, April-October 2003.

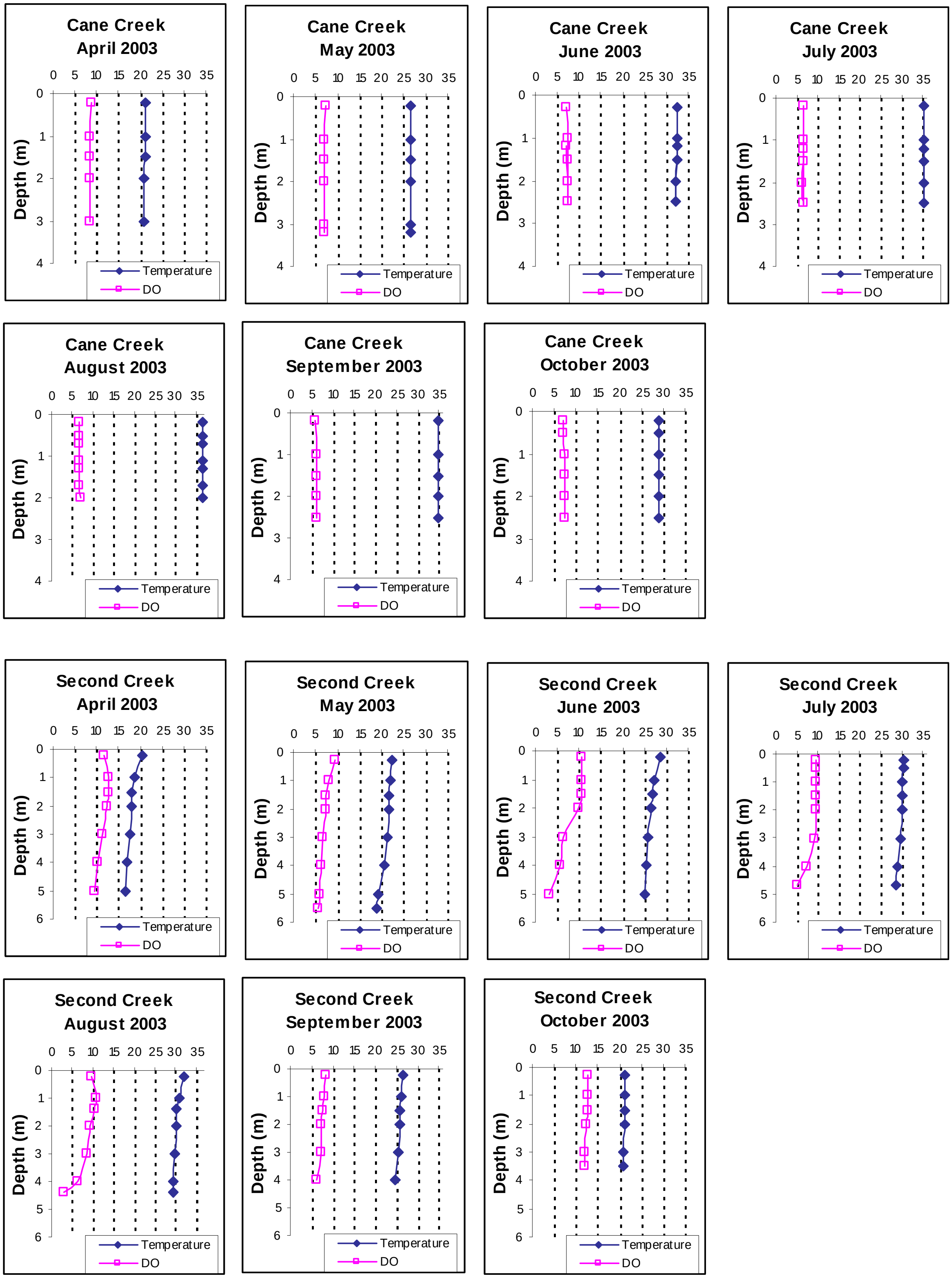


Figure 43. Depth profiles of dissolved oxygen (DO) and temperature in Cane and Second Creeks, tributaries of Pickwick Reservoir, April-October 2003.

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