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Please find attached a copy of the annual "Lake Norman Maintenance Monitoring Program: 2005 Summary," as required by the National Pollutant Discharge Elimination System (NPDES) permit NC0024392. The report includes detailed results and data comparable to that of previous years. The report was submitted to the North Carolina Department of Environment and Natural Resources on January 10, 2007.

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LAKE NORMAN

MAINTENANCE MONITORING PROGRAM:

2005 SUMMARY

McGuire Nuclear Station: NPDES No. NC0024392

Principal Investigators:

D. Hugh Barwick
John E. Derwort
William J. Foris

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November 2006

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EXECUTIVE SUMMARY

In accordance with National Pollutant Discharge Elimination System (NPDES) permit number NC0024392 for McGuire Nuclear Station (MNS), the Lake Norman Maintenance Monitoring Program continued during 2005. No obvious short-term or long-term impacts of station operations were observed in water quality, phytoplankton, zooplankton, and fish communities. The 2005 station operation data is summarized and continues to demonstrate compliance with thermal limits and cool water requirements.

The average monthly capacity factors for MNS during critical summer months was 100.7% (July), 101.3% (August), and 77.7% (September). Average monthly discharge temperatures were below the 99.0 °F (37.2 °C) thermal limit for these critical months. The volume of cool water in Lake Norman was adequate to comply with both the Nuclear Regulatory Commission Technical Specification requirements and the NPDES discharge water temperature limits.

Annual precipitation in the vicinity of MNS was 45.6 inches and similar to that measured in 2004 and long-term precipitation averages for this area. Air temperatures in 2005 were generally warmer than the long-term mean and noticeably warmer than 2004 winter and late-summer temperatures.

Temporal and spatial trends in 2005 water temperature and dissolved oxygen (DO) were similar to those observed historically. All data were within the range of previously measured values. Winter water temperatures in 2005 were generally warmer than those observed in 2004 in both the mixing and background zones. Spring and summer water temperatures in 2005 were generally similar to those observed in 2004 with several exceptions. Water temperatures in the upper 10 m of the water column in June 2005 were up to 5.2 °C cooler than in June 2004. July and August water temperatures in the metalimnion (10-15 m) were also slightly cooler in 2005 than in 2004. Additionally, in September 2005 water temperatures in the hypolimnion (below 20 m) were cooler than in September 2004. Fall and early winter water temperatures in 2005 were generally similar to those measured in 2004, and followed the trend exhibited in air temperatures.

Winter and early spring DO values in 2005 were generally equal to or slightly lower than those measured in 2004 in both the background and mixing zones with one exception. In January 2005 the mixing zone exhibited slightly higher oxygen concentrations than in

January 2004. Spring and summer DO values in 2005 were highly variable throughout the water column in both the mixing and background zones, similar to patterns observed in previous years. Considerable differences were observed between 2005 and 2004 late summer and fall DO concentrations in both the mixing and background zone, especially in the metalimnion and hypolimnion during September and to a lesser extent during October and November. DO concentrations in September 2005 were notably lower than those observed during September 2004 while DO values observed in October and November 2005 were higher than in 2004.

Reservoir-wide isotherm and isopleth information for 2005, coupled with heat content and hypolimnetic oxygen data, illustrate that Lake Norman thermal and oxygen dynamics are characteristic of historical conditions and similar to other Southeastern reservoirs of comparable size, depth, flow conditions, and trophic status. Adult striped bass habitat conditions were marginally better in 2005 than observed in most previous years and similar in distribution and amount to 2004. Striped bass mortalities in 2005 (20 fish) were much less than in 2004 (2610 fish).

All chemical parameters measured in 2005 were similar to 2004, and within the concentration ranges previously reported for the lake during both preoperational and operational years of MNS. Metal concentrations in 2005 were low or below the analytical reporting limits. Cadmium, lead, zinc, and copper values did not exceed the NC water quality standards during 2005. Manganese and iron concentrations in the surface and bottom waters were generally low in 2005, except during summer and fall when bottom waters became anoxic releasing forms of these metals into the water column. Iron concentrations did not exceed NC's water quality standard (1.0 mg/L). Manganese levels, however, exceeded the State standard (200 μg/L) in the bottom waters throughout the lake in the summer and fall. Manganese concentrations measured in 2005 are characteristic of historical conditions.

Lake Norman continues to support highly variable and diverse phytoplankton communities. Chlorophyll concentrations during 2005 were generally within historical ranges. Lake-wide mean chlorophyll *a* concentrations were most often in the mesotrophic range in 2005 except in November when mean chlorophyll concentrations were in the oligotrophic range. Lake Norman is classified as oligo-mesotrophic based on long-term, annual mean chlorophyll concentrations. The highest chlorophyll value (11.12 μg/L) recorded in 2005 was well below the NC water quality standard (40 μg/L).

Phytoplankton densities and biovolumes during 2005 were also within historical ranges and never exceeded the NC guidelines for algae blooms. In February and May 2005, total phytoplankton densities and biovolumes were higher than those observed during 2004. In August and November, phytoplankton densities and biovolumes were lower than in 2004.

Seston dry and ash-free weights were more often lower in 2005 than in 2004. Maximum dry and ash-free weights occurred most often at uplake Location 69.0 while minimum values were noted mostly downlake at Locations 2.0 through 8.0. The higher proportion of ash-free dry weights to dry weights in 2005 compared to 2004 indicates an increase in organic composition.

Secchi depths reflected suspended solids, with shallow depths related to high dry weights. The lake-wide mean Secchi depth in 2005 was slightly lower than in 2004 and was within historical ranges recorded since 1992.

The taxonomic composition of phytoplankton communities during 2005 was similar to those of many previous years and more diverse than any other year of this monitoring program. Cryptophytes were dominant in February, while diatoms were dominant during May and November. Green algae dominated phytoplankton assemblages during August. Blue-green algae were slightly more abundant during 2005 than in 2004, however, their contribution to total densities seldom exceeded 4%.

The phytoplankton index (Myxophycean) characterized Lake Norman as oligotrophic during 2005, and was the lowest annual index value recorded. Quarterly index values were highest in May and lowest in November thus reflecting maximum and minimum chlorophyll values. Location index values tended to reflect increases in chlorophyll and phytoplankton standing crops from down-lake to mid-lake.

Lake Norman continues to support a highly diverse and viable zooplankton community. Zooplankton densities, as well as seasonal and spatial trends were similar to historical data, and no impacts of plant operations were observed. Maximum epilimnetic zooplankton densities occurred in April at all locations except Location 2.0, where the maximum density occurred in May. Minimum zooplankton densities occurred most often in September. Mean zooplankton densities were generally higher at background locations than at mixing zone locations during 2005 and epilimnetic densities were higher than whole column densities.

This is similar to historical data. Long-term trends show increasing densities in the mixing zone during May and higher year-to-year variability at background locations.

Overall relative abundance of copepods decreased from 2004 to 2005. Copepods dominated only two samples collected during spring and fall. Cladocerans were dominant in five samples during the summer and showed more year-to-year variability. Rotifers dominated over 82% of all samples. Microcrustaceans increased slightly in relative abundance since 2004.

Adult copepods rarely accounted for more than 7% of zooplankton densities in 2005. The most important adult copepod was *Tropocyclops*. *Bosmina* was the predominant cladoceran, while *Bosminopsis* dominated most cladoceran populations during the summer. The most abundant rotifers observed in 2005 were *Polyarthra*, *Conochilus*, and *Keratella*. These results are consistent with results from previous years.

In accordance with the Lake Norman Maintenance Monitoring Program, monitoring of specific fish population parameters were coordinated with the North Carolina Wildlife Resources Commission (NCWRC) and continued during 2005. Spring electrofishing indicated that numbers and biomass of fish in 2005 were generally similar to those noted since 1993. Declines in largemouth bass numbers, which were first observed in 2000, appear to be an exception. Striped bass mortalities declined significantly from summer 2004 to summer 2005 and the 2005 data were similar to that observed historically. Mean relative weights (W_r) for Lake Norman striped bass collected in November and December 2005 was slightly higher than values measured in 2003 and 2004. Little change was observed in crappie populations in Lake Norman. The prey fish population estimate was comparable to values measured from 1997 to 2003 and shows declining percentages of alewife to forage fish species composition and a shift in threadfin shad lengths toward smaller size ranges observed prior to the alewife invasion.

Lake Norman Maintenance Monitoring results from 2005 are consistent with results from previous years. No obvious short-term or long-term impacts were observed in water quality or biota of Lake Norman.

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CHAPTER 1

MCGUIRE NUCLEAR STATION

INTRODUCTION

The following annual report was prepared for the McGuire Nuclear Station (MNS) National Pollutant Discharge Elimination System (NPDES) permit (# NC0024392) issued by North Carolina Department of Environment and Natural Resources (NCDENR). This report summarizes environmental monitoring of Lake Norman conducted during 2005.

OPERATIONAL DATA FOR 2005

Station operational data for 2005 are listed in Table 1-1. The monthly average capacity factors for MNS were 100.7, 101.3 and 77.7% during July, August, and September, respectively. These are the months when conservation of cool water is most critical and compliance with discharge temperatures is most challenging. These three months are also when the thermal limit for MNS increases from a monthly average of 95.0 °F (35.0 °C) to 99.0 °F (37.2 °C). The average monthly discharge temperature was 95.5 °F (35.3 °C) for July, 98.4 °F (36.9 °C) for August, and 96.1 °F (35.6 °C) for September 2005. The volume of cool water in Lake Norman was tracked throughout the year to ensure that an adequate volume was available to comply with both the Nuclear Regulatory Commission Technical Specification requirements and the NPDES discharge water temperature limits.

Table 1-1. Average monthly capacity factors (%) and monthly average discharge water temperatures for McGuire Nuclear Station during 2005.

	MONTHLY AVERAGE CAPACITY FACTORS (%)			MONTHLY AVERAGE NPDES DISCHARGE TEMPERATURES	
Month	**Unit 1**	**Unit 2**	**Station**	**°F**	**°C**
January	105.3	105.0	105.2	70.0	21.1
February	105.1	105.0	105.0	68.4	20.2
March	105.0	1.4	53.2	68.9	20.5
April	104.6	30.6	67.6	71.1	21.7
May	103.9	104.4	104.1	82.6	28.1
June	103.0	103.6	103.3	89.1	31.7
July	99.1	102.4	100.7	95.5	35.3
August	101.1	101.4	101.3	98.4	36.9
September	54.0	101.5	77.7	96.1	35.6
October	38.2	103.1	70.6	87.1	30.6
November	100.5	101.6	101.1	79.5	26.4
December	98.0	105.4	101.7	72.0	22.2
Average	93.2	88.8	91.0	81.6	27.5

CHAPTER 2

WATER CHEMISTRY

INTRODUCTION

The objectives of the water chemistry portion of the MNS NPDES Maintenance Monitoring Program are to:

1. maintain continuity in the chemical data base of Lake Norman to allow detection of any significant station-induced and/or natural change in the physicochemical structure of the lake; and
2. compare, where applicable, these physicochemical data to similar data in other hydropower reservoirs and cooling impoundments in the Southeast.

This report focuses primarily on 2004 and 2005. Where appropriate, reference to pre-2004 data will be made by citing reports previously submitted to the NCDENR.

METHODS AND MATERIALS

The complete water chemistry monitoring program for 2005, including specific variables, locations, depths, and frequencies is outlined in Table 2-1. Sampling locations are identified in Figure 2-1, whereas specific chemical methods and associated analytical reporting limits, along with the appropriate references, are presented in Table 2-2. Measurements of temperature, dissolved oxygen (DO), DO saturation, pH, and specific conductance were taken, in situ, at each location with a Hydrolab Data-Sonde (Hydrolab 1986) starting at the lake surface (0.3 m) and continuing at one meter intervals to lake bottom. Pre- and post-calibration procedures associated with operation of the Hydrolab were strictly followed, and documented in hard-copy format. Hydrolab data were captured and stored electronically, and following a data validation step, converted to spreadsheet format for permanent filing.

Water samples for laboratory analysis were collected with a Kemmerer water bottle at the surface (0.3 m), and from one meter above bottom, where specified (Table 2-1). Samples not requiring filtration were placed directly in single-use polyethylene terephthalate (PET) bottles which were pre-rinsed in the field with lake-water just prior to obtaining a sample. Samples processed, in the field, by filtering a known volume of water through a 0.45 μ glass-fiber filter (Gelman AquaPrep 600 Series Capsule) which was pre-rinsed with 500 mL of sample water. Upon collection, all water samples were immediately preserved and stored in the dark, and on ice, to minimize the possibility of physical, chemical, or microbial transformation.

Water quality data were subjected to various graphical and statistical techniques in an attempt to describe spatial and temporal trends within the lake, and interrelationships among constituents. Whenever analytical results were reported to be equal to or less than the method reporting limit, these values were set equal to the reporting limit for statistical purposes. Data were analyzed using two approaches, both of which were consistent with earlier Duke Power Company, and Duke Power studies on the lake (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a and 2005). The first method involved partitioning the reservoir into mixing, background, and discharge zones, consolidating the data into these sub-sets, and making comparisons among zones and years. In this report, the discharge includes only Location 4; the mixing zone, Locations 1 and 5; the background zone includes Locations 8, 11, and 15. The second approach, applied primarily to the *insitu* data, emphasized a much broader lake-wide investigation and encompassed the plotting of monthly isotherms and isopleths, and summer striped bass habitat. Several quantitative calculations were also performed on the *insitu* Hydrolab data; these included the calculation of the areal hypolimnetic oxygen deficit (AHOD), maximum whole-water column and hypolimnion oxygen content, maximum whole-water column and hypolimnion heat content, mean epilimnion and hypolimnion heating rates over the stratified period, and the Birgean heat budget.

Heat content (Kcal/cm^2), oxygen content (mg/cm^2), and mean oxygen concentration (mg/L) of the reservoir were calculated according to Hutchinson (1957), using the following equation:

$$Lt = A_o^{-1} \bullet \int_{z_0}^{z_m} TO \bullet Az \bullet dz$$

where;

Lt = reservoir heat (Kcal/cm^2) or oxygen (mg/cm^2) content

A_o = surface area of reservoir (cm^2)

TO = mean temperature (°C) or oxygen content (mg/L) of layer z

Az = area (cm^2) at depth z

dz = depth interval (cm)

z_o = surface

z_m = maximum depth (m)

Precipitation and air temperature data were obtained from a meteorological monitoring site established near MNS in 1975. These data are employed principally by Duke Power as input variables into meteorological modeling studies to address safety issues associated with potential radiological releases into the atmosphere by MNS (Duke Power 2004b), as required by the Nuclear Regulatory Commission. The data also serve to document localized temporal trends in air temperatures and rainfall patterns. Data on lake level and hydroelectric flows were obtained from Duke Energy-Carolinas Fossil/Hydroelectric Department, which monitors these metrics hourly.

RESULTS AND DISCUSSION

Precipitation and Air Temperature

Annual precipitation in the vicinity of MNS in 2005 totaled 45.6 inches (Figures 2-2a, b) or 1.0 inches more than observed in 2004 (44.6 inches); it was also similar to the long-term precipitation average for this area (46.3 inches), based on Charlotte, NC airport data. Monthly precipitation totals were remarkably similar between years except for the months of September and October which exhibited reverse patterns. In September 2005, rainfall totaled only 0.16 inches and contrasted markedly with the 7.73 inches recorded in September 2004. Hurricanes Frances and Ivan, both of which bypassed the greater Charlotte area, exerted a considerable effect on the North Carolina mountains and foothills, and accounted for the majority of September 2004 rainfall totals.

Air temperatures in 2005 were generally warmer than the long-term mean, based on monthly average data; they were also noticeably warmer than 2004 temperatures in the winter, and late-summer (Figure 2-2c). The temporal differences were most pronounced in January and August when 2005 temperatures averaged 2.1 °C and 2.4 °C warmer, respectively, than 2004.

Temperature and Dissolved Oxygen

Water temperatures measured in 2005 illustrated similar temporal and spatial trends in the background and mixing zones (Figures 2-3 and 2-4), as they did in 2004. This similarity in temperature patterns between zones has been a dominant feature of the thermal regime in Lake Norman since MNS began operations in 1983.

Winter (January and February) water temperatures in 2005 were generally warmer than those observed in 2004 in both the mixing and background zones, and paralleled interannual differences exhibited in air temperatures (Figures 2-2c, 2-3, and 2-4). Minimum water temperatures in 2005 were recorded in early February and ranged from 7.1 °C to 9.6 °C in the background zone, and from 7.8 °C to 16.1 °C in the mixing zone. Temperature differences between 2005 and 2004 were most pronounced in the surface waters where maximum delta T values of 1.9 °C and 4.7 °C were observed in the background and mixing zones, respectively. Minimum water temperatures measured in 2005 were within the observed historical range (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005).

Spring and summer water temperatures in 2005 were generally similar to that observed in 2004, with several exceptions. The greatest between-year variability in summer water temperature was observed in June in both the mixing and background zones, with the primary differences occurring in the upper 10 m of the water column (Figures 2-3 and 2-4). Water temperatures in this portion of the water column were up to 5.2 °C cooler in 2005 than 2004, and the differences appear to be related to the antecedent May air temperatures (Figure 2-2c), which were the warmest recorded over the last 40 years in May 2004 (unpublished data, Charlotte airport). Similarly, July and August water temperatures in the metalimnion (10-15 m) were also slightly cooler in 2005 than 2004 with the largest difference (4.7 °C) observed in the mixing zone at a depth of 11 m. Conversely, September 2005 epilimnion temperatures were up to 3.1 °C warmer than in 2004, and appear to be related to above average air temperatures in August and September (Figure 2-2c). Minimal differences in hypolimnetic (below 20 m) temperatures were observed between 2005 and 2004 during the summer. The lone exception was in September 2005 when the deeper waters were cooler (and the surface waters were warmer) than observed in 2004, especially in the background zone. These thermal differences can be explained by differential cooling of the water column in 2005 versus 2004, in response to higher air temperatures in the preceding month of August 2005 (Figure 2-2c).

Fall and early winter water temperatures (October, November and December) in 2005 were generally similar to those measured in 2004, and followed the trend exhibited in air temperatures (Figure 2-3) Some differences were observed between years, and in certain portions of the water column, but overall cooling of the water column proceeded at a similar rate in 2004 and 2005.

Temperature data at the discharge location in 2005 were generally similar to 2004 (Figure 2-5) and historically (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005). Temperatures in 2005 were slightly warmer (by a maximum of 3.8 °C) in the spring, and slightly cooler (by a maximum of 3.6 °C) in the summer than observed in 2004. The warmest discharge temperature of 2005 at Location 4 occurred in August and measured 37.1 °C, or 1.7 °C cooler than measured in August, 2004 (Duke Power 2005).

Seasonal and spatial patterns of DO in 2005 were reflective of the patterns exhibited for temperature, i.e., generally similar in both the mixing and background zones (Figures 2-6 and 2-7). As observed with water column temperatures, this similarity in DO patterns between zones has been a dominant feature of the oxygen regime in Lake Norman since MNS began operations in 1983.

Winter and early spring DO values in 2005 were generally equal to or slightly lower, in both the background and mixing zones, than measured in 2004, except in January in the mixing zone which exhibited slightly higher oxygen concentrations in 2005 versus 2004 (Figures 2-6 and 2-7). The interannual differences in DO values measured during February and March appear to be related predominantly to the warmer water column temperatures in 2005 versus 2004. Warmer water would be expected to exhibit a lesser oxygen content because of the direct effect of temperature on oxygen solubility, which is an inverse relationship, and indirectly via a restricted convective mixing regime which would limit water column reaeration. DO concentrations in March 2005 were about 0.3 mg/L less throughout the water column in the background zone than measured in 2004, and 0.6 mg/L less than 2004 in the mixing zone.

Spring and summer DO values in 2005 were highly variable throughout the water column in both the mixing and background zones ranging from highs of 6 to 8 mg/L in surface waters to lows of 0 to 2 mg/L in bottom waters. This pattern is similar to that measured in 2004 and earlier years (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005). Epilimnetic and metalimnetic DO values in May and June ranged from 0.4 to 2.5 mg/L higher in 2005 than 2004, and corresponded closely with the cooler water temperatures measured in this portion of the water column in 2005 relative to 2004. Conversely, August 2005 DO concentrations between 7 and 13 m were less than recorded in 2004 despite being somewhat cooler (Figures 2-3, 2-4, 2-6 and 2-7). This apparent discrepancy can be explained by between-year differences in the depth of the epilimnion, or the warm and well oxygenated surface portion of the water column, which was noticeably deeper in 2005 than 2004, especially in the mixing zone (Figures 2-3 and 2-4). Hypolimnetic DO values measured during this period were also either equal to or slightly greater than measured in 2004 in both the mixing and background zones. All dissolved oxygen values recorded in 2005 were within the historical range (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005).

Considerable differences were observed between 2005 and 2004 late summer and fall DO values in both the mixing and background zone, especially in the metalimnion and hypolimnion during the months of September, and to a lesser extent in October and November (Figures 2-6 and 2-7). These interannual differences in DO levels during the cooling season are common in Catawba River reservoirs and can be explained by the effects of variable weather patterns on water column cooling (heat loss) and mixing. Warmer air temperatures delay water column cooling (Figure 2-3 and 2-4) which, in turn, delays the onset of convective mixing of the water column and the resultant reaeration of the metalimnion and hypolimnion. Conversely, cooler air temperatures increase the rate and magnitude of water column heat loss, thereby promoting convective mixing and resulting in higher DO values earlier in the year.

The 2005 late summer and autumn DO data indicate that convective reaeration was temporally variable in the rate at which it occurred, compared to 2004. Concentrations of DO in September 2005 were considerably lower than observed in September 2004, especially below 10 m in the background zone (Figures 2-6 and 2-7). These between-year differences in DO corresponded strongly with the degree of thermal stratification which, as discussed earlier, correlated with interannual differences in air temperatures (Figures 2-2c, 2-3, and 2-4). Conversely, DO values in October, and to some extent November 2005, were greater than in 2004 indicating that reaeration during these months proceeded somewhat faster in 2005 than 2004.

The seasonal pattern of DO in 2005 at the discharge location was similar to that measured historically, with the highest values observed during the winter and lowest observed in the summer and early fall (Figure 2-5). The lowest DO concentration measured at the discharge location in 2005 (4.87 mg/L) occurred in August, and was slightly lower than measured in 2004, but about 0.8 mg/L higher than measured in August 2003 (4.1 mg/L).

Reservoir-wide Temperature and Dissolved Oxygen

The monthly reservoir-wide temperature and DO data for 2005 are presented in Figures 2-8 and 2-9. These data are similar to that observed in previous years and are characteristic of cooling impoundments and hydropower reservoirs in the Southeast (Cole and Hannan 1985; Hannan et al. 1979; Petts 1984). Detailed discussions on the seasonal and spatial dynamics of temperature and dissolved oxygen during both the cooling and heating periods in Lake Norman have been presented previously (Duke Power Company 1992, 1993, 1994, 1995, 1996).

The seasonal heat content of both the entire water column and the hypolimnion for Lake Norman in 2005 are presented in Figure 2-10a; additional information on the thermal regime in the reservoir for the years 2004 and 2005 is found in Table 2-3. Annual minimum heat content for the entire water column in 2005 (9.57 Kcal/cm^2; 9.74 °C) occurred in early February, whereas the maximum heat content (29.76 Kcal/cm^2; 29.00 °C) occurred in early July. Heat content of the hypolimnion exhibited a somewhat different temporal trend as that observed for the entire water column. Annual minimum hypolimnetic heat content occurred in early February and measured 4.75 Kcal/cm^2 (7.65 °C), whereas the maximum occurred in early October and measured 15.69 Kcal/cm^2 (24.8 °C). Heating of both the entire water column and the hypolimnion occurred at approximately a linear rate from minimum to maximum heat content. The mean heating rate of the entire water column equaled 0.103 Kcal/cm^2/day and 0.045 Kcal/cm^2/day for the hypolimnion. The 2005 heat content and heating rate data were similar to that observed in previous years (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005).

The seasonal oxygen content and percent saturation of the whole water column, and the hypolimnion, are depicted for 2005 in Figure 2-10b. Additional oxygen data can be found in Table 2-4 which presents the 2005 AHOD for Lake Norman and similar estimates for 18 Tennessee Valley Authority (TVA) reservoirs. Reservoir oxygen content was greatest in mid-winter when DO content measured 10.5 mg/L for the whole water column and 10.4 mg/L for the hypolimnion. Percent saturation values at this time approached 93% for the entire water column and 91% for the hypolimnion. Beginning in early spring, oxygen content began to decline precipitously in both the whole water column and the hypolimnion, and continued to decline linearly until reaching a minimum in mid summer. Minimum summer volume-weighted DO values for the entire water column measured 4.4 mg/L (60% saturation), whereas the minimum for the hypolimnion was 0.06 mg/L (0.8% saturation). The mean rate of DO decline in the hypolimnion over the stratified period, i.e., the AHOD, was 0.040 mg/cm^2/day (0.063 mg/L/day) (Figure 2-10b), and is similar to that measured in 2004 (Duke Power 2005).

Hutchinson (1938, 1957) proposed that the decrease of DO in the hypolimnion of a waterbody should be related to the productivity of the trophogenic zone. Mortimer (1941) adopted a similar perspective and proposed the following criteria for AHODs associated with various trophic states; oligotrophic - $\leq$ 0.025 mg/cm^2/day, mesotrophic - 0.026 mg/cm^2/day to 0.054 mg/cm^2/day, and eutrophic - $\geq$ 0.055 mg/cm^2/day. Employing these limits, Lake Norman should be classified as mesotrophic based on the calculated AHOD value of 0.040 mg/cm^2/day for 2005. The oxygen based mesotrophic classification agrees well with the mesotrophic classification based on chlorophyll *a* levels (Chapter 3). The 2005 AHOD value is also similar to that found in other Southeastern reservoirs of comparable depth, chlorophyll *a* status, and Secchi depth (Table 2-4).

<u>Striped Bass Habitat</u>

Suitable pelagic habitat for adult striped bass, defined as that layer of water with temperatures $\leq$ 26 °C and DO levels $\geq$ 2.0 mg/L, was found lake-wide from mid September 2004 through early July 2005. Beginning in late June 2005, habitat reduction proceeded rapidly throughout the reservoir both as a result of deepening of the 26 °C isotherm and metalimnetic and hypolimnetic deoxygenation (Figure 2-11). Habitat reduction was most severe from mid July through early September when no suitable habitat was observed in the reservoir except for a thin layer located in the metalimnion and a small, but variable, zone of refuge in the upper, riverine portion of the reservoir, near the confluence of Lyles Creek with Lake Norman.

Habitat measured in the upper reaches of the reservoir appeared to be influenced by both inflow from Lyles Creek and discharges from Lookout Shoals Hydroelectric facility, which were somewhat cooler than ambient conditions in Lake Norman. Upon entering Lake Norman, this water apparently mixes and then proceeds as a subsurface underflow as it migrates downriver (Ford 1985).

An additional refuge was also observed in the hypolimnion near the dam during this period, but this lasted only until 18 July when dissolved oxygen was reduced to < 2.0 mg/L by microbial demands. Summer-time habitat conditions for adult striped bass in 2005 were similar to 2004 when the largest striped bass die-off ever was observed in the reservoir (2610 fish). Conditions were also marginally better than observed in most previous years, including 2003 which exhibited complete habitat elimination for a period of about 30-35 days. Striped bass mortalities in 2005 totaled 20 fish.

Physicochemical habitat was observed to have expanded appreciably by mid September, primarily as a result of epilimnion cooling and deepening, and in response to changing meteorological conditions. The temporal and spatial pattern of striped bass habitat expansion and reduction observed in 2005 was generally similar to that previously reported in Lake Norman, and many other Southeastern reservoirs (Coutant 1985; Matthews et al. 1985; (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005).

Turbidity and Specific Conductance

Surface turbidity values were generally low at the MNS discharge, mixing zone, and mid-lake background locations during 2005, ranging from 1.0 to 3.2 NTU's (Table 2-5). Bottom turbidity values were also relatively low over the 2005 study period, ranging from 1.1 to 4.0 NTU's (Table 2-5). Turbidity values observed in 2005, as a whole, were slightly lower than measured in 2004 (Table 2-5), but well within the historical range (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005).

Specific conductance in Lake Norman in 2005 ranged from 37 to 75 umho/cm, and was generally similar to that observed in 2004 (Table 2-5), and historically (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005). Specific conductance values in surface and bottom waters in 2005 were similar throughout the year except during the period of intense thermal stratification, i.e., August through November, when an increase in bottom conductance values was observed. These increases in bottom conductance values appeared to be related primarily to the release of soluble iron and manganese from the lake bottom under anoxic conditions (Table 2-5). This phenomenon is common in both natural lakes and reservoirs that exhibit extensive hypolimnetic oxygen depletion (Hutchinson 1957, Wetzel 1975), and is an annually recurring phenomenon in Lake Norman.

pH and Alkalinity

During 2005, pH and alkalinity values were similar among MNS discharge, mixing and background zones (Table 2-5). Values of pH were also generally similar to values measured in 2004 (Table 2-5), and historically ((Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005). Values of pH in 2005 ranged from 6.8 to 7.6 in surface waters, and from 6.0 to 7.2 in bottom waters. Alkalinity values in 2005 ranged from 11 to 14.5 mg/L, expressed as $CaCO_3$, in surface waters and from 10.5 to 17.5 mg/L in bottom waters.

Major Cations and Anions

The concentrations of major ionic species in the MNS discharge, mixing, and mid-lake background zones are provided in Table 2-5. Lake-wide, the major cations were sodium, calcium, magnesium, and potassium, whereas the major anions were bicarbonate, sulfate, and chloride. The overall ionic composition of Lake Norman during 2005 was generally similar to that reported for 2004 (Table 2-5) and previously (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005).

Nutrients

Nutrient concentrations in the discharge, mixing, and mid-lake background zones of Lake Norman for 2004 and 2005 are provided in Table 2-5. Overall, nutrient concentrations in 2005 were well within historical ranges (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005). Nitrogen and phosphorus levels in 2005 were low and generally similar to those measured in 2004 (Duke Power 2005). Total phosphorus and ortho-phosphorus concentrations were typically measured at or below the analytical reporting limits (ARL) for these constituents, i.e., 5 µg/L. (Note that the reporting limit for total phosphorus was lowered from 10 µg/L to 5 µg/L in 2005). For total phosphorus, all 44 samples analyzed in 2005 exceeded the ARL, but most measurements (29 of 44) were ≤ 10 µg/L, and the maximum recorded value was 16 µg/L. For ortho-phosphorus all 44 of the samples assayed measured ≤ 5 µg/L. Nutrients in 2005 were generally higher in the upper portions of the reservoir compared to the lower sections, but the differences were slight and not statistically significant ($p < 0.05$). Spatial variability in various chemical constituents, especially nutrient concentrations, is common in long, deep reservoirs (Soballe et al. 1992).

Nitrite-nitrate and ammonia nitrogen concentrations were low at all locations sampled in 2005 (Table 2-5), and also were generally similar to 2004 and historical values (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005).

Metals

Metal concentrations in the discharge, mixing, and mid lake background zones of Lake Norman for 2005 were similar to those measured in 2004 (Table 2-5) and historically (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005). Iron concentrations in surface and bottom waters were generally low (≤ 0.2 mg/L) during 2005, the lone exception being a 0.30-mg/L value measured in the bottom waters at Location 5 in August. Nowhere in the reservoir in 2005 did iron concentrations exceed NC's water quality standard (NCDENR 2004) for this constituent (1.0 mg/L), which is unusual. Historically, iron concentrations typically increase in the bottom waters during the late summer, and early fall, in response to changing redox conditions (see below). It's unclear why this phenomenon was not as prevalent in 2004 and 2005, as in previous years.

Similarly, manganese concentrations in the surface and bottom waters were generally low (≤ 100 µg/L) in 2005, except during the summer and fall when bottom waters were anoxic (Table 2-5). Manganese concentrations were also appreciably lower in 2005 than 2004, especially in the bottom waters. This phenomenon, i.e., the release of manganese (and iron) from bottom sediments in response to low redox conditions (low oxygen levels), is common in stratified waterbodies (Stumm and Morgan 1970, Wetzel 1975). Manganese concentrations in the bottom waters rose above NC's water quality standard (NCDENR

2004) for this constituent, i.e., 200 µg/L, at various locations throughout the lake in summer and fall of 2005, and is characteristic of historical conditions (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005).

Concentrations of other metals in 2005 were typically low, and often below the analytical reporting limit for the specific constituent (Table 2-5). These findings are similar to those observed for earlier years (Duke Power Company 1985, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996; Duke Power 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005). All values for cadmium, lead and zinc were reported as either equal to or below the reporting limit for each constituent, and no NC water quality standard was exceeded. Most copper concentrations were less than 3 µg/L, whereas the highest copper concentration reported was 5.2 µg/L. All copper values reported were below the NC standard of 7 µg/L (NCDENR 2004).

FUTURE STUDIES

No changes are planned for the Water Chemistry portion of the Lake Norman maintenance-monitoring program.

SUMMARY

Annual precipitation in the vicinity of MNS in 2005 totaled 45.6 inches or 1.0 inches more than observed in 2004 (44.6 inches) but was similar to the long-term precipitation average for this area (46.3 inches). Air temperatures in 2005 were generally warmer than measured in 2004, as well as the long-term mean. Temporal differences were most pronounced in January and August when 2005 temperatures averaged 2.1 °C and 2.4 °C warmer, respectively, than 2004.

Temporal and spatial trends in water temperature and DO in 2005 were similar to those observed historically, and all data were within the range of previously measured values. Winter water temperatures in 2005 ranged from 1.9 °C to 4.7 °C warmer than observed in 2004 in both the mixing and background zones, and paralleled interannual differences exhibited in air temperatures. Spring and summer water temperatures in 2005 were generally similar to that observed in 2004, with several exceptions. Water temperatures in the upper 10 m of the water column in June 2005 were up to 5.2 °C cooler than in 2004, and the differences appear to be related to the antecedent May 2004 air temperatures which were the warmest recorded over the last 40 years. Similarly, July and August water temperatures in the metalimnion (10-15 m) were also slightly cooler in 2005 than 2004 with the largest difference (4.7 °C) observed in the mixing zone at a depth of 11 m. Minimal differences in hypolimnetic (below 20 m) temperatures were observed between 2005 and 2004 during the summer, the lone exception being September when the deeper waters were cooler (and the surface waters were warmer) than observed in 2004, especially in the background zone. These thermal differences can be explained by differential cooling of the water column in 2005 versus 2004, in response to higher air temperatures in the preceding month of August 2005. Fall and early winter water temperatures in 2005 were generally similar to those measured in 2004, and followed the trend exhibited in air temperatures.

Winter and early spring DO values in 2005 were generally equal to or slightly lower, in both the background and mixing zones, than measured in 2004, except in January in the mixing zone which exhibited slightly higher oxygen concentrations in 2005 versus 2004. The interannual differences in DO values measured during February and March appeared to be related predominantly to the warmer water column temperatures in 2005 versus 2004. DO concentrations in March 2005 were about 0.3 mg/L less throughout the water column in the background zone than measured in 2004, and 0.6 mg/L less than 2004 in the mixing zone.

Spring and summer DO values in 2005 were highly variable throughout the water column in both the mixing and background zones ranging from highs of 6 to 8 mg/L in surface waters to lows of 0 to 2 mg/L in bottom waters. This pattern is similar to that measured in 2004 and earlier years. Epilimnetic and metalimnetic DO values in May and June ranged from 0.4 to 2.5 mg/L higher in 2005 than 2004, and corresponded closely with the cooler water temperatures measured in this portion of the water column in 2005. Conversely, August 2005 DO concentrations in the waters between 7 and 13 m were less than recorded in 2004 despite being somewhat cooler. This apparent discrepancy can be explained by between-year differences in the depth of the epilimnion, which was noticeably deeper in 2005 than 2004, especially in the mixing zone. Hypolimnetic DO values measured during this period were also either equal to or slightly greater than measured in 2004 in both the mixing and background zones.

Considerable differences were observed between 2005 and 2004 late summer and fall DO values in both the mixing and background zone, especially in the metalimnion and hypolimnion during the months of September, and to a lesser extent in October and November. Concentrations of DO in September 2005 were markedly lower than observed in September 2004, especially below 10 m in the background zone, whereas DO values in October, and to some extent November 2005, were greater than in 2004. These between-year differences in DO corresponded strongly with the degree of thermal stratification which, in turn, correlated with interannual differences in air temperatures. All dissolved oxygen values recorded in 2005 were within the historical ranges.

Reservoir-wide isotherm and isopleth information for 2005, coupled with heat content and hypolimnetic oxygen data, illustrated that Lake Norman exhibited thermal and oxygen dynamics characteristic of historical conditions and similar to other Southeastern reservoirs of comparable size, depth, flow conditions, and trophic status. Availability of suitable pelagic habitat for adult striped bass in Lake Norman in 2005 was generally similar in distribution and amount to 2004 when the largest striped bass die-off ever was observed in the reservoir (2610 fish). Conditions were also marginally better than observed in most previous years, including 2003 which exhibited complete habitat elimination for a period of about 30-35 days. Striped bass mortalities in 2005 totaled 20 fish.

All chemical parameters measured in 2005 were similar to 2004, and within the concentration ranges previously reported for the lake during both preoperational and operational years of MNS. Specific conductance values, and all concentrations of cation and anion species measured, were low. Nutrient concentrations were also low with most values reported close to or below the analytical reporting limit for that test. Concentrations of metals in 2005 were low, and often below the analytical reporting limits. All values for cadmium, lead, and zinc were reported as either equal to or below each constituent's reporting limit, and no NC water quality standard was exceeded. Most copper concentrations were less than 3 μg/L, while the maximum copper concentration reported in 2005 was 5.2 μg/L. All copper values reported were below the NC standard of 7 μg/L.

Manganese and iron concentrations in the surface and bottom waters were generally low in 2005, except during the summer and fall when bottom waters became anoxic and the release of soluble forms of these metals into the water column was observed. In contrast to historical observations, at no time during 2005 did iron concentrations exceed NC's water quality standard (1.0 mg/L). Manganese levels, however, did exceed the State standard (200 μg/L) in the bottom waters throughout the lake in the summer and fall, and are characteristic of historical conditions.

Table 2-1. Water chemistry program for the McGuire Nuclear Station NPDES Maintenance Monitoring Program on Lake Norman.

2005 McGUIRE NPDES SAMPLING PROGRAM

PARAMETERS	LOCATIONS	1	2	4	5	8	9.5	11	13	14	15	15.9	62	69	72	80	16
	DEPTH (m)	33	33	5	20	32	23	27	21	10	23	23	15	7	5	4	3
IN-SITU ANALYSIS																	
	Method																
Temperature	Hydrolab																
Dissolved Oxygen	Hydrolab	In-situ measurements are collected monthly at the above locations at 1m intervals from 0.3m to 1m above bottom.															
pH	Hydrolab	Measurements are taken weekly from July-August for striped bass habitat.															
Conductivity	Hydrolab																
NUTRIENT ANALYSES																	
Ammonia	AA-Nut	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Nitrate+Nitrite	AA-Nut	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Orthophosphate	AA-Nut	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Total Phosphorus	AA-TP,DG-P	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Silica	AA-Nut	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Cl	AA-Nut	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
TKN	AA-TKN	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Total Organic Carbon	TOC	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Dissolved Organic Carbon	DOC	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
ELEMENTAL ANALYSES																	
Aluminum	ICP-MS-D	Q/T,B	S/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Calcium	ICP-24	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Iron	ICP-MS-D	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Magnesium	ICP-24	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Manganese	ICP-MS-D	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Potassium	306-K	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Sodium	ICP-24	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Zinc	ICP-MS-D	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Arsenic	ICP-MS-D	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Cadmium	ICP-MS-D	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Copper (Total Recoverable)	ICP-MS-D	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Copper (Dissolved)	ICP-MS	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Lead	ICP-MS-D	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Selenium	ICP-MS-D	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
ADDITIONAL ANALYSES																	
Hardness		Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Alkalinity	T-ALKT	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Turbidity	F-TURB	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Sulfate	UV_SO4	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Total Solids	S-TSE	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T
Total Suspended Solids	S-TSSE	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T,B	Q/T	Q/T,B	Q/T,B		Q/T,B			S/T

CODES: Frequency Q = Quarterly (Feb, May, Aug, Nov) S = Semi-annually (Feb,Aug) T = Top (0.3m) B = Bottom (1m above bottom)

Table 2-2. Analytical methods and reporting limits employed in the McGuire Nuclear Station NPDES Maintenance Monitoring Program for Lake Norman.

Parameter	Method (EPA/APHA)	Preservation	Reporting Limit
Alkalinity, Total	Total Inflection Point, EPA 310.1	4 C	0.01 meq/L
Aluminum	ICP, EPA 200.7	0.5% HNO_3	0.05 mg/L
Cadmium, Total Recoverable	ICP Mass Spectroscopy, EPA 200.8	0.5% HNO_3	0.5 µg/L
Calcium	ICP, EPA 200.7	0.5% HNO_3	30 µg/L
Chloride	Colorimetric, EPA 325.2	4 C	1.0 mg/L
Copper, Total Recoverable	ICP Mass Spectroscopy, EPA 200.8	0.5% HNO_3	2.0 µg/L
Copper, Dissolved	ICP Mass Spectroscopy, EPA 200.8	0.5% HNO_3	2.0 µg/L
Iron, Total Recoverable	ICP, EPA 200.7	0.5% HNO_3	10 µg/L
Lead, Total Recoverable	ICP Mass Spectroscopy, EPA 200.8	0.5% HNO_3	2.0 µg/L
Magnesium	Atomic Emission/ICP, EPA 200.7	0.5% HNO_3	30 µg/L
Manganese, Total Recoverable	ICP Mass Spectroscopy, EPA 200.8	0.5% HNO_3	1.0 µg/L
Nitrogen, Ammonia	Colorimetric, EPA 350.1	4 C	20 µg/L
Nitrogen, Nitrite + Nitrate	Colorimetric, EPA 353.2	4 C	20 µg/L
Nitrogen, Total Kjeldahl	Colorimetric, EPA 351.2	4 C	100 µg/L
Phosphorus, Orthophosphorus	Colorimetric, EPA 365.1	4 C	5 µg/L
Phosphorus, Total	Colorimetric, EPA 365.1	4 C	5 µg/L
Organic Carbon, Total	EPA 415.1	0.5% H_2SO_4	0.1 mg/L
Organic Carbon, Dissolved	EPA 415.1	0.5% H_2SO_4	0.1 mg/L
Potassium	ICP, EPA 200.7	0.5% HNO_3	250 µg/L
Silica	APHA 4500Si-F	0.5% HNO_3	500 µg/L
Sodium	Atomic Emission/ICP, EPA 200.7	0.5% HNO_3	1.5 mg/L
Solids, Total	Gravimetric, EPA 160.2	4 C	0.1 mg/L
Solids, Total Suspended	Gravimetric, EPA 160.2	4 C	0.1 mg/L
Sulfate	Ion Chromatography	4 C	0.1 mg/L
Turbidity	Turbidimetric, EPA 180.1	4 C	0.05 NTU
Zinc, Total Recoverable	ICP Mass Spectroscopy, EPA 200.8	0.5% HNO_3	1 µg/L

References: USEPA 1983, and APHA 1995

Table 2-3. Heat content calculations for the thermal regime in Lake Norman for 2004 and 2005.

	2005	2004
Maximum Areal Heat Content (g·cal/cm^2)	29,764	29,718
Minimum Areal Heat Content (g·cal/cm^2)	9,574	7,921
Birgean Heat Budget (g·cal/ cm^2)	20,190	21,797
Epilimnion (above 11.5 m) Heating Rate (°C /day)	0.123	0.122
Hypolimnion (below 11.5 m) Heating Rate (°C /day)	0.076	0.076

Table 2-4. A comparison of areal hypolimnetic oxygen deficits (AHOD), summer chlorophyll *a* (Chl a), Secchi depth, and mean depth of Lake Norman and 18 TVA reservoirs.

Reservoir	AHOD ($mg/cm^2/day$)	Summer Chl a (ug/L)	Secchi Depth (m)	Mean Depth (m)
Lake Norman (2005)	0.040	5.5	2.2	10.3
TVA [a]				
Mainstem				
Kentucky	0.012	9.1	1.0	5.0
Pickwick	0.010	3.9	0.9	6.5
Wilson	0.028	5.9	1.4	12.3
Wheelee	0.012	4.4		5.3
Guntersville	0.007	4.8	1.1	5.3
Nickajack	0.016	2.8	1.1	6.8
Chickamauga	0.008	3.0	1.1	5.0
Watts Bar	0.012	6.2	1.0	7.3
Fort London	0.023	5.9	0.9	7.3
Tributary				
Chatuge	0.041	5.5	2.7	9.5
Cherokee	0.078	10.9	1.7	13.9
Douglas	0.046	6.3	1.6	10.7
Fontana	0.113	4.1	2.6	37.8
Hiwassee	0.061	5.0	2.4	20.2
Norris	0.058	2.1	3.9	16.3
South Holston	0.070	6.5	2.6	23.4
Tims Ford	0.059	6.1	2.4	14.9
Watauga	0.066	2.9	2.7	24.5

[a] Data from Higgins et al. (1980), and Higgins and Kim (1981)

Table 2-5. Quarterly surface (0.3 m) and bottom (bottom minus 1 m) water chemistry for the McGuire Nuclear Station discharge, mixing zone, and background locations on Lake Norman during 2004 and 2005. Values less than detection were assumed to be equal to the detection limit for calculating a mean.

LOCATION:	Mixing Zone 1.0				Mixing Zone 2				MNS Discharge 4.0		Mixing Zone 5.0				Background 8.0				Background 11.0			
DEPTH:	Surface		Bottom		Surface		Bottom		Surface		Surface		Bottom		Surface		Bottom		Surface		Bottom	
PARAMETERS YEAR:	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Turbidity (ntu)																						
Feb	2.81	1.6	2.39	1.90	3.12	1.80	1.94	2.10	NS	1.50	2.12	1.90	1.61	2.00	2.02	2.10	3.51	1.70	3.36	2.20	3.36	3.00
May	1.50	1.4	1.52	1.20	NS	1.80	NS	1.30	1.02	1.30	1.38	1.20	NS	1.60	1.25	1.40	1.31	1.20	1.28	1.50	0.94	1.80
Aug	1.45	1.7	2.57	1.30	1.5	1.70	2.09	1.70	1.4	1.70	1.46	1.60	3.63	4.00	1.32	1.40	2.99	1.60	2.11	1.80	2.49	2.50
Nov	2.80	1.1	2.8	3.30	3.13	1.30	3.69	1.70	3.05	1.20	2.98	1.80	7.53	1.60	2.72	3.20	5.77	1.10	3.32	1.20	6.46	3.60
Annual Mean	2.14	1.45	2.32	1.9	2.58	1.7	2.57	1.7	1.82	1.4	1.99	1.6	4.26	2.3	1.83	2.0	3.40	1.4	2.52	1.7	3.31	2.7
Specific Conductance (umho/cm)																						
Feb	52.0	51	51.0	49	52	51	50	49	53	52	52	52	51.0	49	51	50	50	49	51	51	50	49
May	53.0	56	53	52	57	53	53	50	58	55	57	54	54	51	56	37	54	44	58	46	55	46
Aug	63.0	56	59.0	58	62.0	56	60.0	61	64.0	56	62.0	56	66.0	61	60.0	56	58.0	56	62.0	57	59.0	59
Nov	56.0	55	99.0	55	56.0	55	100.0	75	58.0	56	57.0	55	58.0	55	56.0	55	98.0	52	52.0	54	52.0	51.0
Annual Mean	56.0	54.5	65.5	53.5	56.8	53.8	65.8	58.8	58.3	54.8	57.0	54.3	57.3	54.0	55.8	49.5	65.0	50.3	55.8	52.0	54.0	51.3
pH (units)																						
Feb	7.0	7.4	7.0	7.0	7.3	7.3	7.1	7.1	7.3	7.3	7.4	7.3	7.1	7.0	7.4	7.4	7.2	7.2	7.3	7.4	7.1	7.0
May	7.2	7.3	6.3	6.5	7.4	7.4	6.6	6.7	7.3	7.4	7.4	7.4	6.6	6.7	7.7	7.4	6.6	6.5	7.7	7.0	6.7	6.4
Aug	7.3	6.9	6.0	6.0	7.4	7.0	6.1	6.1	7.1	6.8	7.3	7.0	6.3	6.2	8.0	7.6	6.1	6.1	7.1	7.5	6.1	6.2
Nov	6.5	7.0	6.8	6.9	NS	7.0	NS	6.6	6.9	7.0	7.0	7.1	6.7	6.8	7.0	7.1	6.9	6.6	7.0	7.1	6.7	6.6
Annual Mean	7.00	6.53	6.53	6.60	7.37	7.18	6.60	6.63	7.15	7.10	7.28	7.20	6.68	6.68	7.53	7.38	6.70	6.60	7.28	7.25	6.65	6.55
Alkalinity (mg CaCO3/l)																						
Feb	13.5	11.5	13.0	11.5	13.0	11.5	13.0	11.5	NS	11.0	13.0	11.5	13.0	11.5	13.0	13.5	13.0	11.5	13.0	12.0	13.0	12.0
May	13.5	12.5	13.5	12.5	NS	12.5	NS	12.5	14.0	12.5	13.5	12.5	NS	12.5	13.0	12.5	13.5	12.5	14.0	13.0	13.0	13.0
Aug	15.0	13.5	14.5	14.0	15.0	14.0	14.5	14.0	14.5	13.5	15.0	14.0	20.0	17.5	15.0	14.5	14.5	14.5	15.0	14.5	15.0	15.0
Nov	13.0	14.5	36.0	16.0	13.5	12.5	35.5	FQC	13.5	14.0	13.0	FQC	14.0	15.0	13.0	FQC	15.0	13.0	12.0	FQC	12.5	12.5
Annual Mean	13.8	13.0	19.3	13.5	13.8	12.6	21.0	12.7	14.0	12.8	13.6	12.7	15.7	14.1	13.5	13.5	14.0	12.9	13.5	13.2	13.4	13.1
Chloride (mg/l)																						
Feb	4.0	4.3	4.2	4.4	4.1	4.6	4.0	4.3	NS	4.4	3.9	4.5	4.1	4.3	4.1	4.5	4.0	4.4	4.3	4.4	4.1	4.4
May	4.5	4.4	4.5	4.3	NS	4.4	NS	4.4	4.8	4.4	4.6	4.5	NS	4.4	4.6	4.5	4.6	4.4	5.2	4.5	4.6	4.5
Aug	5.3	4.1	4.8	4.3	5.3	4.4	4.7	4.2	5.4	4.2	5.3	4.2	5.2	4.2	5.4	4.3	4.9	4.2	5.4	4.3	4.8	4.2
Nov	4.6	4.4	4.7	4.4	4.5	4.4	4.8	4.5	4.4	4.3	4.4	4.3	4.6	4.4	4.5	4.5	4.5	4.3	4.1	4.1	4.1	4.3
Annual Mean	4.6	4.3	4.6	4.4	4.6	4.5	4.5	4.4	4.9	4.3	4.6	4.4	4.6	4.3	4.7	4.5	4.5	4.3	4.8	4.3	4.4	4.4
Sulfate (mg/l)																						
Feb	NS	4.2	NS	4.5	5.0	4.3	4.7	4.3	NS	4.4	NS	4.3	NS	4.2	4.7	4.7	4.8	5.3	NS	4.3	6.7	4.2
May	NS	4.4	NS	4.4	NS	4.4	NS	4.4	5.1	4.4	NS	4.5	NS	4.7	5.1	4.5	5.0	4.4	NS	4.4	NS	4.3
Aug	NS	4.2	NS	4.5	4.6	4.2	4.7	4.5	4.7	4.2	NS	4.3	NS	4.5	4.6	4.4	4.7	4.5	NS	4.3	NS	4.5
Nov	NS	3.9	NS	4.0	4.5	6.0	3.2	3.9	4.5	4.0	NS	4.1	NS	4.0	4.5	4.0	4.4	4.0	NS	4.0	NS	4.0
Annual Mean	NA	4.2	NA	4.4	4.7	4.7	4.2	4.3	4.8	4.3	NA	4.3	NA	4.4	4.7	4.4	4.7	4.6	NA	4.3	6.7	4.3
Calcium (mg/l)																						
Feb	3.12	2.96	3.09	3.07	3.15	2.96	3.10	3.09	NS	2.99	3.09	2.95	3.09	2.97	3.06	3.15	3.12	3.29	2.94	3.20	2.89	3.11
May	2.92	3.35	3.07	3.65	NS	3.31	NS	3.53	3.02	3.44	3.65	3.35	NS	3.33	3.47	3.33	3.24	3.81	3.29	3.47	3.16	3.51
Aug	2.69	3.45	2.97	3.54	2.71	3.19	2.92	3.71	2.73	3.51	2.77	3.15	3.67	3.84	2.73	3.29	3.06	3.69	3.27	3.52	3.15	3.71
Nov	2.99	3.06	4.18	3.09	2.98	3.05	4.10	3.15	3.00	3.04	2.98	3.15	3.03	3.07	2.97	3.06	3.04	2.44	2.78	2.94	2.84	2.46
Annual Mean	2.93	3.21	3.33	3.34	2.95	3.13	3.37	3.37	2.92	3.25	3.12	3.15	3.26	3.30	3.06	3.21	3.12	3.31	3.07	3.28	3.01	3.20
Magnesium (mg/l)																						
Feb	1.39	1.33	1.37	1.33	1.40	1.32	1.38	1.37	NS	1.33	1.39	1.32	1.39	1.32	1.38	1.35	1.40	1.31	1.33	1.35	1.33	1.32
May	1.37	1.40	1.44	1.42	NS	1.40	NS	1.42	1.41	1.41	1.56	1.41	NS	1.41	1.55	1.40	1.48	1.41	1.45	1.42	1.42	1.45
Aug	1.48	1.41	1.55	1.44	1.49	1.39	1.53	1.45	1.49	1.40	1.51	1.39	1.75	1.53	1.48	1.40	1.57	1.47	1.65	1.44	1.62	1.49
Nov	1.33	1.52	1.68	1.52	1.35	1.52	1.66	1.53	1.34	1.52	1.34	1.52	1.35	1.52	1.34	1.52	1.35	1.47	1.25	1.51	1.25	1.47
Annual Mean	1.39	1.42	1.51	1.43	1.41	1.41	1.52	1.44	1.41	1.42	1.45	1.41	1.50	1.45	1.44	1.42	1.45	1.42	1.42	1.43	1.41	1.43

NS = Not Sampled: NA= Not Applicable; FQC = Failed Quality Control

Table 2-5 (Continued)

LOCATION:	Mixing Zone 1.0				Mixing Zone 2				MNS Discharge 4.0		Mixing Zone 5.0				Background 8.0				Background 11.0			
DEPTH:	Surface		Bottom		Surface		Bottom		Surface		Surface		Bottom		Surface		Bottom		Surface		Bottom	
PARAMETERS YEAR:	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Potassium (mg/l)																						
Feb	1.59	1.74	1.57	1.71	1.62	1.72	1.60	1.60	NS	1.74	1.57	1.70	1.59	1.69	1.57	1.64	1.60	1.70	1.46	1.65	1.46	1.64
May	1.63	1.61	1.57	1.63	NS	1.64	NS	1.63	1.58	1.62	1.59	1.66	NS	1.64	1.57	1.62	1.59	1.60	1.53	1.47	1.54	1.55
Aug	1.67	1.56	1.62	1.60	1.60	1.54	1.61	1.57	1.64	1.55	1.64	1.53	1.70	1.63	1.61	1.54	1.64	1.61	1.62	1.54	1.62	1.61
Nov	1.62	1.74	1.68	1.72	1.59	1.71	1.72	1.74	1.59	1.72	1.61	1.74	1.57	1.73	1.66	1.74	1.62	1.84	1.63	1.77	1.59	1.85
Annual Mean	1.63	1.66	1.61	1.67	1.60	1.65	1.64	1.64	1.60	1.66	1.60	1.66	1.62	1.67	1.60	1.64	1.61	1.69	1.56	1.61	1.55	1.66
Sodium (mg/l)																						
Feb	4.27	4.37	4.28	4.30	4.25	4.37	4.32	4.40	NS	4.38	4.24	4.33	4.22	4.28	4.25	4.16	4.22	4.33	4.43	4.20	4.39	4.12
May	4.53	4.42	4.49	4.41	NS	4.40	NS	4.37	4.61	4.41	4.59	4.40	NS	4.29	4.68	4.39	4.61	4.34	4.98	4.55	4.67	4.43
Aug	5.22	4.41	4.73	4.27	5.17	4.34	4.66	4.29	5.21	4.36	5.22	4.32	4.89	4.39	5.09	4.36	4.75	4.34	5.28	4.39	4.77	4.33
Nov	4.62	4.42	4.89	4.44	4.61	4.41	4.81	4.43	4.63	4.42	4.60	4.42	4.62	4.43	5.19	4.42	4.49	4.42	4.08	4.39	4.07	4.40
Annual Mean	4.66	4.41	4.60	4.36	4.68	4.38	4.60	4.37	4.82	4.39	4.66	4.37	4.58	4.35	4.80	4.33	4.52	4.36	4.69	4.38	4.48	4.32
Aluminum (mg/l)																						
Feb	0.050	0.055	0.098	0.050	0.088	0.063	0.099	0.051	NS	0.050	0.094	0.050	0.113	0.064	0.080	0.062	0.176	0.050	0.132	0.050	0.140	0.071
May	0.050	0.050	0.050	0.053	NS	0.050	NS	0.050	0.050	0.050	0.050	0.050	NS	0.071	0.050	0.050	0.093	0.055	0.057	0.050	0.063	0.065
Aug	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.066	0.050
Nov	0.109	0.050	0.066	0.054	0.108	0.050	0.076	0.050	0.100	0.056	0.103	0.050	0.173	0.055	0.102	0.050	0.199	0.144	0.122	0.055	0.066	0.158
Annual Mean	0.065	0.052	0.066	0.052	0.082	0.053	0.075	0.050	0.067	0.052	0.074	0.050	0.112	0.060	0.071	0.053	0.130	0.075	0.090	0.051	0.084	0.086
Iron (mg/l)																						
Feb	0.088	0.100	0.150	0.150	0.106	0.100	0.127	0.190	NS	0.120	0.106	0.110	0.149	0.150	0.087	0.110	0.240	0.130	0.149	0.110	0.151	0.210
May	0.059	0.100	0.061	0.120	NS	0.100	NS	0.100	0.060	0.100	0.045	0.100	NS	0.160	0.040	0.100	0.141	0.100	0.080	0.100	0.100	0.250
Aug	0.044	0.100	0.051	0.100	0.037	0.100	0.046	0.100	0.031	0.100	0.030	0.100	0.625	0.300	0.043	0.100	0.046	0.100	0.088	0.100	0.046	0.100
Nov	0.126	0.098	0.055	0.172	0.120	0.105	0.072	0.243	0.131	0.086	0.107	0.094	0.206	0.150	0.132	0.074	0.291	0.226	0.162	0.075	0.079	0.279
Annual Mean	0.079	0.100	0.079	0.136	0.088	0.101	0.082	0.158	0.074	0.102	0.072	0.101	0.327	0.190	0.076	0.096	0.180	0.139	0.120	0.096	0.094	0.210
Manganese (ug/l)																						
Feb	14	15	22	40	14	15	19	35	NS	16	14	15	22	32	11	16	22	14	20	20	21	30
May	12	7	24	23	NS	14	NS	17	8	8	7	7	NS	36	6	6	30	19	11	10	21	34
Aug	23	19	481	502	24	19	245	264	34	28	30	23	1906	1337	14	13	549	522	108	16	663	868
Nov	117	71	8694	274	94	81	8500	484	262	68	125	73	438	188	60	50	985	294	55	41	284	201
Annual Mean	42	28	2305	210	44	32	2922	200	101	30	44	30	789	398	23	21	396	212	48	22	247	283
Cadmium (ug/l)																						
Feb	NS	0.5	NS	0.5	0.5	0.5	0.5	0.5	NS	0.5	NS	0.5	NS	0.5	0.5	0.5	0.5	0.5	NS	0.5	NS	0.5
May	NS	0.5	NS	0.5	NS	0.5	NS	0.5	0.5	0.5	NS	0.5	NS	0.5	0.5	0.5	0.5	0.5	NS	0.5	NS	0.5
Aug	NS	0.5	NS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NS	0.5	NS	0.5	0.5	0.5	0.5	0.5	NS	0.5	NS	0.5
Nov	NS	0.5	NS	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NS	0.5	NS	0.5	0.5	0.5	0.5	0.5	NS	0.5	NS	0.5
Annual Mean	NA	0.5	NA	0.5	0.5	0.5	0.5	0.5	0.5	0.5	NA	0.5	NA	0.5	0.5	0.5	0.5	0.5	NA	0.5	NA	0.5
Copper (ug/l)																						
Feb	NS	2.0	NS	2.2	2.3	2.0	2.4	2.1	NS	2.1	NS	2.1	NS	2.1	2.0	2.7	2.4	2.0	NS	3.0	NS	2.3
May	NS	2.0	NS	2.2	2.6	2.0	NS	2.0	2.6	2.3	NS	2.0	NS	2.0	2.8	2.3	2.6	2.3	NS	3.3	NS	2.4
Aug	NS	2.0	NS	2.0	2.3	2.0	2.1	2.0	2.4	2.0	NS	2.0	NS	2.0	2.6	2.0	2.0	2.0	NS	2.9	NS	2.0
Nov	NS	2.3	NS	2.0	2.0	2.0	2.0	2.0	2.0	2.0	NS	2.0	NS	2.0	2.1	2.0	2.0	2.2	NS	5.2	NS	2.3
Annual Mean	NA	2.1	NA	2.1	2.3	2.0	2.2	2.0	2.3	2.1	NA	2.0	NA	2.0	2.4	2.3	2.3	2.1	NA	3.6	NA	2.3
Lead (ug/l)																						
Feb	NS	2.0	NS	2.0	2.0	2.0	2.0	2.0	NS	2.0	NS	2.0	NS	2.0	2.0	2.0	2.0	2.0	NS	2.0	NS	2.0
May	NS	2.0	NS	2.0	2.0	2.0	NS	2.0	2.0	2.0	NS	2.0	NS	2.0	2.0	2.0	2.0	2.0	NS	2.0	NS	2.0
Aug	NS	2.0	NS	2.0	2.0	2.0	2.0	2.0	2.0	2.0	NS	2.0	NS	2.0	2.0	2.0	2.0	2.0	NS	2.0	NS	2.0
Nov	NS	2.0	NS	2.0	2.0	2.0	2.0	2.0	2.0	2.0	NS	2.0	NS	2.0	2.0	2.0	2.0	2.0	NS	2.0	NS	2.0
Annual Mean	NA	2.0	NA	2.0	2.0	2.0	2.0	2.0	2.0	2.0	NA	2.0	NA	2.0	2.0	2.0	2.0	2.0	NA	2.0	NA	2.0

NS = Not Sampled: NA= Not Applicable; FQC = Failed Quality Control

Table 2-5 (Continued)

PARAMETERS	Mixing Zone 1.0				Mixing Zone Mi: 2				MNS Discharge 4.0		Mixing Zone 5.0				Background 8.0				Background 11.0			
DEPTH:	Surface		Bottom		Surface		Bottom		Surface		Surface		Bottom		Surface		Bottom		Surface		Bottom	
YEAR:	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Zinc (ug/l)																						
Feb	20.0	1.0	20.0	1.0	20.0	1.0	30.0	1.0	NS	1.0	20.0	1.0	20.0	1.0	20.0	1.0	20.0	1.0	20.0	1.0	20.0	1.0
May	20.0	1.0	20.0	1.4	NS	1.1	NS	1.5	20.0	8.0	20.0	1.2	NS	5.8	20.0	1.0	20.0	2.1	20.0	1.0	20.0	1.5
Aug	20.0	1.0	20.0	1.0	20.0	1.0	20.0	1.0	20.0	1.0	20.0	1.0	20.0	1.0	20.0	1.0	20.0	1.0	20.0	1.0	20.0	1.0
Nov	20.0	3.4	20.0	1.7	20.0	1.5	20.0	1.6	20.0	5.3	20.0	1.0	20.0	1.8	27.0	1.5	20.0	1.7	20.0	3.3	20.0	1.6
Annual Mean	20.0	1.6	20.0	1.3	20.0	1.2	23.3	1.3	20.0	3.8	20.0	1.1	20.0	2.4	21.8	1.1	20.0	1.5	20.0	1.6	20.0	1.3
Nitrite-Nitrate (ug/l)																						
Feb	200	270	210	270	200	260	220	270	NS	270	200	280	200	270	200	270	200	310	250	330	240	180
May	210	240	250	290	NS	240	NS	290	210	240	220	250	NS	290	190	230	260	290	220	230	270	300
Aug	90	130	330	320	70	130	340	350	90	160	110	150	340	210	40	80	340	310	100	70	310	300
Nov	180	130	20	570	190	120	20	80	190	100	190	130	170	120	190	130	180	230	220	260	220	290
Annual Mean	170.0	192.5	202.5	362.5	153.3	187.5	193.3	247.5	163.3	192.5	180.0	202.5	236.7	222.5	155.0	177.5	245.0	285.0	197.5	222.5	260.0	267.5
Ammonia (ug/l)																						
Feb	30	60	50	100	40	30	40	60	NS	40	40	30	40	70	40	20	30	70	20	30	30	40
May	20	20	50	70	NS	20	NS	60	30	30	20	20	NS	60	20	20	70	70	30	30	70	90
Aug	20	90	30	120	20	90	20	80	20	90	20	60	90	130	20	40	20	100	20	230	20	100
Nov	80	130	540	120	70	80	570	140	70	80	70	75	100	110	50	77	140	340	90	82	110	130
Annual Mean	37.5	75.0	167.5	102.5	43.3	55.0	210.0	85.0	40.0	60.0	37.5	46.3	76.7	92.5	32.5	39.3	65.0	145.0	40.0	93.0	57.5	90.0
Total Phosphorous (ug/l)																						
Feb	10	10	10	10	10	10	10	10	NS	10	10	10	10	10	10	10	10	10	10	10	10	10
May	11	10	10	10	NS	10	NS	9	10	10	10	11	NS	11	10	11	10	10	12	15	10	14
Aug	7	9	5	11	8	11	6	9	11	11	5	11	8	11	5	11	10	10	5	12	6	12
Nov	5	8	5	8	5	10	7	8	7	7	5	7	7	8	5	7	7	16	5	9	5	16
Annual Mean	8.3	9.3	7.5	9.8	7.7	10.3	7.7	9.0	9.3	9.5	7.5	9.8	8.3	10.0	7.5	9.8	9.3	11.5	8.0	11.5	7.8	13.0
Orthophosphate (ug/l)																						
Feb	5	5	5	5	5	5	5	5	NS	5	5	5	5	5	5	5	5	5	5	5	5	5
May	6	5	9	5	NS	5	NS	5	9	5	8	5	NS	5	9	5	5	5	10	5	9	5
Aug	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Nov	5	5	5	5	5	5	13	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Annual Mean	5.3	5.0	6.0	5.0	5.0	5.0	7.7	5	6.3	5	5.8	5	5.0	5	6.0	5	5.0	5	6.3	5.0	6.0	5
Silicon (mg/l)																						
Feb	4.9	4.7	5.0	4.8	5.0	4.7	5.2	4.8	NS	4.7	5.0	4.8	4.8	4.8	5.0	4.8	5.0	4.7	5.1	4.9	5.1	4.9
May	4.3	4.2	4.9	4.7	NS	4.2	NS	4.6	4.4	4.3	4.3	4.3	NS	4.7	4.2	4.1	5.0	4.6	3.9	4.1	4.9	4.7
Aug	3.8	3.7	5.4	4.9	3.8	3.8	5.4	4.9	3.9	3.9	3.8	3.8	5.2	4.7	3.7	3.6	5.4	4.8	4.2	3.9	5.4	4.9
Nov	4.2	4.6	5.6	4.7	4.3	4.7	5.6	4.8	4.3	4.7	4.3	4.7	4.4	4.7	4.3	4.7	4.4	5.3	4.4	4.8	4.6	5.3
Annual Mean	4.3	4.3	5.2	4.8	4.4	4.4	5.4	4.8	4.2	4.4	4.4	4.4	4.8	4.7	4.3	4.3	5.0	4.9	4.4	4.4	5.0	5.0

NS = Not Sampled: NA= Not Applicable; FQC = Failed Quality Control

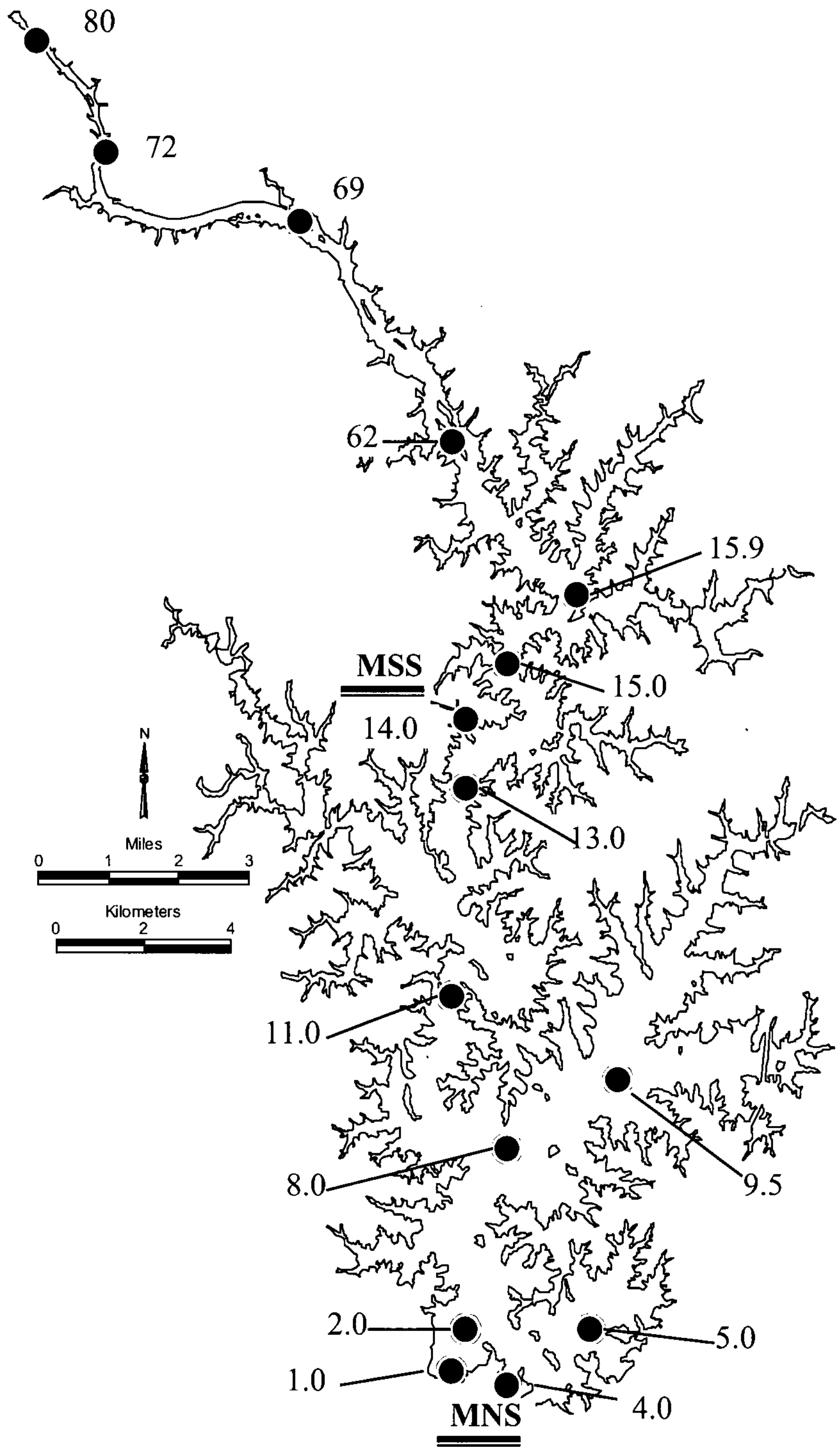


Figure 2-1. Water quality sampling locations (numbered) for Lake Norman. Approximate locations of Marshall Steam Station, and McGuire Nuclear Station are also shown.

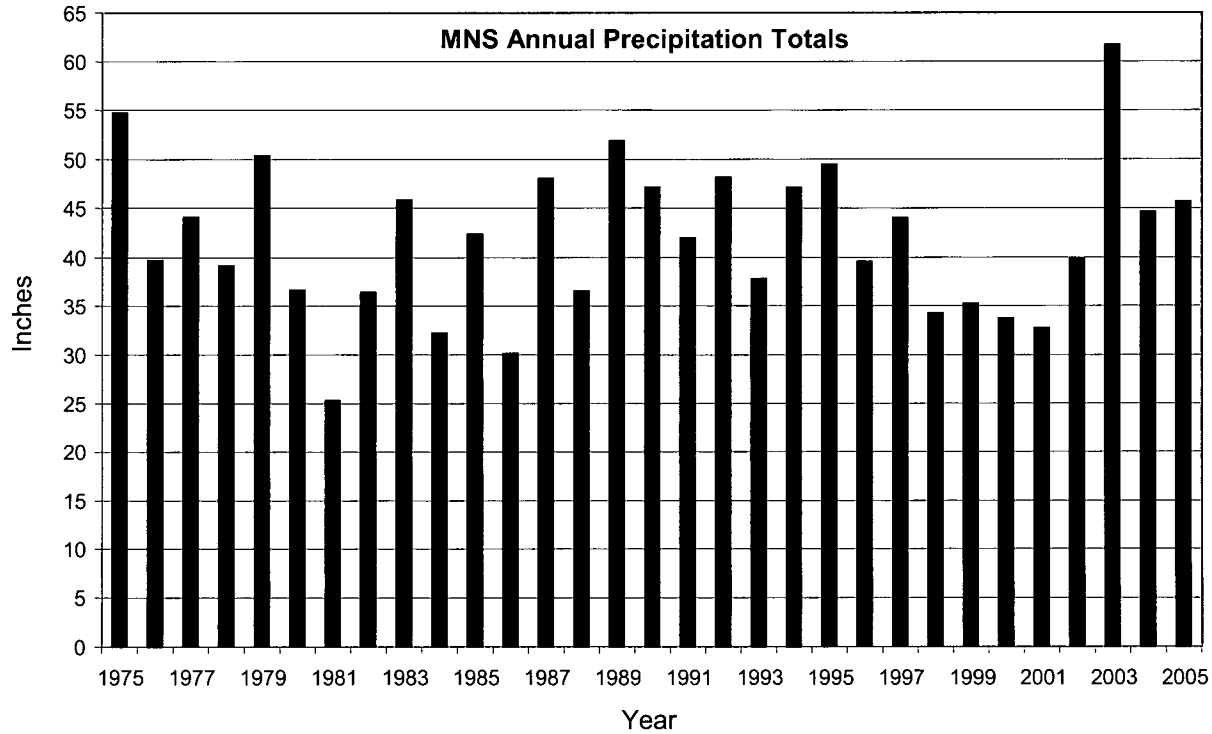


Figure 2-2a. Annual precipitation totals in the vicinity of McGuire Nuclear Station.

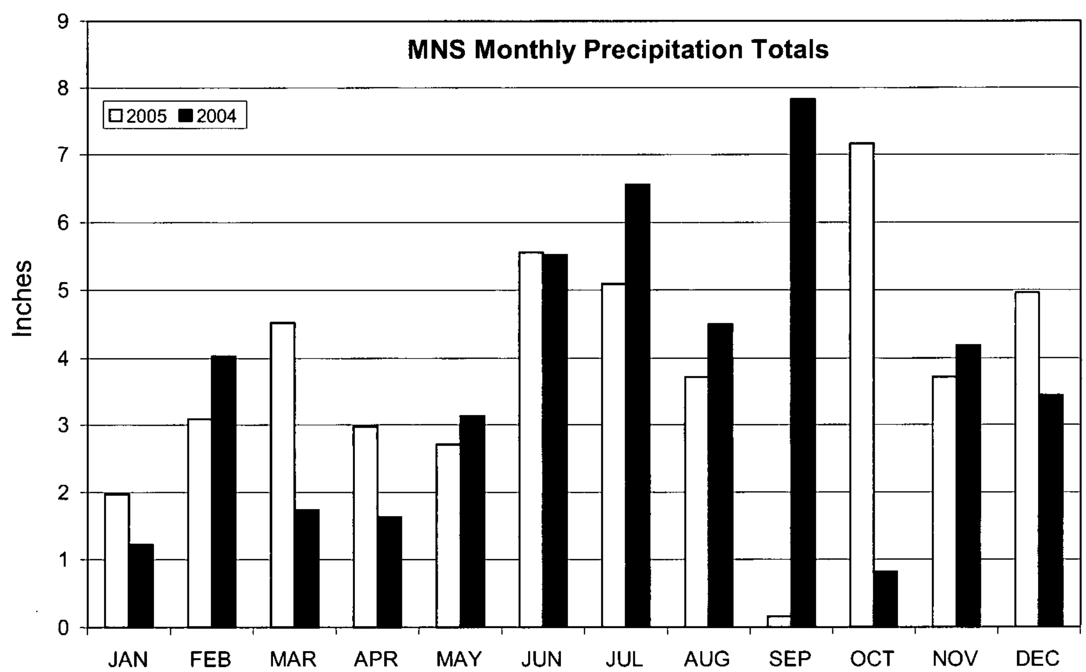


Figure 2-2b. Monthly precipitation totals in the vicinity of McGuire Nuclear Station in 2004 and 2005.

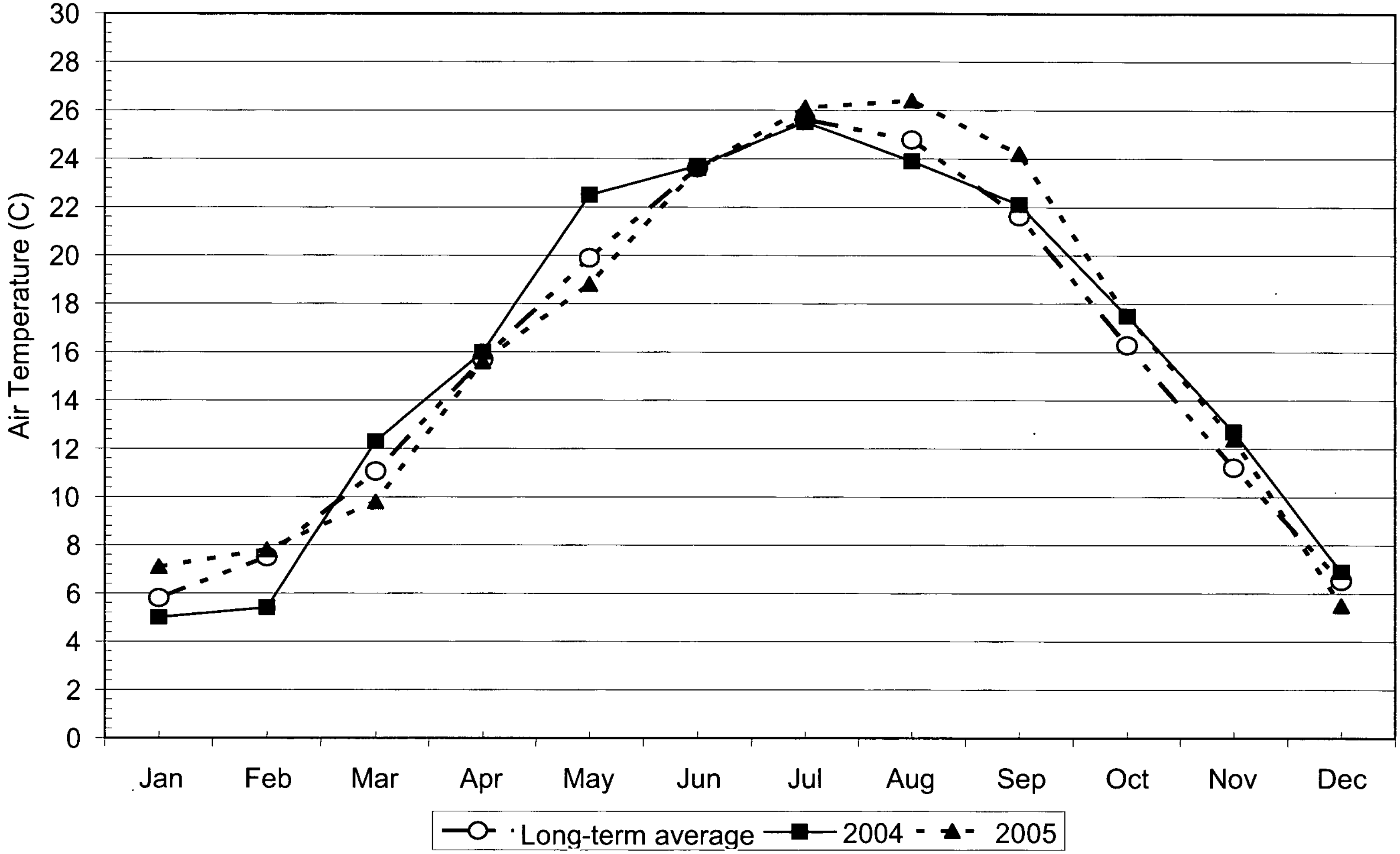


Figure 2-2c. Mean monthly air temperatures recorded at McGuire Nuclear Station beginning in 1989. Data are complied from average daily temperatures which, in turn, were created from hourly measurements.

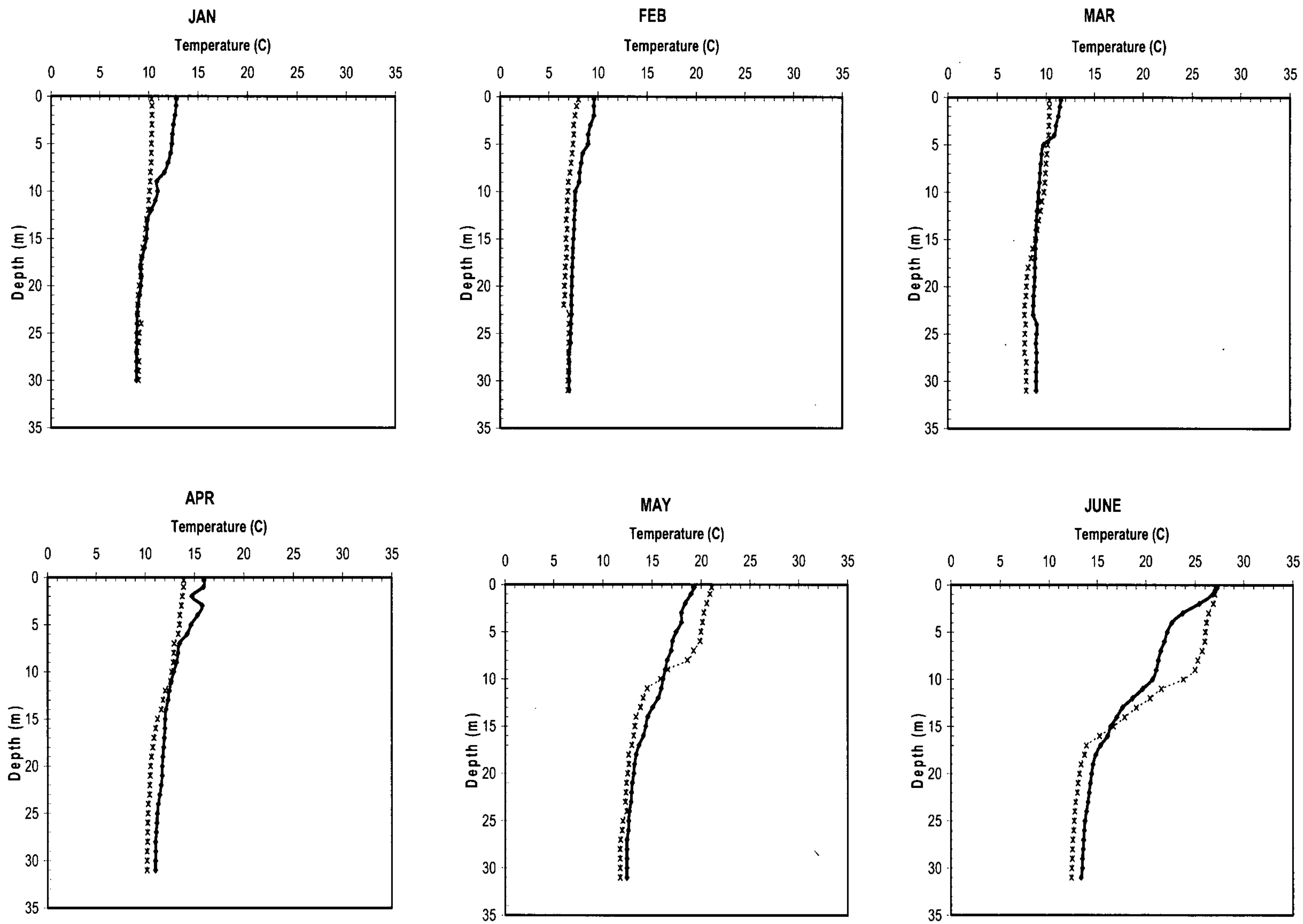


Figure 2-3. Monthly mean temperature profiles for the McGuire Nuclear Station background zone in 2004 (xx) and 2005 (♦♦).

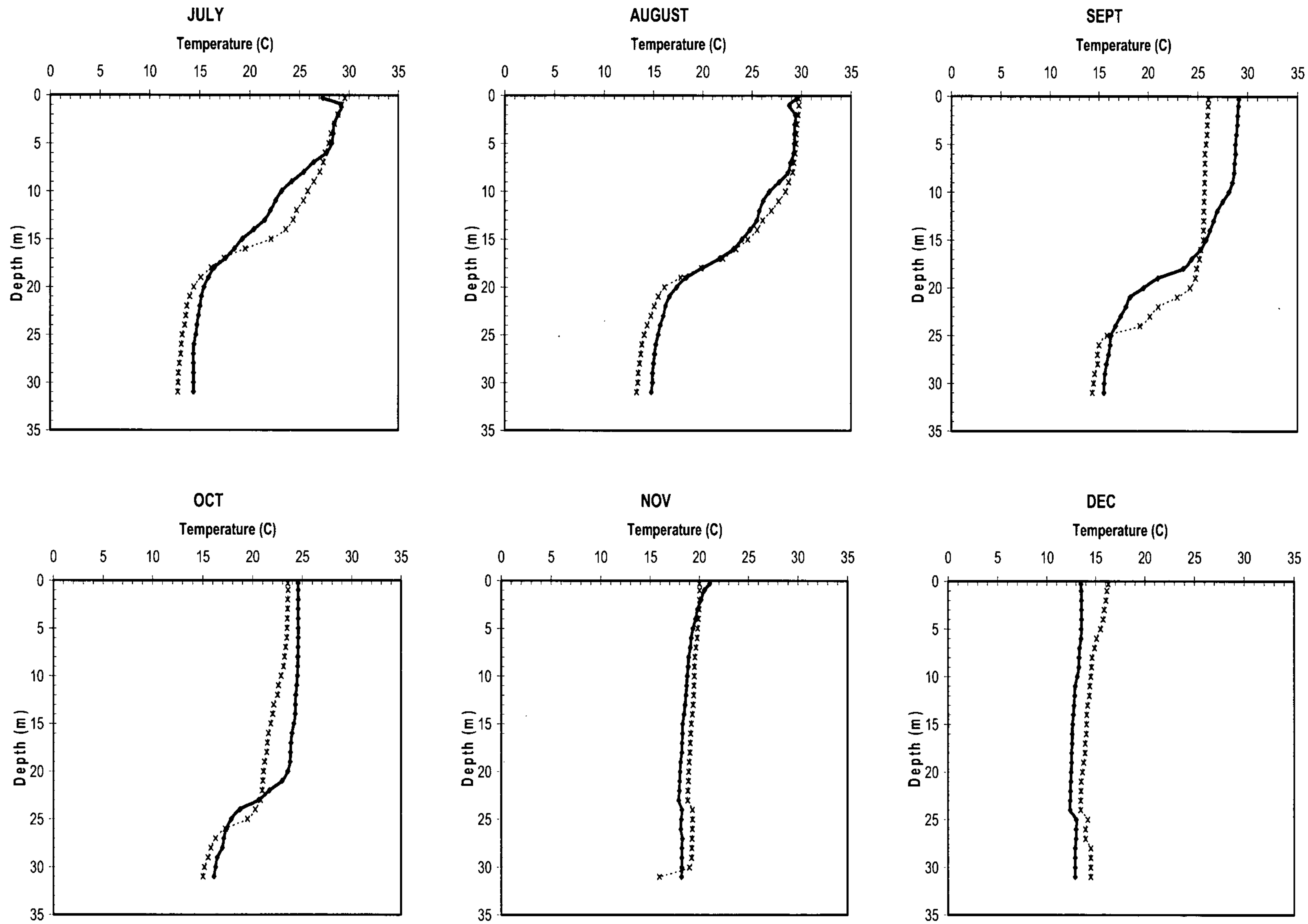


Figure 2-3. (Continued).

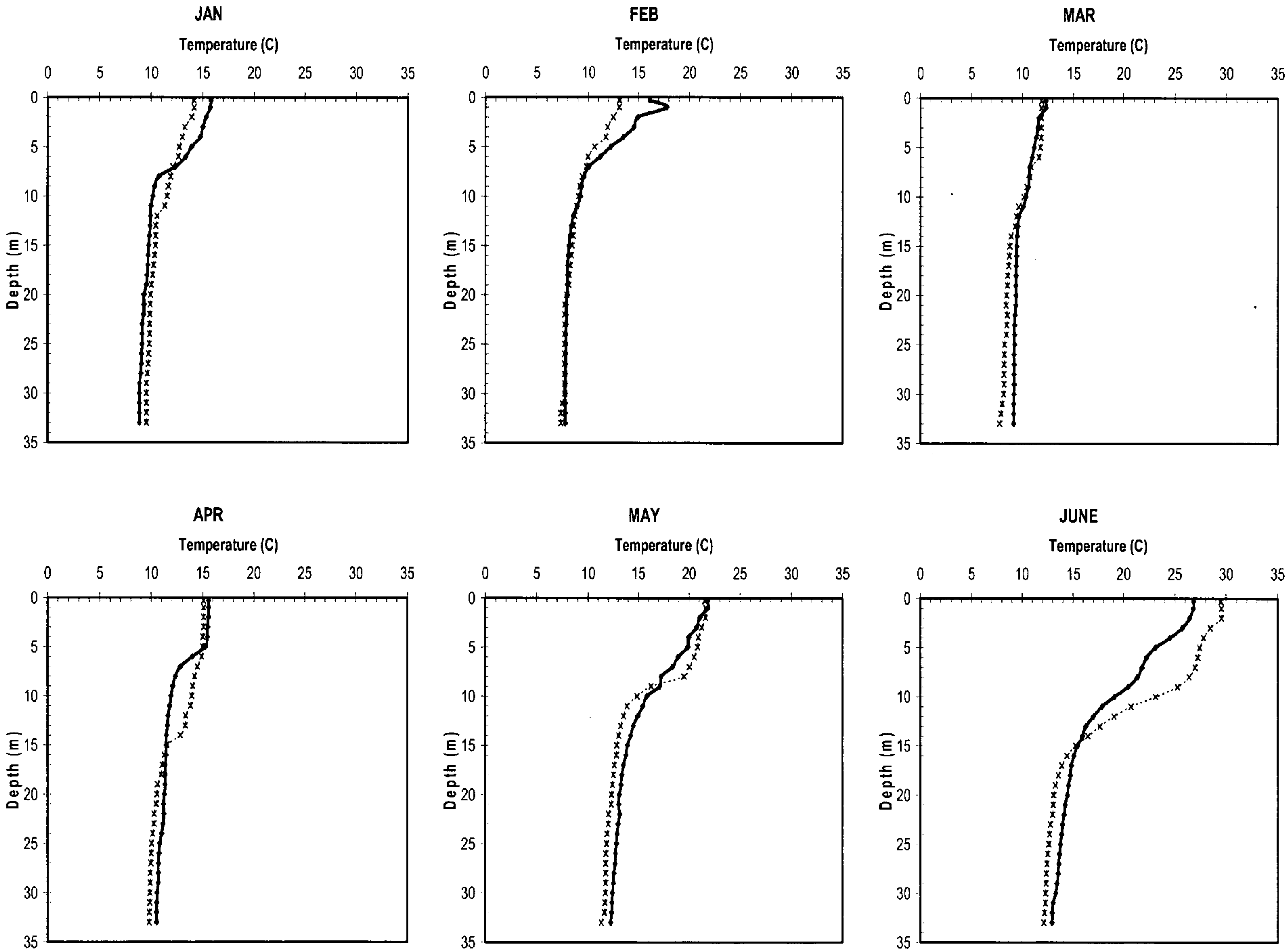


Figure 2-4. Monthly mean temperature profiles for the McGuire Nuclear Station mixing zone in 2004 (xx) and 2005 (♦♦).

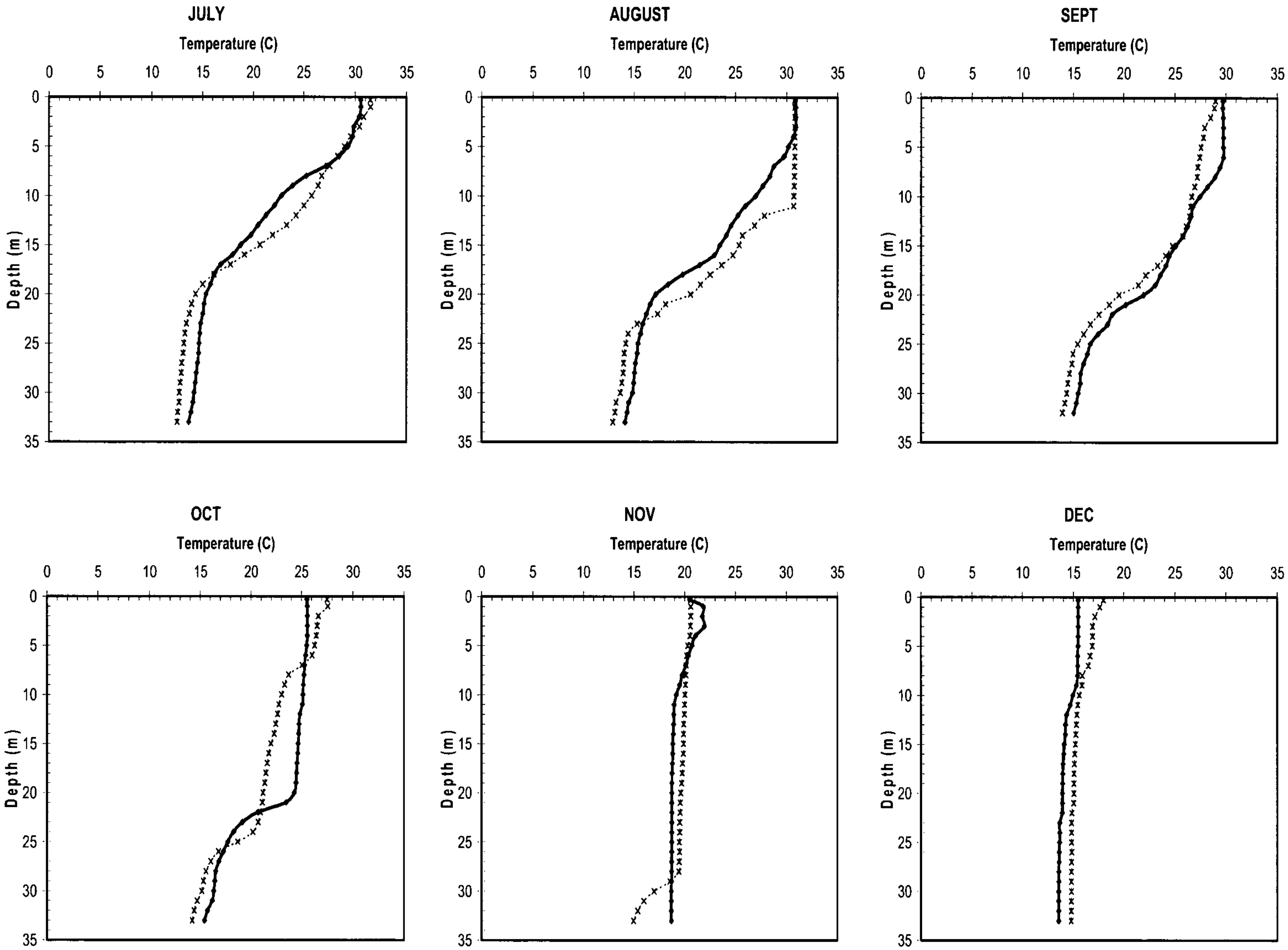


Figure 2-4. (Continued).

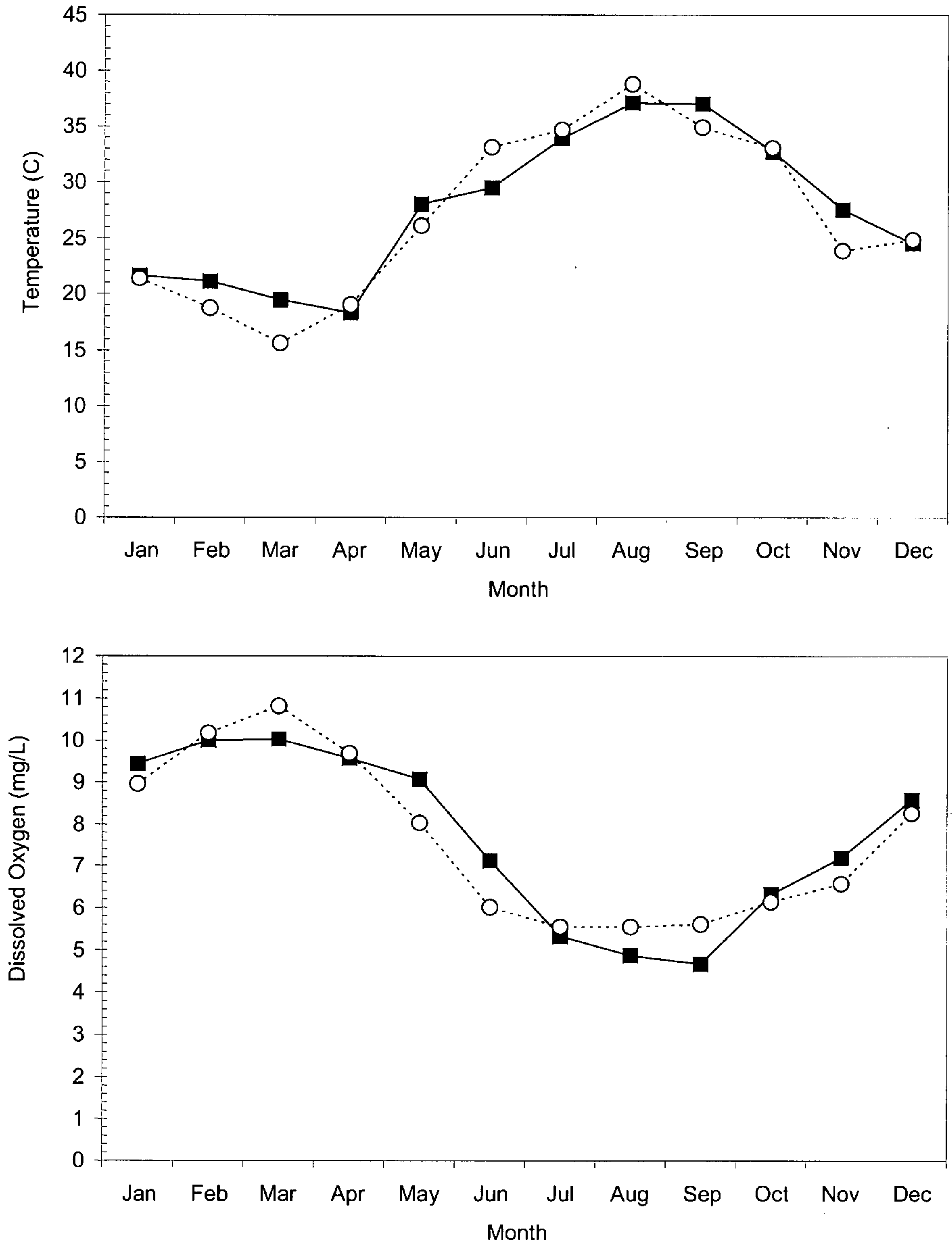


Figure 2-5. Monthly surface (0.3 m) temperature and dissolved oxygen data at the discharge location (loc. 4.0) in 2004 (○) and 2005 (■).

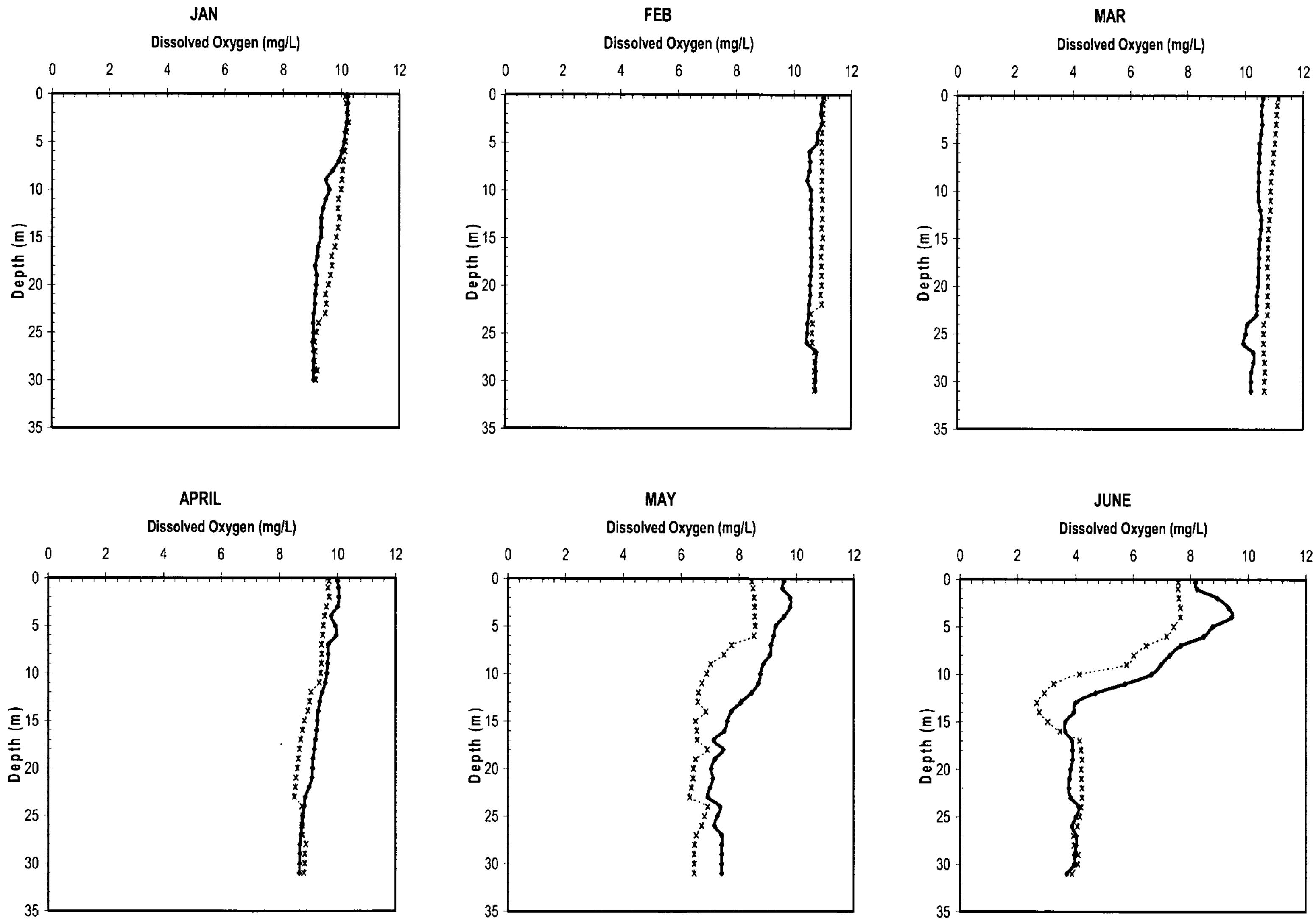


Figure 2-6. Monthly mean dissolved oxygen profiles for the McGuire Nuclear Station background zone in 2004 (xx) and 2005 (♦♦) and 2005.

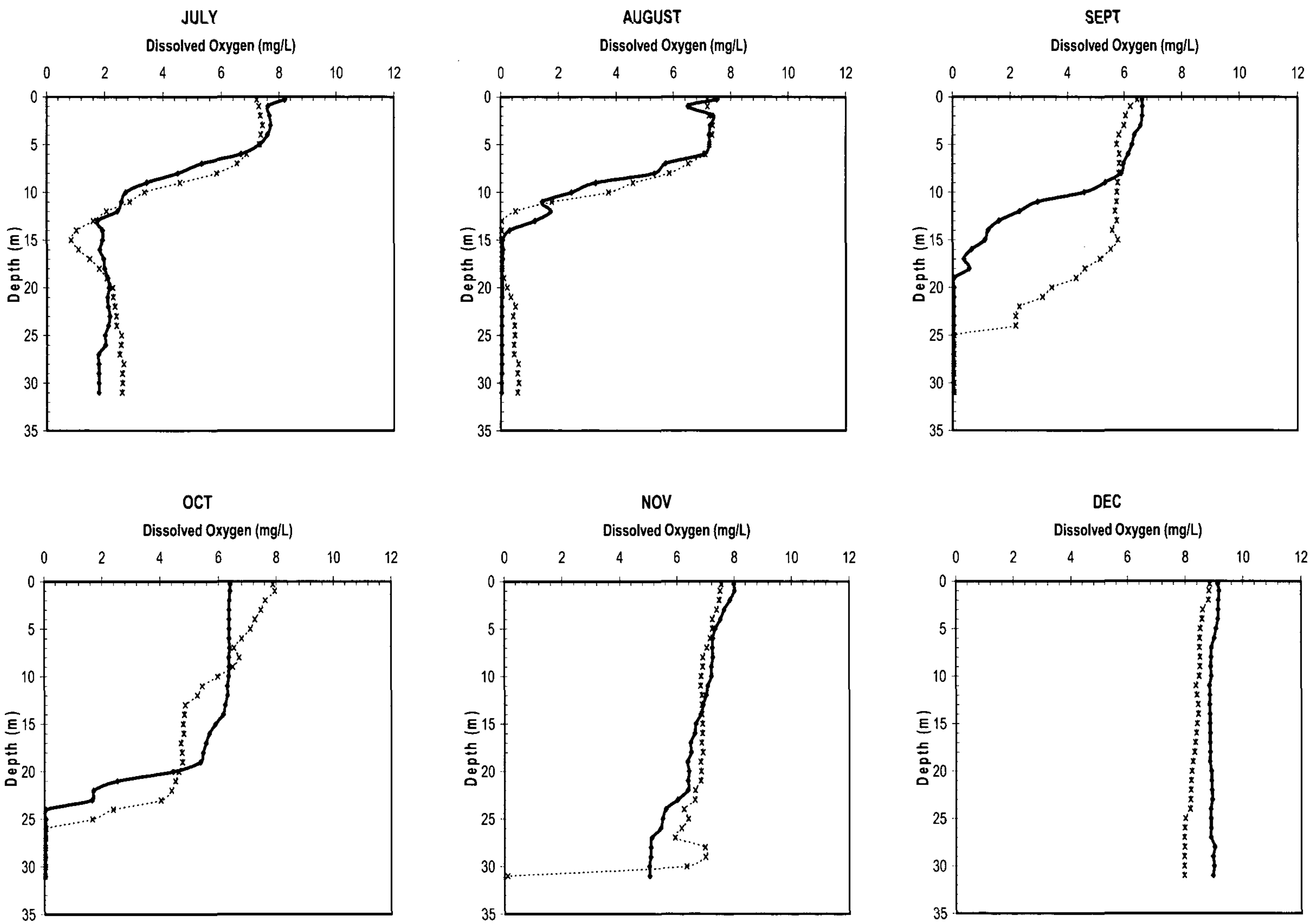


Figure 2-6. (Continued).

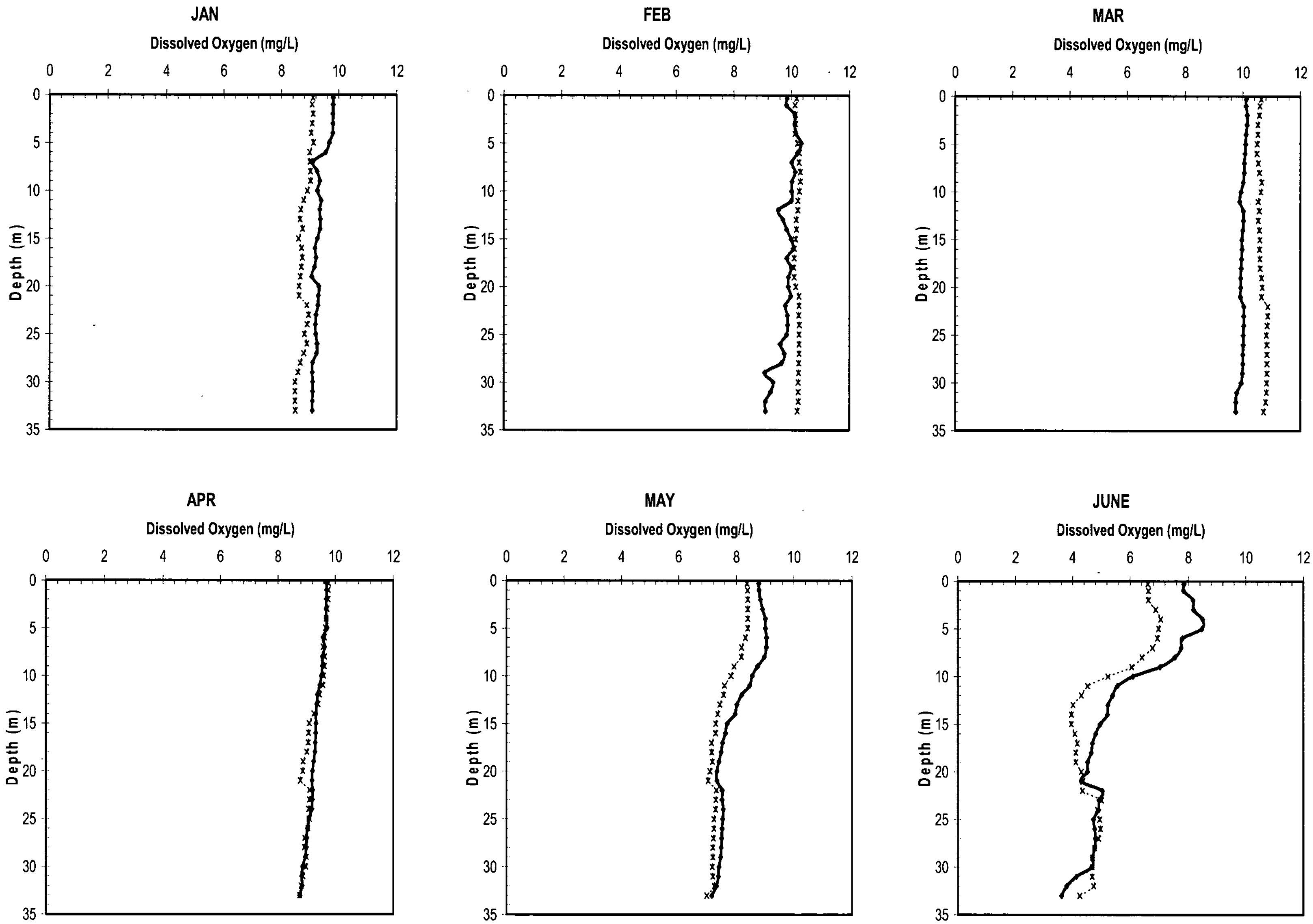


Figure 2-7. Monthly mean dissolved oxygen profiles for the McGuire Nuclear Station mixing zone in 2004 (xx) and 2005 (♦♦).

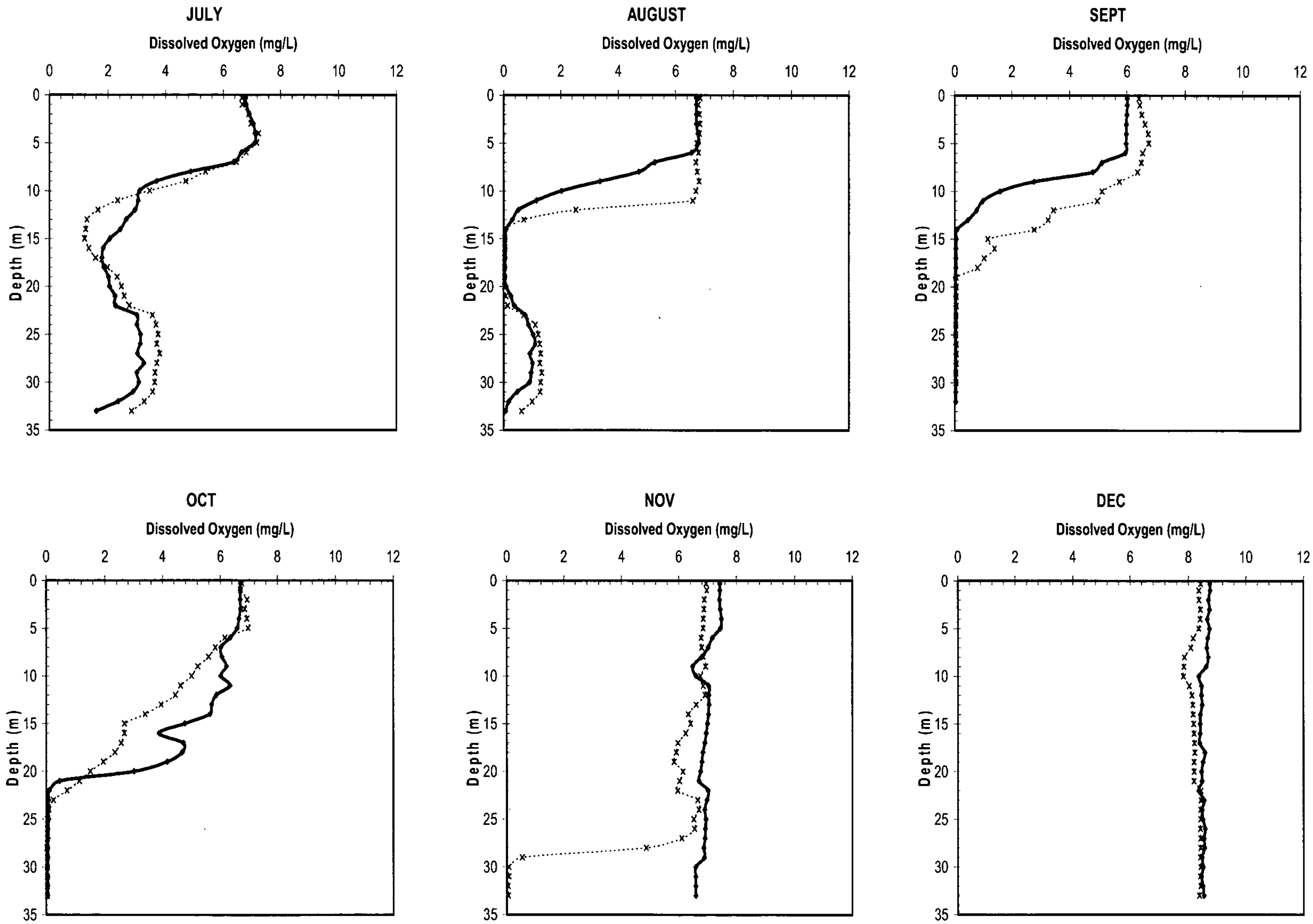


Figure 2-7. (Continued).

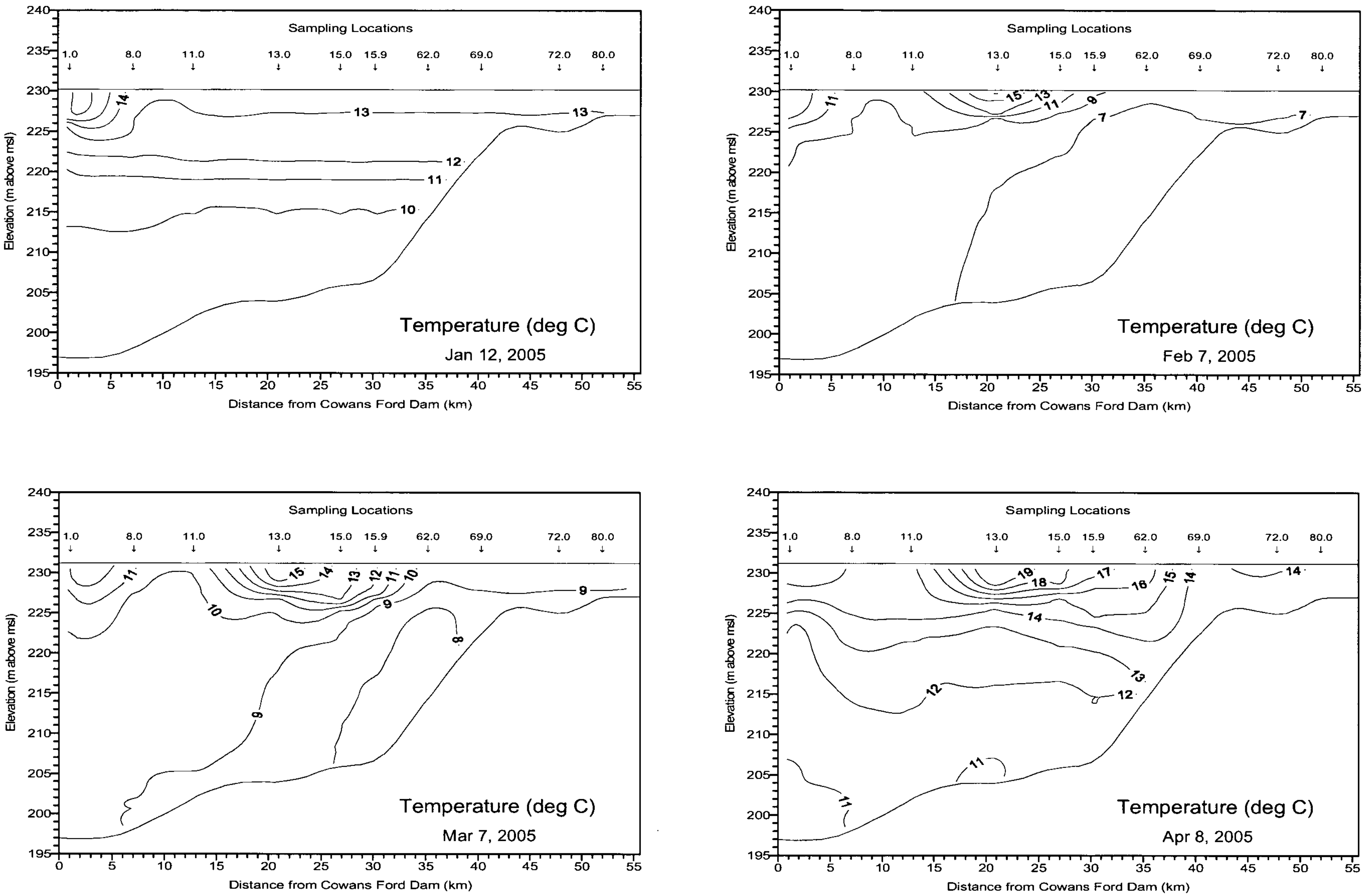


Figure 2-8. Monthly reservoir-wide temperature isotherms for Lake Norman in 2005.

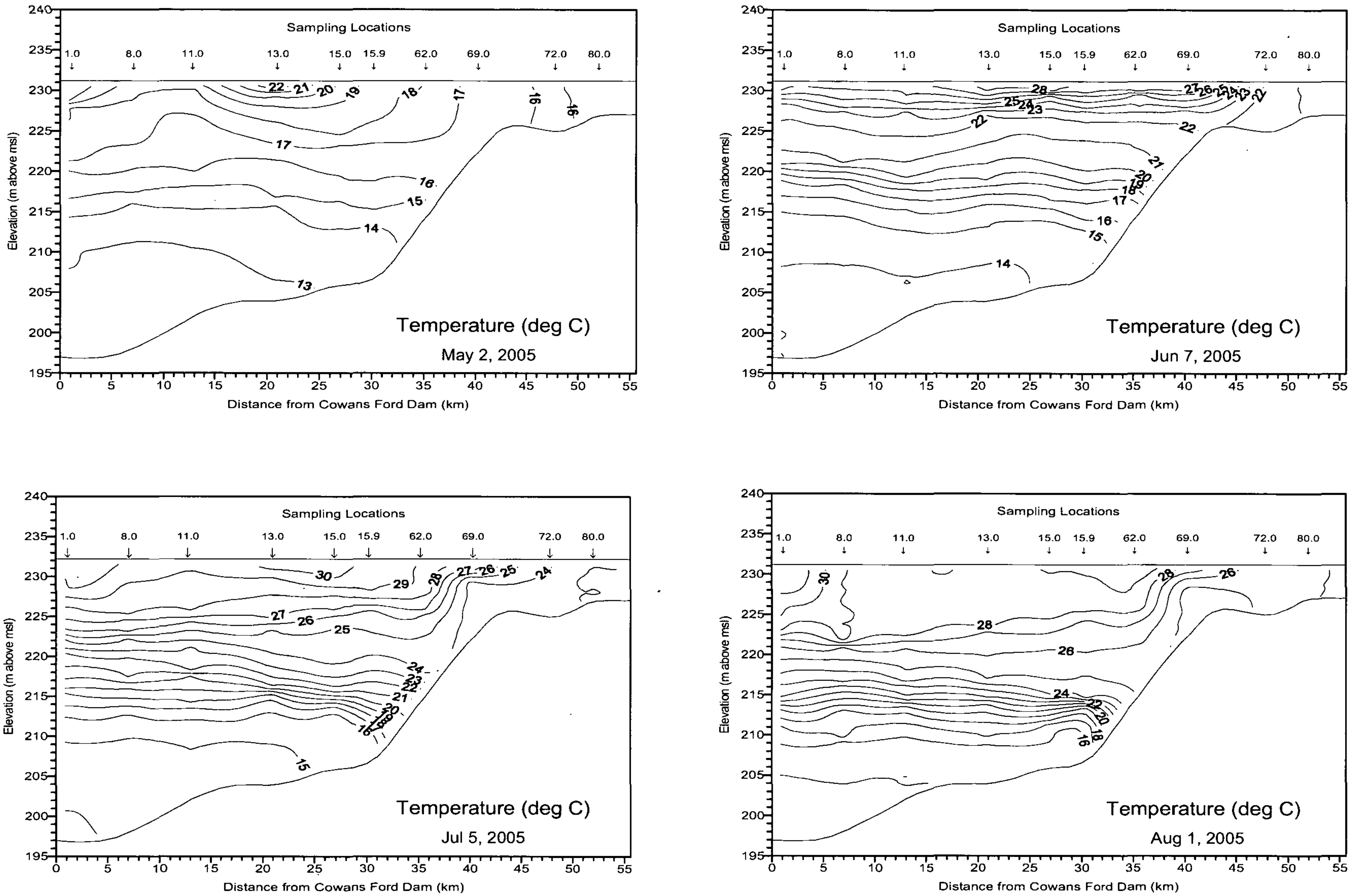


Figure 2-8. (Continued).

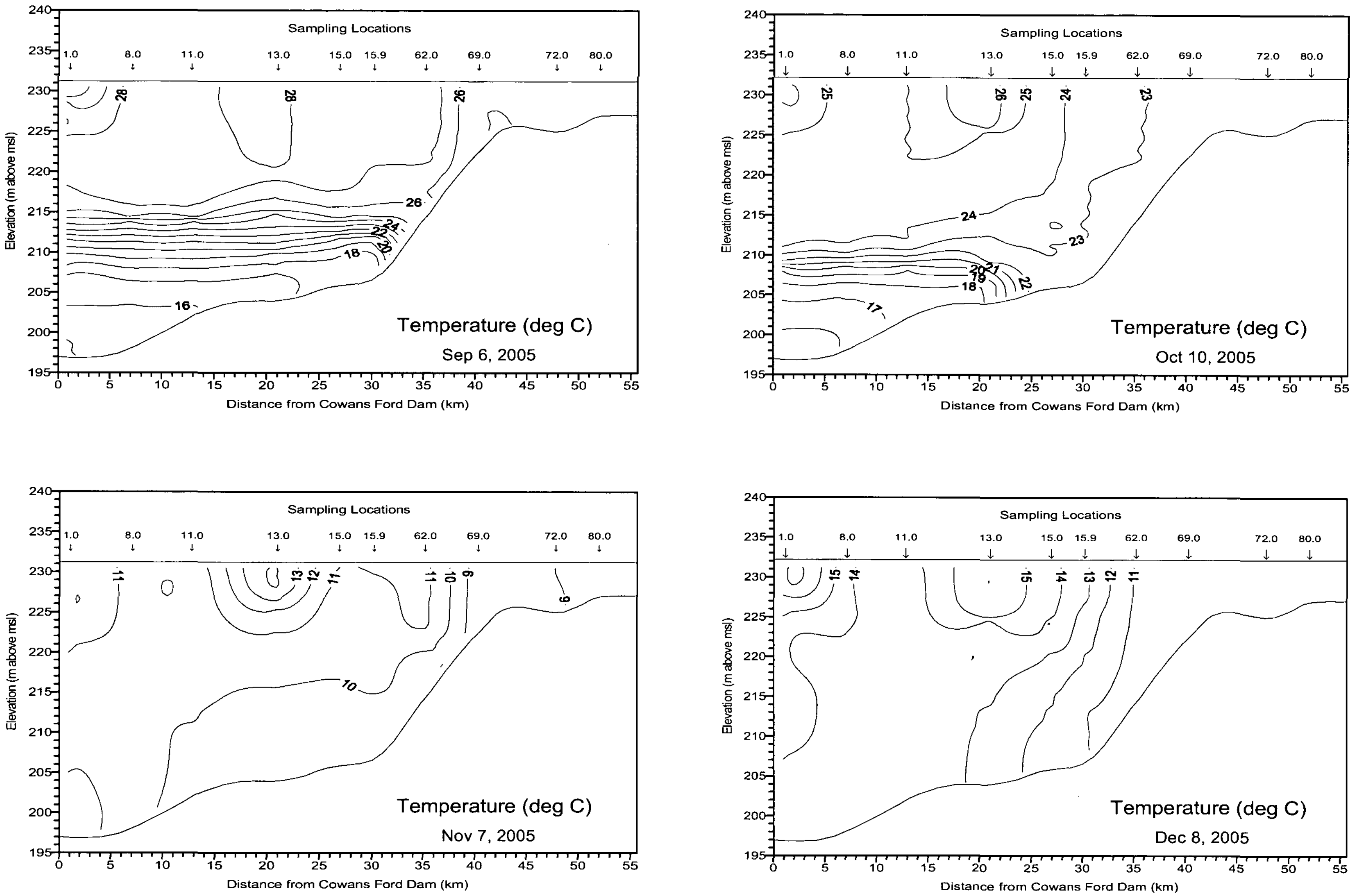


Figure 2-8. (Continued).

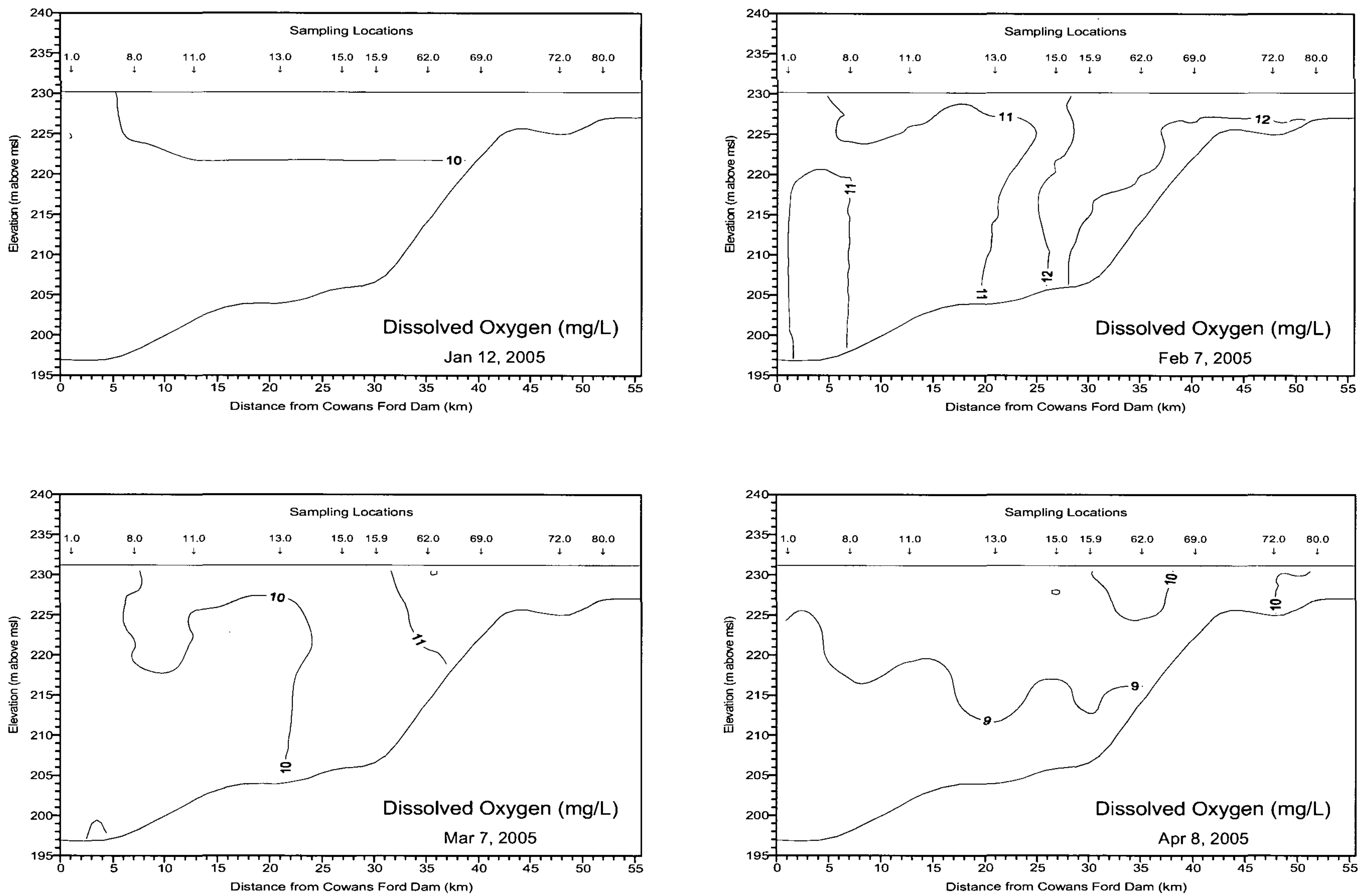


Figure 2-9. Monthly reservoir-wide dissolved oxygen isopleths for Lake Norman in 2005.

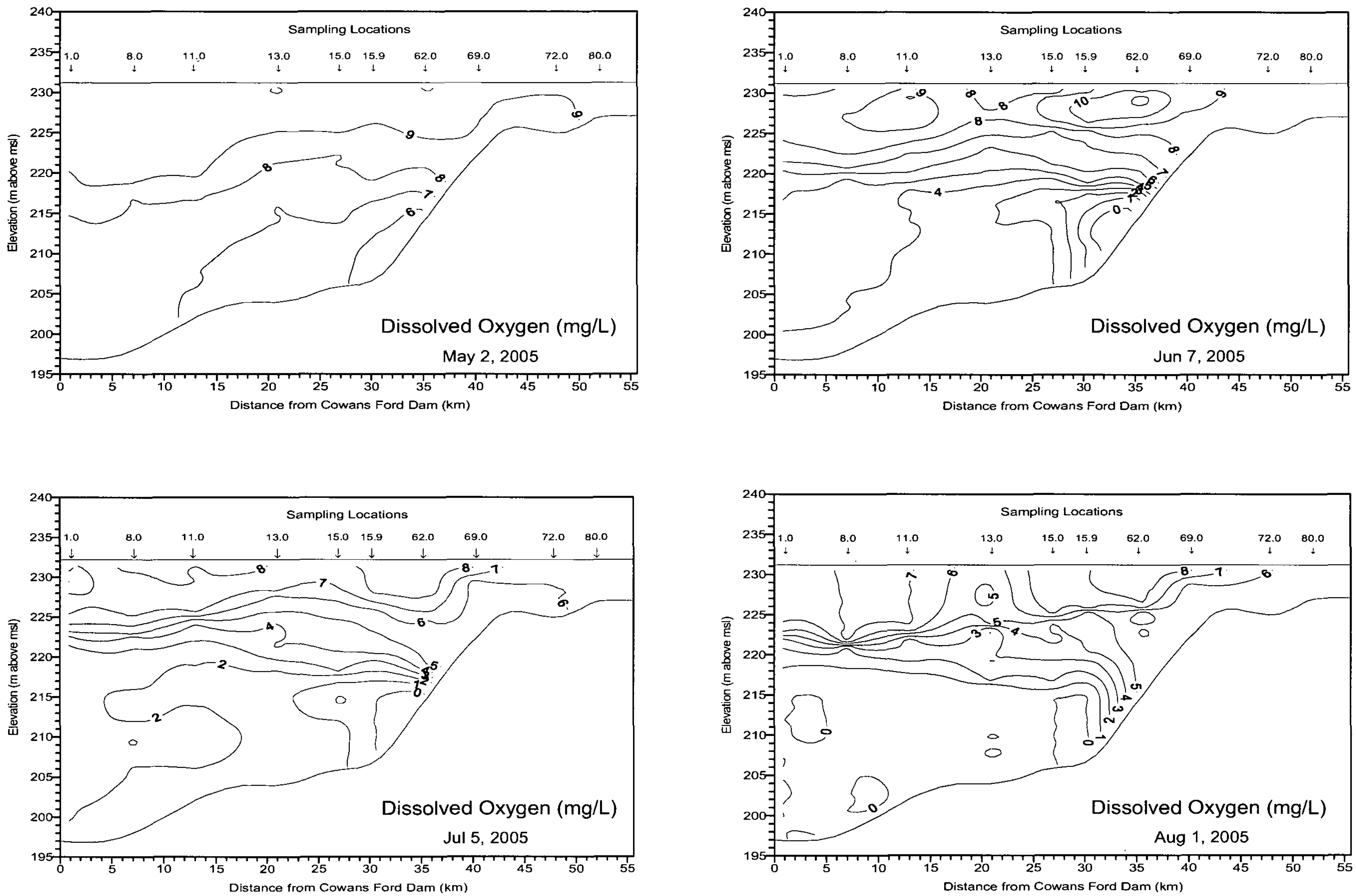


Figure 2-9. (Continued).

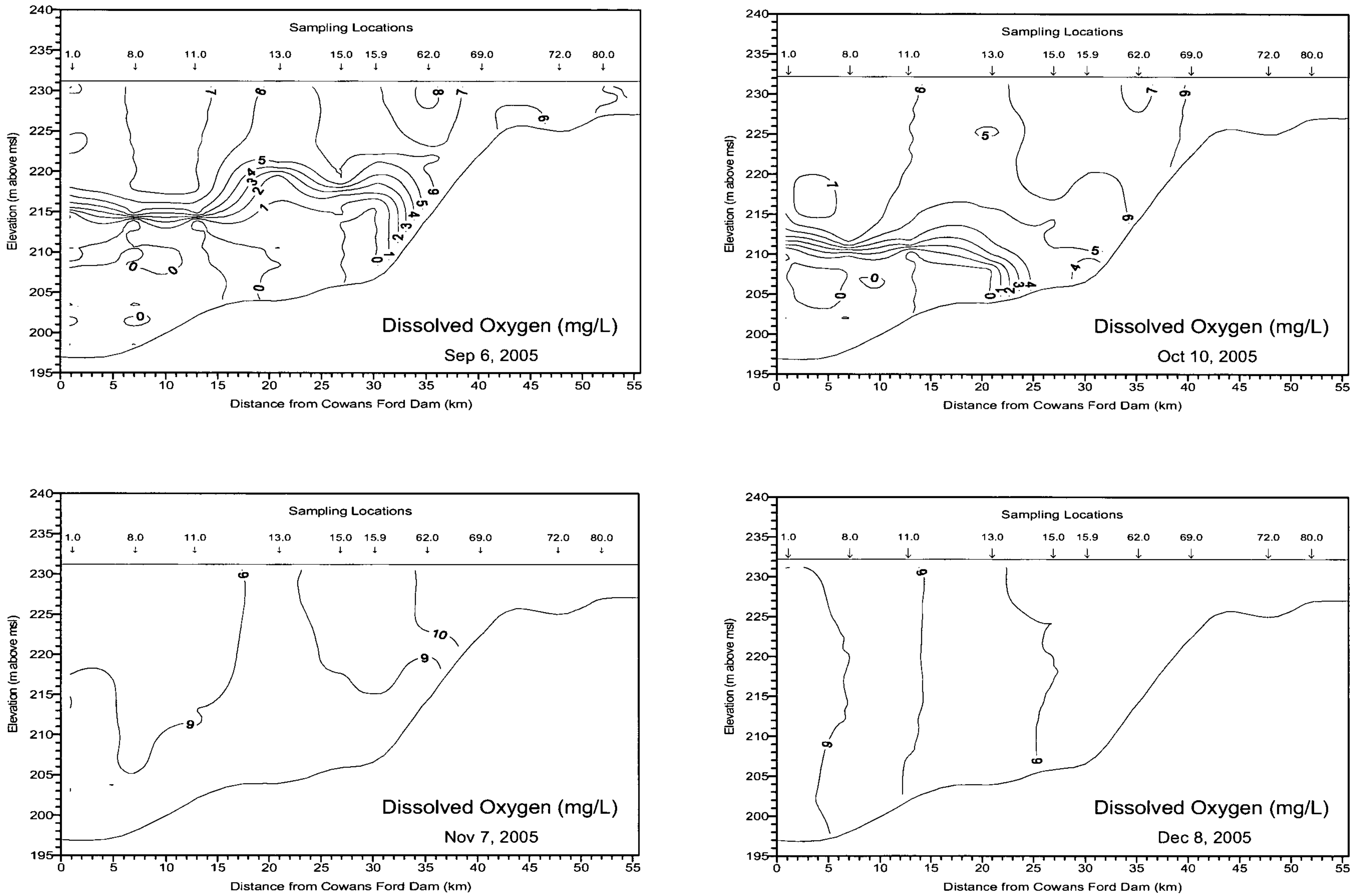


Figure 2-9. (Continued).

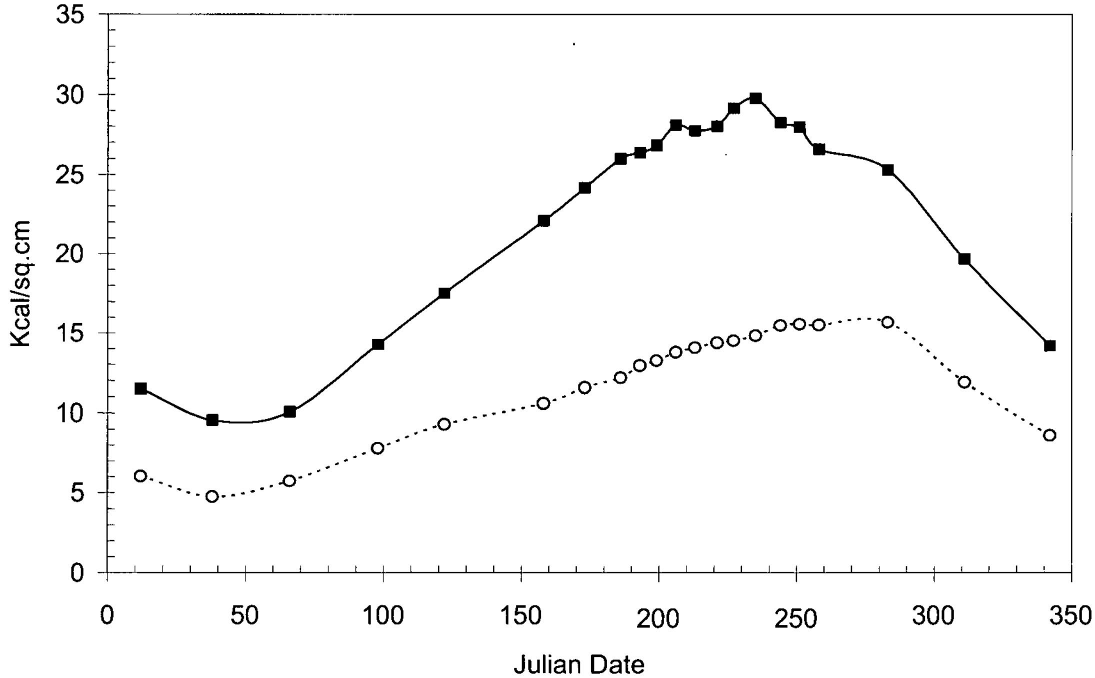


Figure 2-10a. Heat content of the entire water column (■) and the hypolimnion (○) in Lake Norman in 2005.

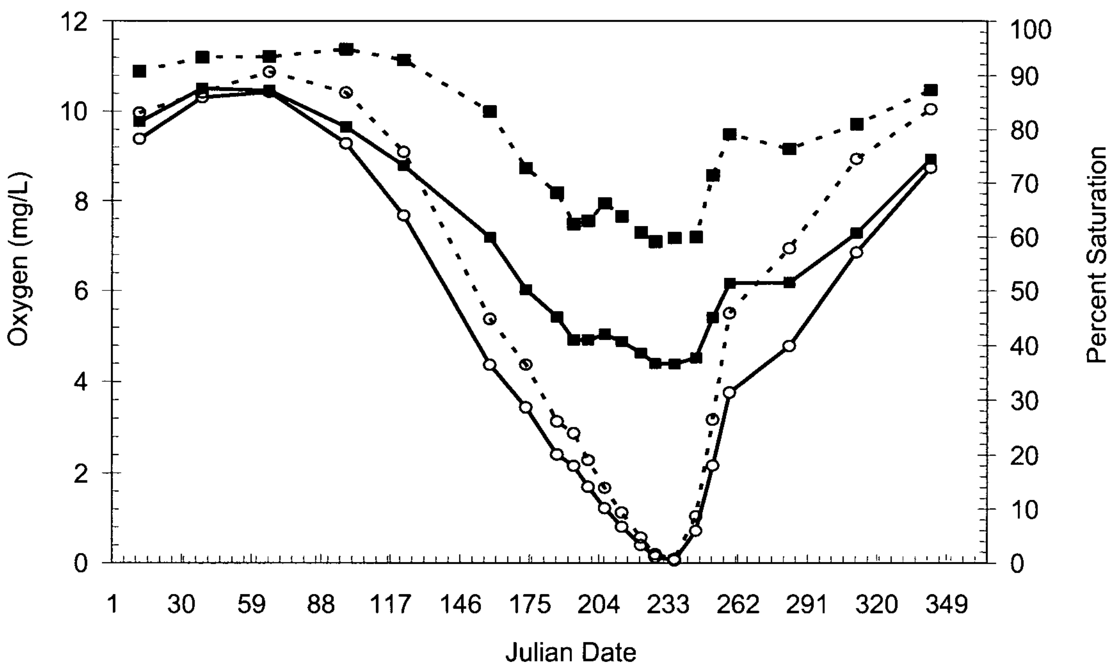


Figure 2-10b. Dissolved oxygen content (–) and percent saturation (---) of the entire water column (■) and the hypolimnion (○) of Lake Norman in 2005.

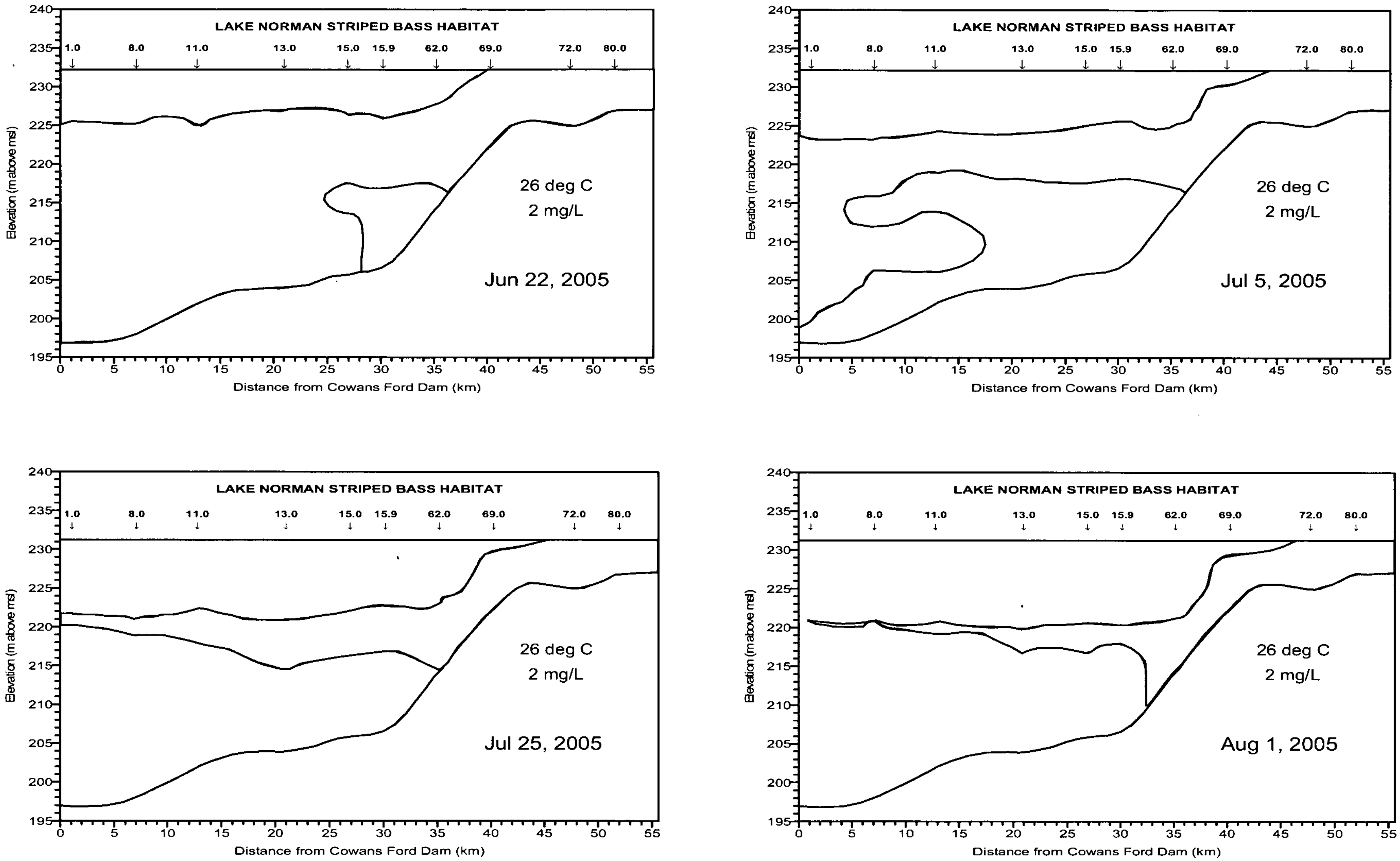


Figure 2-11. Striped bass habitat (shaded areas; temperatures ≤ 26 °C and dissolved oxygen ≥ 2 mg/L) in Lake Norman, summer 2005.

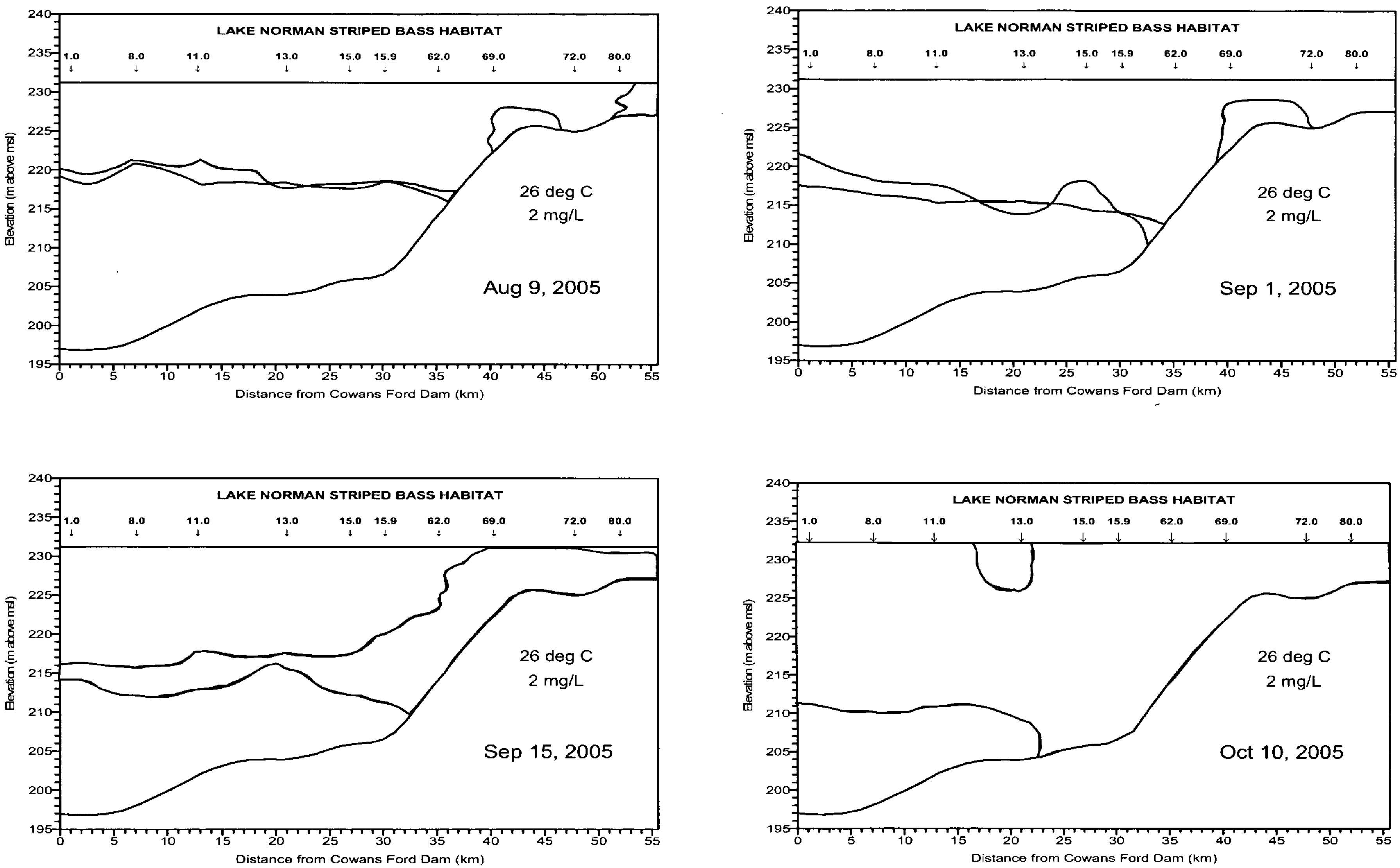


Figure 2-11. (Continued).

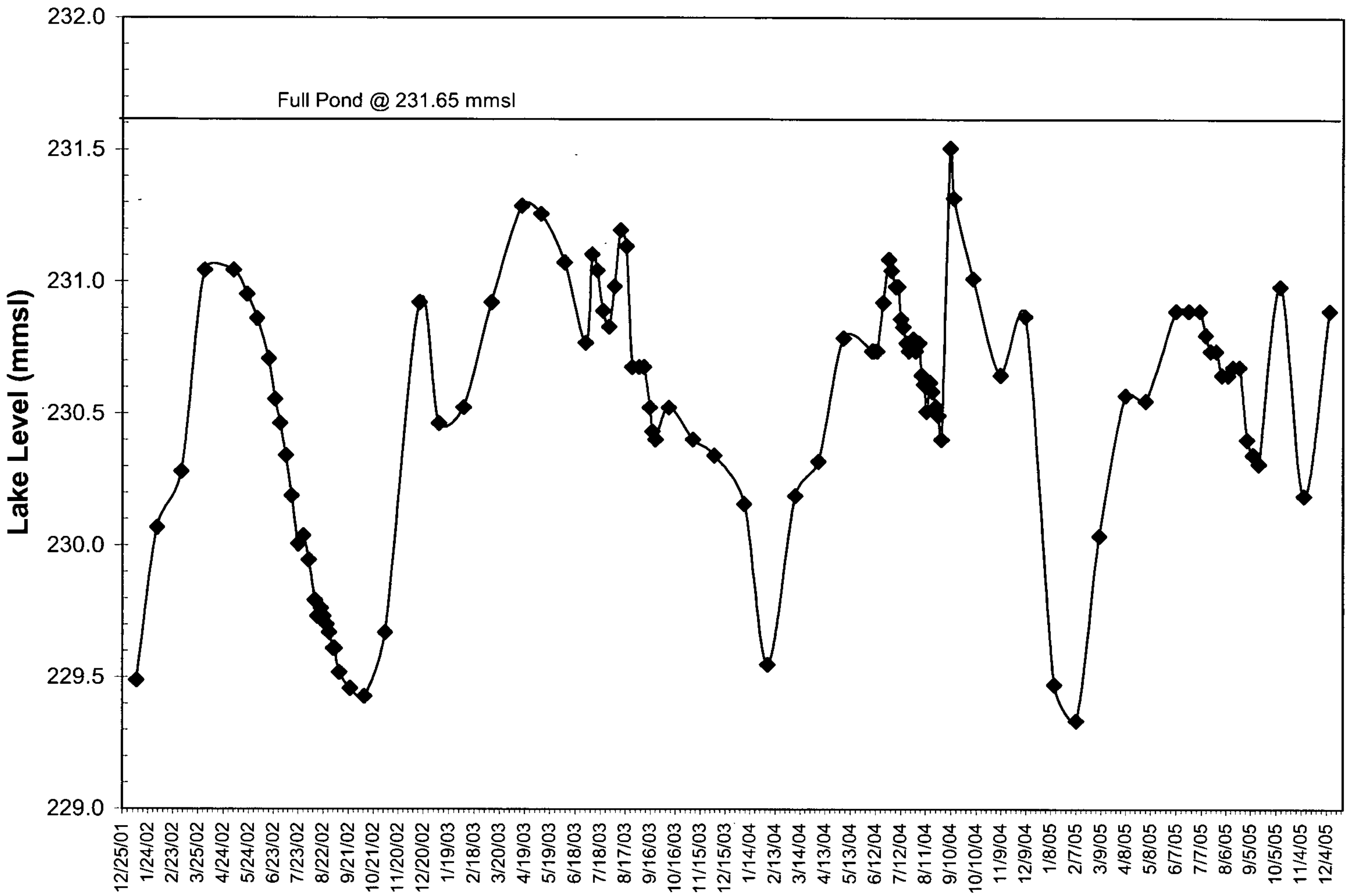


Figure 2-12. Lake Norman lake levels, expressed in meters above mean sea level (mmsl) for 2002, 2003, 2004 and 2005. Lake level data correspond to the water quality sampling dates over this time period.

CHAPTER 3

PHYTOPLANKTON

INTRODUCTION

Phytoplankton standing crop parameters were monitored in 2005 in accordance with the NPDES permit for McGuire Nuclear Station (MNS). The objectives of the phytoplankton section of the Lake Norman Maintenance Monitoring Program are to:

1. Describe quarterly patterns of phytoplankton standing crop and species composition throughout Lake Norman; and
2. Compare phytoplankton data collected during this study (February, May, August, and November 2005) with data collected in other years during these months.

In previous studies on Lake Norman considerable spatial and temporal variability in phytoplankton standing crops and taxonomic composition have been reported (Duke Power Company 1976, 1985; Menhinick and Jensen 1974; Rodriguez 1982). Rodriguez (1982) classified the lake as oligo-mesotrophic (low to intermediate productivity) based on phytoplankton abundance, distribution, and taxonomic composition. Past Maintenance Monitoring Program studies have confirmed this classification.

METHODS AND MATERIALS

Quarterly sampling was conducted at Locations 2.0, 5.0 (mixing zone), 8.0, 9.5, 11.0, 13.0, 15.9, and 69.0 in Lake Norman (Figure 2-1). Duplicate grabs from 0.3, 4.0, and 8.0 m (i.e., the estimated euphotic zone) were taken and then composited at all but Location 69.0, where grabs were taken at 0.3, 3.0, and 6.0 m due to the depth. Sampling was conducted in February, May, August, and November 2005. Secchi depths were recorded from all sampling locations. Phytoplankton density, biovolume, and taxonomic composition were determined for samples collected at Locations 2.0, 5.0, 9.5, 11.0, and 15.9; chlorophyll *a* concentrations and seston dry and ash-free dry weights were determined for samples from all locations. Chlorophyll *a* and total phytoplankton densities and biovolumes were used in determining phytoplankton standing crop. Field sampling and laboratory methods used for chlorophyll *a*, seston dry weights and population identification and enumeration were identical to those used by Rodriguez (1982). Data collected in 2005 were compared with corresponding data from quarterly monitoring beginning in August 1987.

RESULTS AND DISCUSSION

Standing Crop

Chlorophyll a

Chlorophyll *a* concentrations (mean of two replicate composites) ranged from a low of 2.30 µg/L at Location 2.0 in November, to a high of 11.12 µg/L at Location 15.9 in February (Table 3-1, Figure 3-1). All values were below the North Carolina water quality standard of 40 µg/L (NCDENR 1991). Lake-wide mean chlorophyll concentrations during all sampling periods were within ranges of those reported in previous years (Figure 3-2). Based on quarterly mean chlorophyll concentrations, the trophic level of Lake Norman was in the mesotrophic (intermediate) range during February, May, and August, and in the oligotrophic (low) range in November 2005. Over 23% of individual chlorophyll values were less than 4 µg/L (oligotrophic) while all of the remaining chlorophyll concentrations were between 4 and 12 µg/L (mesotrophic). Lake-wide quarterly mean concentrations of below 4 µg/L have been recorded on eleven previous occasions, while lake-wide mean concentrations of greater than 12 µg/L were only recorded during May of 1997 and 2000 (Duke Power 2001).

During 2005 chlorophyll *a* concentrations showed a certain degree of spatial variability. Maximum concentrations were observed at Location 15.9 during all sampling periods. Minimum concentrations occurred at Location 69.0 in February and May, Location 5.0 in August, and Location 2.0 in November (Table 3-1). The trend of increasing chlorophyll concentrations from down-lake to up-lake, which had been observed during many previous years, was apparent through Location 15.9 during all quarters of 2005 (Table 3-1, Figure 3-1). Chlorophyll concentrations declined sharply from Location 15.9 to location 69.0. Flow in the riverine zone of a reservoir is subject to wide fluctuations depending, ultimately, on meteorological conditions (Thornton, et al. 1990), although influences may be moderated due to upstream dams. During periods of high flow, algal production and standing crop would be depressed, due in great part, to washout. Conversely, production and standing crop would increase during periods of low flow and high retention time. Over long periods of low flow, production and standing crop would gradually decline once more. These conditions result in the comparatively high variability in chlorophyll concentrations observed between Locations 15.9 and 69.0 throughout the year, as opposed to Locations 2.0 and 5.0 which were usually similar during each sampling period.

Average quarterly chlorophyll concentrations during the period of record (August 1987 – November 2005) have varied considerably, resulting in moderate to wide historical ranges. During February 2005, chlorophyll values at all locations were in the mid to upper historical ranges (Figure 3-3). Long-term February peaks at Locations 2.0 through 9.5 occurred in 1996, while the long-term February peak at Location 11.0 was observed in 1991. The highest February value at location 69.0 occurred in 2001. All locations had higher chlorophyll concentrations in February 2005 than in February 2004 (Duke Power 2005).

During May chlorophyll concentrations at Locations 2.0 through 9.5 were in the upper historical ranges, while concentrations at Locations 11.0 through 69.0 were in the mid range (Figure 3-3). Long-term May peaks at Locations 2.0 and 9.5 occurred in 1992; at Location 5.0 in 1991; at Locations 8.0, 11.0, and 13.0 in 1997; at Location 15.9 in 2000; and at Location 69.0 in 2001. May 2005 chlorophyll concentrations at all locations were higher than those of 2004 (Duke Power 2005).

August chlorophyll concentrations at Locations 2.0, 11.0, and 15.9 were in the mid range for that time of year, while concentrations at Locations 5.0, 8.0, 9.5, and 69.0 were in the low range for August (Figure 3-4). The concentration at Location 13.0 was in the high range. Long-term August peaks at Locations 2.0 and 5.0 were observed in 1998, while year-to-year maxima at Locations 8.0 and 9.5 occurred in 1993. Long-term August peaks at Locations 11.0 and 13.0 were observed in 1991 and 1993, respectively. The highest August chlorophyll concentration from Location 15.9 was observed in 1998, while Location 69.0 experienced its long-term August peak in 2001. Locations, 11.0, 13.0, and 15.9 had higher chlorophyll concentrations in August 2005 than in August of the previous year, while concentrations at other locations were lower than in August 2004 (Duke Power 2005).

During November 2005 all locations had chlorophyll concentrations in the low range for that month (Figure 3-4). In fact, the long-term minima for Locations 8.0 and 11.0 were recorded in November 2005. Long-term November peaks at Locations 5.0, 8.0, and 11.0 through 15.9 occurred in 1996, while November maxima at Locations 2.0 and 9.5 were observed in 1997. The highest November chlorophyll concentration at location 69.0 occurred in 1991.

November 2005 chlorophyll concentrations at all locations were lower than during November 2004 (Duke Power 2005).

Total Abundance

Density and biovolume are measurements of phytoplankton abundance. The lowest density (575 units/mL) occurred at Location 5.0 in November, while the lowest biovolume (383 mm^3/m^3) during 2005 was recorded from Location 2.0 during the same month (Table 3-2, Figure 3-1). The maximum density (5,168 units/mL) was observed at Location 15.9 in August and the highest biovolume (4,912 mm^3/m^3) was recorded from this same location in May. Standing crop values during February and May 2005 were higher than those of 2004, while values from August and November were generally lower than those of the previous year (Duke Power 2005). Phytoplankton densities and biovolumes during 2005 never exceeded the NC guideline for algae blooms of 10,000 units/mL density or 5,000 mm^3/m^3 biovolume (NCDEHNR 1991). Densities and biovolumes in excess of NC guidelines were recorded in 1987, 1989, 1997, 1998, 2000, and 2003 (Duke Power Company 1988, 1990; Duke Power 1998, 1999, 2001, 2004a). During most sampling periods phytoplankton densities and biovolumes demonstrated a spatial trend similar to that of chlorophyll; that is, lower values at down-lake locations verses up-lake locations (Table 3-2, Figure 3-1).

Low chlorophyll concentrations and algae standing crops in November may have been due, in part, to exceptionally high rainfall during the month before sampling. The rainfall total for October was over twice the historical average (Figure 2-2b). High rainfall and subsequent flushing would have caused a depression in algae throughout the system.

Seston

Seston dry weights represent a combination of algal matter, and other organic and inorganic material. Dry weights during all but May 2005 were generally lower than those of 2004, while dry weights in May were most often higher than in the previous year. As was observed in algal standing crops, a general pattern of increasing values from down-lake to up-lake was observed in all quarters to varying extents (Figure 3-1). From 1995 through 1997 seston dry weights had been increasing (Duke Power 1998). Values from 1998 through 2001 represented a reversal of this trend, and were in the low range at most locations during 1999 through 2001 (Duke Power 2002). Low dry weights during these years were likely a result of prolonged drought conditions (Figure 2-2a). Since 2002, dry weights have gradually increased throughout the lake.

Seston ash-free dry weights represent organic material and may reflect trends of algal standing crops. This relationship held true in 2005, at least through Location 15.9 in the upper lake; however chlorophyll concentrations dropped drastically between Locations 15.9 and 69.0, while ash-free dry weights generally showed gradual increases between these locations during all periods (Tables 3-2 and 3-3). This would indicate that the principle component of ash-free dry weights from Location 69.0 were non-algal organic materials. The proportions of organic material among solids during 2005 were most often higher than in 2004. From 1996 through 2001 there was a trend of decreasing ash-free dry weight to dry weight ratios, followed by a trend of increasing ratios through 2005, indicating higher organic contributions to total solids over the last four years (Duke Power Company 1997; Duke Power 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005).

Secchi Depths

Secchi depth is a measure of light penetration. Secchi depths were often the inverse of suspended sediment (seston dry weight), with the shallowest depths at Locations 13.0 through 69.0 and deepest from Locations 9.5 through 2.0 down-lake. Depths ranged from 0.88 m at Location 69.0 in November, to 2.60 m at Location 9.5 in February (Table 3-1). The lake-wide mean Secchi depth during 2005 was slightly lower than in 2004, and was within historical ranges for the years since measurements were first reported in 1992. The deepest lake-wide mean Secchi depth was recorded for 1999 (Duke Power Company 1993, 1994, 1995, 1996, 1997; Duke Power 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005). Lower overall Secchi depths during 2005 as compared to 2004 were due to relatively low Secchi depths in May 2005 as compared to May 2004.

Community Composition

One indication of "balanced indigenous populations" in a reservoir is the diversity, or number of taxa observed over time. Lake Norman typically supports a rich community of phytoplankton species. This was certainly true in 2005. Ten classes comprising 100 genera and 242 species, varieties, and forms of phytoplankton were identified in samples collected during 2005, as compared to 90 genera and 210 lower taxa identified in 2004 (Table 3-4). The 2005 total represented the highest number of individual taxa recorded in any year since monitoring began in 1987 (Duke Power 2004a). Fourteen taxa previously unrecorded during the Maintenance Monitoring Program were identified during 2005.

Species Composition and Seasonal Succession

The phytoplankton community in Lake Norman may vary both seasonally and spatially within the reservoir. In addition, considerable variation may occur between years for the same months sampled.

During February 2005, cryptophytes (Cryptophyceae) dominated densities at all locations (Table 3-5, Figures 3-5 through 3-9). During most previous years, cryptophytes, and occasionally diatoms, dominated February phytoplankton samples in Lake Norman. The most abundant cryptophyte during February 2005 was the small flagellate *Rhodomonas minuta*. *R. minuta* has been one of the most common and abundant forms observed in Lake Norman samples since monitoring began in 1987. Cryptophytes are characterized as light limited, often found deeper in the water column, or near surface under low light conditions, which are common during winter (Lee 1989).

In May, diatoms (Bacillariophyceae) were dominant at all locations (Table 3-5, Figures 3-5 through 3-9). The most abundant diatom was the pennate, *Fragillaria crotonensis*. Diatoms have typically been the predominant forms in May samples of previous years; however, cryptophytes dominated May samples in 1988, and were co-dominants with diatoms in May 1990, 1992, 1993, and 1994 (Duke Power Company 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997; Duke Power 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005).

During August 2005 green algae (Chlorophyceae) dominated densities at all locations (Figures 3-5 through 3-9). The most abundant green alga was the small desmid, *Cosmarium asphearosporum* var. *strigosum* (Table 3-7). During August periods of the Lake Norman study prior to 1999, green algae, with blue-green algae (Myxophyceae) as occasional dominants or co-dominants, were the primary constituents of summer phytoplankton assemblages, and the predominant green alga was also *C. asphearosporum* var. *strigosum* (Duke Power Company 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997; Duke Power 1998, 1999). During August periods of 1999 through 2001, Lake Norman phytoplankton assemblages were dominated by diatoms, primarily the small pennate *Anomoeoneis vitrea* (Duke Power 2000, 2001, 2002). *A. vitrea* has been described as typically periphytic, and widely distributed in freshwater habitats. It was described as a major contributor to periphyton communities on natural substrates during studies conducted from 1974 through 1977 (Derwort 1982). The possible causes of this significant shift in summer taxonomic composition were discussed in earlier reports, and included deeper light penetration (the three deepest lake-wide Secchi depths were recorded from 1999 through 2001), extended periods of low water due to draw-down, and shifts in nutrient inputs and concentrations (Duke Power 2000, 2001, 2002). Whatever the cause, the phenomenon was lake-wide, and not localized near MNS or Marshall Steam Station; therefore, it was most likely due to a combination of environmental factors, and not station operations. Since 2002, taxonomic composition has shifted back to green algae predominance (Duke Power 2003, 2004a, 2005).

During November 2005, densities at all locations were again dominated by diatoms, although predominant species varied among locations (Table 3-5, Figures 3-5 through 3-9). The dominant species at Locations 2.0 was the pennate diatom, *Synedra planktonic,* while at Location 5.0, the centrate *Melosira granulate* var. *angustissima* was the most important diatom. At Locations 9.5 and 11.0, diatom populations were dominated by the centric forms, *Cyclotella stelligera* and *Rhyzosolenia* spp., respectively. *Tabellaria fenestrata*, another common pennate, was the dominant diatom at Location 15.9. All of these diatoms have been common and abundant in Lake Norman diatom assemblages during the course of monitoring.

Blue-green algae, which are often implicated in nuisance blooms, were never abundant in 2005 samples. Their overall contribution to phytoplankton densities was slightly higher than in 2004; however, densities of blue-greens seldom exceeded 4% of totals. Prior to 1991, blue-green algae were often dominant at up-lake locations during the summer (Duke Power Company 1988, 1989, 1990, 1991, 1992).

Phytoplankton index

Phytoplankton indexes have been used with varying degrees of success ever since the concept was formalized by Kolkwitz and Marsson in 1902 (Hutchinson 1967). Nygaard (1949) proposed a series of indexes based on the number of species in certain taxonomic categories (Divisions, Classes, and Orders). The Myxophycean index was selected to help determine long-term changes in the trophic status of Lake Norman. This index is a ratio of the number of blue-green algae taxa to desmid taxa, and was designed to reflect the "potential" trophic status as opposed to chlorophyll, which gives an "instantaneous" view of phytoplankton concentrations (Nygaard 1949). This index was calculated three ways for Lake Norman phytoplankton: On an annual basis for the entire lake, for each sampling period of 2005, and for each location during 2005 (Figure 3-10).

For the most part, the long-term annual Myxophycean index values confirmed that Lake Norman has been primarily in the oligo-mesotrophic range since 1988 (Figure 3-10). Values were in the high, or eutrophic, range in 1989, 1990, and 1992; in the intermediate, or mesotrophic, range in 1991, 1993, 1994, 1996, 1998, 2000, and 2001; and in the low, or oligotrophic, range in 1988, 1995, 1997, 1999, 2002, 2003, and 2004. The index for 2005 fell into the oligotrophic range, and was the lowest annual index value recorded.

The highest index value among sample periods of 2005 was observed in May, and the lowest index value occurred in November (Figure 3-10). The index did reflect the annual maximum and minimum mean chlorophyll concentrations in May and November, respectively; however, August chlorophyll concentrations were often higher than those of February, although February had a much higher index value. The index values for locations during 2005 showed a general increase from down-lake to up-lake locations. This spatial trend was similar to those observed for chlorophyll and standing crop values.

FUTURE STUDIES

No changes are planned for the phytoplankton portion of the Lake Norman Maintenance Monitoring Program.

SUMMARY

In 2005 lake-wide mean chlorophyll *a* concentrations were most often in the mesotrophic range with the exception of November, when chlorophyll concentrations averaged in the oligotrophic range. Chlorophyll concentrations during 2005 were generally within historical ranges. Lake Norman continues to be classified as oligo-mesotrophic based on long-term, annual mean chlorophyll concentrations. Lake-wide mean chlorophyll increased from February to the annual maximum in May, then declined through August to the annual minimum in November. Some spatial variability was observed in 2005; however, maximum chlorophyll concentrations were most often observed up-lake at Location 15.9, while comparatively low chlorophyll concentrations were recorded from mixing zone and mid-lake locations. Location 69.0, the location furthest upstream, demonstrated minimum chlorophyll concentrations in February and May of 2005, and concentrations were always substantially lower than those at Location 15.9 The highest chlorophyll value recorded in 2005, 11.12 µg/L, was well below the NC water quality standard of 40 µg/L.

Phytoplankton densities and biovolumes during 2005 were within historical ranges. In February and May 2005, total phytoplankton densities and biovolumes were higher than those observed during 2004, while the opposite was true in August and November. Phytoplankton densities and biovolumes during 2005 never exceeded the NC guidelines for algae blooms. Standing crop values in excess of bloom guidelines have been recorded during six previous years of the Program. As in past years, high standing crops were usually observed at up-lake locations; while comparatively low values were noted down-lake.

Seston dry and ash-free weights were more often lower in 2005 than in 2004 and down-lake to up-lake differences were apparent during all quarters. Maximum dry and ash-free weights were most often observed at Location 69.0. Minimum values were always noted at Locations 2.0 through 8.0. The proportions of ash-free dry weights to dry weights in 2005 were higher than those of 2004, indicating an increase in organic composition among 2005 samples.

Secchi depths reflected suspended solids, with shallow depths related to high dry weights. The lake-wide mean Secchi depth in 2005 was slightly lower than in 2004 and was within historical ranges recorded since 1992.

Diversity, or numbers of taxa, of phytoplankton had increased since 2004, and the number of individual taxa was the highest yet recorded. The taxonomic composition of phytoplankton communities during 2005 was similar to those of many previous years. Cryptophytes were dominant in February, while diatoms were dominant during May and November. Green algae dominated phytoplankton assemblages during August. Blue-green algae were slightly more abundant during 2005 than during 2004; however, their contribution to total densities seldom exceeded 4%.

The most abundant alga, on an annual basis, was the cryptophyte *Rhodomonas minuta*. The most abundant diatom in May was *Fragillaria crotonensis*. During November, each location supported a different dominant diatom. The small desmid, *Cosmarium asphearosporum* var. *strigosum* was dominant in August 2005. All of these taxa have been common and abundant throughout the Maintenance Monitoring Program.

The phytoplankton index (Myxophycean) characterized Lake Norman as oligotrophic during 2005, and was the lowest annual index value recorded. Quarterly index values increased from February to the highest value in May, then declined through August to the lowest in November. Quarterly values did reflect maximum and minimum chlorophyll concentrations, but were not indicative of chlorophyll concentrations in February and August. Location index values tended to reflect increases in chlorophyll and phytoplankton standing crops from down-lake to mid-lake.

Lake Norman continues to support highly variable and diverse phytoplankton communities. No obvious short-term or long-term impacts of station operations were observed.

Table 3-1. Mean chlorophyll *a* concentrations (μg/L) in composite samples and Secchi depths (m) observed in Lake Norman in 2005.

Chlorophyll *a* Location	FEB	MAY	AUG	NOV
2.0	4.32	6.74	5.27	2.30
5.0	4.38	5.98	3.39	2.31
8.0	5.50	6.69	5.39	2.32
9.5	5.09	7.04	5.74	2.40
11.0	6.84	7.17	7.56	2.44
13.0	6.84	7.25	5.96	4.92
15.9	11.12	9.53	9.42	6.41
69.0	2.59	5.65	6.48	2.58

Secchi depths Location	FEB	MAY	AUG	NOV
2.0	2.20	2.30	2.46	2.41
5.0	2.28	2.20	2.32	2.34
8.0	2.50	1.90	2.47	1.94
9.5	2.60	1.93	2.46	2.10
11.0	1.80	1.87	2.32	1.52
13.0	1.58	1.48	1.30	1.14
15.9	1.60	1.80	1.55	0.89
69.0	1.10	1.16	0.70	0.88

Table 3-2. Total mean phytoplankton densities (units/mL) and biovolumes (mm^3/m^3) from samples collected in Lake Norman during 2005.

Density						
			Locations			
Month	2.0	5.0	9.5	11.0	15.9	Mean
FEB	1546	1655	1833	2482	3782	2260
MAY	3101	2536	3624	3738	4165	3433
AUG	3167	2151	3660	4459	5168	3721
NOV	591	575	615	661	1667	822

Biovolume						
			Locations			
Month	2.0	5.0	9.5	11.0	15.9	Mean
FEB	798	971	861	1926	2757	1462
MAY	3050	1753	3592	3908	4912	3443
AUG	2037	1449	2021	2856	4351	2543
NOV	383	444	669	626	1657	756

Table 3-3. Total mean seston dry and ash free dry weights (in mg/L) from samples collected in Lake Norman during 2005.

				Locations Dry weights					
Month	2.0	5.0	8.0	9.5	11.0	13.0	15.9	69.0	Mean
FEB	2.93	3.13	1.82	2.66	2.06	2.64	2.69	3.76	2.71
MAY	1.19	0.87	1.05	1.30	1.18	2.27	1.87	4.12	1.73
AUG	1.26	1.79	1.20	2.20	1.54	1.67	1.99	6.57	2.28
NOV	1.08	1.27	1.23	1.30	1.41	1.40	1.52	4.43	1.70
				Ash free dry weights					
FEB	0.81	0.80	1.04	0.85	0.97	1.01	1.54	1.43	1.06
MAY	0.55	0.57	0.68	0.69	0.83	1.47	1.07	1.67	0.94
AUG	1.11	1.12	0.90	1.05	1.13	1.15	1.56	2.00	1.25
NOV	0.37	0.52	0.60	0.60	0.55	0.64	0.76	1.06	0.64

Table 3-4. Phytoplankton taxa identified in quarterly samples collected in Lake Norman each year from 1990 to 2005.

TAXON	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
CLASS: CHLOROPHYCEAE																
Acanthosphaera zachariasi Lemm.	X	X		X												
Actidesmium hookeri Reinsch				X												
Actinastrum hantzchii Lagerheim	X	X	X	X	X								X			
Ankistrodesmus braunii (Naeg) Brunn						X	X	X	X	X	X	X	X	X	X	X
A. convolutus Corda											X					
A. falcatus (Corda) Ralfs	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
A. fusiformis Corda sensu Korsch.	X	X	X	X	X											
A. nannoselene Skuja											X					
A. spiralis (Turner) Lemm.	X	X		X				X								
A. spp. Corda		X		X												
Arthrodesmus convergens Ehrenberg						X							X	X		X
A. incus (Breb.) Hassall		X				X			X			X	X	X	X	X
A. octocornis Ehrenberg													X	X	X	X
A. ralfsii W. West															X	X
A. subulatus Kutzing							X	X	X		X	X	X	X	X	X
A. validus v. *increassalatus*															X	
A. spp. Ehrenberg				X	X											
Asterococcus limneticus G. M. Smith	X	X	X	X	X					X			X	X		X
A. superbus (Cienk.) Scherffel															X	
Botryococcus braunii Kutzing		X	X													
Carteria frtzschii Takeda											X			X	X	X
C. globosa Korsch													X		X	
C. spp. Diesing	X		X	X				X						X		
Characium ambiguum Hermann																X
Characium limneticum Lemmerman														X		
C. spp. Braun [1]																
Chlamydomonas spp. Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chlorella vulgaris Beyerink								X								X
Chlorogonium euchlorum Ehrenberg	X						X	X			X				X	X
C. spirale Scherffel & Pascher					X	X									X	X
Closteriopsis longissima W. & W.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Closterium cornu Ehrenberg										X			X			
C. gracile Brebisson							X									
C. incurvum Brebisson					X	X	X	X	X	X	X	X	X	X	X	X
C. parvulum Nageli																X
C. tumidum Johnson											X					
C. spp. Nitzsch	X	X		X												
Coccomonas orbicularis Stein									X				X		X	X
Coelastrum cambricum Archer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. microporum Nageli						X	X		X		X			X		X
C. reticulatum (Dang.) Sinn.										X						
C. sphaericum Nageli	X	X			X		X			X	X	X	X	X	X	X
C. proboscideum Bohlin		X														
C. spp. Nageli	X	X														
Cosmarium angulosum v. *concin.* (Rab) W&W											X		X		X	X
C. asphaerosporum v. *strigosum* Nord.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 3-4. (Continued).

TAXON	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
C. contractum Kirchner		X			X	X	X	X	X	X	X	X	X	X	X	X
C. moniliforme (Turp.) Ralfs											X			X		X
C. notabile Brebisson													X			
C. phaseolus f. *minor* Boldt.							X	X		X		X				X
C. pokornyanum (Grun.) W. & G.S. West									X				X			X
C. polygonum (Nag.) Archer						X	X	X	X	X	X	X	X	X	X	X
C. raciborskii Lagerheim													X			X
C. regnellii Wille				X			X	X	X	X	X	X	X	X	X	X
C. regnesi Schmidle		X	X	X									X			
C. subreniforme Nordstedt													X			X
C. tenue Archer						X	X	X	X	X	X	X	X	X	X	X
C. tinctum Ralfs				X	X	X	X	X	X	X	X	X	X	X	X	X
C. tinctum v. *subretusum* Messik.											X					
C. tinctum v. *tumidum* Borge.								X		X	X	X	X	X	X	X
C. trilobatum v. *depressum* Printz													X			
C. tumidum Borge													X			
C. spp. Corda	X	X	X	X	X											
Crucigenia apiculata (Lemm.) Schmidl													X	X		
C. crucifera (Wolle) Collins	X	X				X	X	X	X	X	X	X	X	X	X	X
C. fenestrata Schmidle		X											X	X	X	X
C. irregularis Wille			X	X	X		X		X		X		X	X	X	X
C. rectangularis (A. Braun) Gay									X							
C. tetrapedia (Kirch.) West & West	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dictyospaerium ehrenbergianum Nageli											X		X	X	X	X
D. pulchellum Wood	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Dimorphococcus spp. Braun	X															
Elakatothrix gelatinosa Wille	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Errerella bornheimiensis Conrad													X	X		X
Euastrum ansatum v. *dideltiforme* Ducel.													X			
E. banal (Turp.) Ehrenberg													X			
E. denticulatum (Kirch.) Gay						X	X	X	X	X	X	X	X	X	X	X
E. elegans Kutzing														X		
E. spp. Ehrenberg	X		X	X												
Eudorina elegans Ehrenberg							X						X	X		X
Franceia droescheri (Lemm.) G. M. Sm.						X	X	X	X	X	X	X	X	X	X	X
F. ovalis (France) Lemm.	X	X	X	X	X						X		X	X	X	X
F. tuberculata G. M. Smith														X		
Gloeocystis botryoides (Kutz.) Nageli											X			X	X	
G. gigas Kutzing							X	X	X	X	X	X	X	X	X	X
G. major Gerneck *ex.* Lemmermann									X							
G. planktonica (West & West) Lemm.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
G. vesciculosa Naegeli									X				X	X	X	X
G. spp. Nageli	X	X	X	X	X											
Golenkinia paucispina West & West													X	X	X	X
G. radiata Chodat	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gonium pectorale Mueller									X				X			X
G. sociale (Duj.) Warming						X			X	X			X	X	X	X
Kirchneriella contorta (Schmidle) Bohlin	X	X	X	X	X				X				X	X		
K. elongata G.M. Smith											X			X		

Table 3-4. (Continued).

TAXON	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
K. lunaris (Kirch.) Mobius		X												X	X	
K. lunaris v. *dianae* Bohlin								X			X		X	X	X	X
K. lunaris v. *irregularis* G.M. Smith											X			X		
K. obesa W. West	X	X	X	X	X											
K. subsolitaria G. S. West						X	X	X	X	X	X		X	X	X	X
K. spp. Schmidle						X	X	X					X			X
Lagerheimia ciliata (Lag.) Chodat													X			
L. citriformis (Snow) G. M. Smith								X								X
L. longiseta (Lemmermann) Printz													X	X	X	X
L. quadriseta (Lemm.) G. M. Smith	X	X	X													
L. subsala Lemmerman	X	X	X	X	X		X	X	X		X		X	X	X	X
Mesostigma viride Lauterborne						X	X	X	X	X	X		X	X	X	X
Micractinium pusillum Fresen.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Monoraphidium contortum Thuret		X	X	X	X											
M. pusillum Printz		X	X	X	X											
Mougeitia elegantula Whittrock						X	X	X	X	X	X	X	X	X	X	X
M. spp. Agardh			X	X	X											
Nephrocytium agardhianum Nageli		X											X	X	X	X
N. limneticum (G.M. Smith) G.M. Smith										X			X		X	
Oocystis borgii Snow									X	X	X		X	X		X
O. ellyptica W. West									X				X	X	X	
O. lacustris Chodat														X	X	X
O. parva West & West	X					X	X	X	X	X	X	X	X	X	X	X
O. pusilla Hansgirg	X			X	X	X	X	X	X	X	X	X	X	X	X	X
O. pyriformis Prescott									X				X			
O. solitaria Wittrock														X		
O. spp. Nageli	X															
Pandorina charkowiensis Kprshikov																X
P. morum Bory	X		X	X										X		X
Pediastrum biradiatum Meyen																X
P. duplex Meyen	X	X		X		X	X	X		X	X	X	X	X	X	X
P. duplex v. *clatheatum* (A. Braun) Lag.													X			
P. duplex v. *gracillimum* West and West								X	X				X	X	X	X
P. tetras v. *tetroadon* (Corda) Rabenhorst	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. spp. Meyen	X	X														
Planktosphaeria gelatinosa G. M. Smith						X							X		X	X
Quadrigula closterioides (Bohlin) Printz		X					X	X				X	X	X	X	X
Q. lacustris (Chodat) G. M. Smith													X	X	X	X
Scenedesmus abundans (Kirchner) Chodat	X													X		X
S. abundans v. *asymetrica* (Schr.) G. Sm.	X	X	X	X	X		X	X			X		X	X	X	
S. abundans v. *brevicauda* G. M. Smith						X								X	X	
S. acuminatus (Lagerheim) Chodat			X	X	X	X	X		X	X	X	X	X	X	X	X
S. armatus v. *bicaudatus* (Gug.-Pr..)Chod	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. bijuga (Turp.) Lagerheim	X			X	X	X	X	X	X	X	X	X	X	X	X	X
S. bijuga v. *alterans* (Reinsch) Hansg.															X	
S. brasiliensis Bohlin						X	X	X	X	X	X	X	X	X	X	X
S. denticulatus Lagerheim	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
S. denticulatus v. *recurvatus* Schumacher														X	X	X
S. dimorphus (Turp.) Kutzing	X		X	X	X			X	X	X	X		X	X	X	X

Table 3-4. (Continued).

TAXON	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
S. incrassulatus G. M. Smith [1]																
S. opoliensis P. Richter																X
S. parisiensis Chodat														X		X
S. quadricauda (Turp.) Brebisson	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. smithii Teiling							X						X	X		X
S. serratus (Corda) Bohlin															X	
S. spp. Meyen	X	X	X	X	X											
Schizochlamys compacta Prescott							X		X		X		X		X	X
S. gelatinosa A. Braun											X		X		X	X
Schoederia setigera (Schroed.) Lemm.		X											X			
Selenastrum gracile Reinsch		X					X						X			
S. minutum (Nageli) Collins	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. westii G. M. Smith			X			X	X		X	X			X	X	X	X
Sorastrum americanum (Bohlin) Schm.								X								
Sphaerocystis schoeteri Chodat	X					X			X	X	X		X	X	X	X
Sphaerozosma granulatum Roy & Bl. [1]																
Stauastrum americanum (W&W) G. Sm.						X	X	X	X	X	X	X	X	X	X	X
S. apiculatum Brebisson								X	X	X	X	X	X	X	X	X
S. brachiatum Ralfs								X	X	X			X	X	X	X
S. brevispinum Brebisson									X							
S. chaetocerus (Schoed.) G. M. Smith			X	X	X											
S. curvatum W. West	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. cuspidatum Brebisson								X	X	X	X	X	X	X	X	X
S. dejectum Brebisson	X	X	X		X						X				X	
S. dickeii v. *maximum* West & West [1]																
S. dickeii v. *rhomboidium* W.& G.S. West													X			
S. gladiosum Turner				X												
S. leptocladum Nordstedt																X
S. leptocladum v. *sinuatum* Wolle		X														
S. manfeldtii v. *fluminense* Schumacher	X	X			X	X		X	X		X		X	X	X	X
S. megacanthum Lundell				X	X									X	X	X
S. ophiura v. *cambricum* (Lund) W. & W.											X					X
S. orbiculare Ralfs					X								X			
S. paradoxum Meyen	X	X	X	X	X				X	X					X	X
S. paradoxum v. *cingulum* W. & W.															X	X
S. paradoxum v. *parvum* W. West									X				X	X	X	X
S. pentacerum (Wolle) G. M. Smith													X			X
S. subcruciatum Cook & Wille						X		X	X	X	X		X	X	X	X
S. tetracerum Ralfs	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. turgescens de Not.																X
S. vestitum Ralfs													X	X		
S. spp. Meyen	X	X	X		X											
Stichococcus scopulinus Hazen													X			
Stigeoclonium spp. Kutzing												X				
Tetraedron arthrodesmiforme (W.) Wol.													X	X		X
T. bifurcatum v. *minor* Prescott							X									
T. caudatum (Corda) Hansgirg	X		X		X		X	X	X	X	X	X	X	X	X	X
T. limneticum Borge			X													

Table 3-4. (Continued).

TAXON	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Diploneis ellyptica (Kutz.) Cleve															X	
D. ovalis (Hilse) Cleve															X	
D. puella (Schum.) Cleve															X	
D. spp. Ehrenberg	X															
Eunotia flexuosa v. *eurycephala* Grun.											X					
E. zasuminensis (Cab.) Koerner	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
Fragilaria crotonensis Kitton	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
F. construens (Ehr.) Grunow															X	
Frustulia rhomboides (Her.) de Toni[1]																
F. rhomboides v. *saxonica* (Rabh.) de T.														X		
Gomphonema angustatum (Kutz.) Rabh.													X			
G. parvulum Kutz.													X	X		
G. spp. Agardh		X			X											
Melosira ambigua (Grun.) O. Muller	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. distans (Her.) Kutzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. granulata (Ehr.) Ralfs	X	X		X												X
M. granulata v. *angustissima* O. Muller	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. italica (Ehr.) Kutzing [1]																
M. varians Agardh			X	X					X							X
M. spp. Agardh	X	X	X	X	X		X			X		X	X	X	X	X
Meridion circulare Agardh													X			
Navicula cryptocephala Kutzing	X						X	X					X			
N. exigua (Gregory) O. Muller						X							X		X	
N. exigua v. *capitata* Patrick							X									
N. radiosa Kutz.														X		X
N. radiosa v. *tenella* (Breb.) Grun.														X	X	
N. subtilissima Cleve						X					X			X		X
N. spp. Bory	X	X	X	X	X										X	
Nitzschia acicularis W. Smith	X	X	X	X			X	X	X	X	X	X	X	X	X	X
N. agnita Hustedt	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
N. holsatica Hustedt	X	X				X		X	X	X	X	X	X	X	X	X
N. kutzingiana Hilse															X	X
N. linearis W. Smith											X					X
N. palea (Kutzing) W. Smith					X	X	X	X	X				X		X	X
N. sublinearis Hustedt							X		X			X	X			
N. spp. Hassall	X	X	X	X	X								X			X
Pinnularia biceps Gregory																X
P. spp. Ehrenberg				X									X			X
Rhizosolenia spp. Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Skeletonema potemos (Weber) Hilse				X		X	X		X	X	X		X	X		X
Stephanodiscus astraea (Her.) Grunow																X
Stephanodiscus spp. Ehrenberg	X	X	X	X	X	X	X	X	X					X	X	X
Surirella angustata Kutz.														X		
S. linearis v. *constricta* (Ehr.) Gr0.									X							
S .tenuis Mayer																X
Synedra actinastroides Lemmerman					X											
S. acus Kutzing				X	X			X	X		X		X	X	X	X
S. delicatissima Lewis			X	X	X											
S. filiformis v. *exilis* Cleve-Euler									X		X	X	X	X	X	X

Table 3-4. (Continued).

TAXON	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
S. planktonica Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
S. rumpens Kutzing						X	X	X	X	X	X	X	X	X	X	X
S. rumpens v. *fragilarioides* Grunow [1]																
S. rumpens v. *scotica* Grunow [1]																
S. ulna (Nitzsch) Ehrenberg		X				X	X	X	X	X	X		X	X	X	X
S. spp. Ehrenberg	X	X	X	X	X											
Tabellaria fenestrata (Lyngb) Kutzing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
T. flocculosa (Roth.) Kutzing	X				X						X				X	
CLASS: CHRYSOPHYCEAE																
Aulomonas purdyii Lackey				X	X	X	X	X	X	X		X	X		X	X
Bicoeca petiolatum (Stien) Pringsheim							X	X								
Calycomonas pascheri (Van Goor) Lund						X					X			X		
Centritractus belanophorus Lemm.																X
Chromulina spp. Chien.									X				X	X	X	
Chrysococcus rufescens Klebs														X		
Chrysosphaerella solitaria Lauterb.		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Codomonas annulata Lackey							X	X	X	X	X	X		X	X	X
Dinobryon bavaricum Imhof	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D. cylindricum Imhof	X	X	X	X	X		X		X				X	X		X
D. divergens Imhof	X		X	X	X	X	X			X			X	X	X	X
D. sertularia Ehrenberg						X					X		X	X	X	X
D. spp. Ehrenberg	X	X				X	X	X	X	X	X	X	X	X	X	X
Domatomococcus cylindricum Lackey									X	X				X		
Erkinia subaequicilliata Skuja	X				X	X	X	X	X	X	X	X	X	X	X	X
Kephyrion campanuliforme Conrad														X		
K. littorale Lund									X				X	X	X	X
K. petasatum Conrad														X		
K. rubi-claustri Conrad													X	X	X	X
K. skujae Ettl [1]																
K. valkanovii Conrad																X
K. spp. Pascher	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mallomonas acaroides Perty					X											X
M. akrokomos (Naumann) Krieger	X								X	X	X			X		X
M. allorgii (Defl.) Conrad														X		
M. alpina Pascher									X		X					
M. caudata Conrad	X	X	X	X	X	X				X	X	X	X	X		X
M. globosa Schiller	X								X		X	X	X	X	X	X
M. producta Iwanoff											X		X	X		X
M. pseudocoronata Prescott	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. tonsurata Teiling	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
M. spp. Perty	X	X	X	X	X						X					
Ochromonas granularis Doflein									X	X	X	X	X	X	X	X
O. mutabilis Klebs											X					
O. spp. Wyss					X	X	X	X	X	X	X	X	X	X	X	X
Pseudokephyrion concinum (Schill.) Sch.																X
P. schilleri Conrad									X	X		X	X	X		X
P. tintinabulum Conrad									X							
P. spp. Pascher														X		X
Rhizochrisis polymorpha Naumann										X	X	X	X	X	X	X

Table 3-4. (Continued).

TAXON	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
R. spp. Pascher		X														
Salpingoeca frequentissima (Zach.) Lem.									X	X	X			X		X
Stelexomonas dichotoma Lackey	X	X	X	X	X	X	X	X	X		X		X	X		X
Stokesiella epipyxis Pascher								X	X	X						
Synura sphagnicola Korschikov															X	
S. spinosa Korschikov	X					X	X	X	X	X	X	X	X	X	X	X
S. uvella Ehrenberg	X	X		X	X							X				
S. spp. Ehrenberg	X	X	X	X	X											
Uroglenopsis americana (Caulk.) Lemm.						X	X	X		X						
CLASS: HAPTOPHYCEAE																
Chrysochromulina parva Lackey	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CLASS: XANTHOPHYCEAE																
Characiopsis acuta Pascher													X			X
C. dubia Pascher						X	X		X	X	X	X	X	X	X	X
Dichotomococcus curvata Korschikov [1]																
Ophiocytium capitatum v. *longisp.* (M) L.				X	X									X	X	X
Stipitococcus vas Pascher														X		
CLASS: CRYPTOPHYCEAE																
Cryptomonas erosa Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. erosa v. *reflexa* Marsson	X								X	X	X	X	X	X	X	X
C. gracilia Skuja											X					
C. marsonii Skuja	X	X	X	X	X									X		
C. obovata Skuja														X		X
C. ovata Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. phaseolus Skuja	X	X	X	X	X											
C. reflexa Skuja	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C. spp. Ehrenberg	X	X	X	X	X											
Rhodomonas minuta Skuja	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CLASS: MYXOPHYCEAE																
Agmenellum quadriduplicatum Brebisson			X	X	X	X		X	X	X	X	X	X	X	X	X
A. thermale Drouet and Daily														X		
Anabaena catenula (Kutzing) Born.								X	X							
A. inaequalis (Kutz.) Born.											X					
A. scheremetievi Elenkin								X	X	X		X				
A. wisconsinense Prescott						X	X	X	X	X	X	X	X	X	X	X
A. spp. Bory	X	X	X	X	X		X			X		X	X		X	
Anacystis incerta (Lemm.) Druet & Daily	X	X	X	X	X				X		X	X				
A. spp. Meneghini [1]																
Chroococcus dispersus (Keissl.) Lemm.									X		X					
C. limneticus Lemmermann	X							X	X	X	X	X	X	X		X
C. minor Kutzing													X	X		X
C. turgidus (Kutz.) Lemmermann		X		X												
C. spp. Nageli	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Coelosphaerium kuetzingiana Nageli	X															

Table 3-4. (Continued).

TAXON	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Dactylococcopsis irregularis Hansgirg	X	X			X									X	X	X
D. rupestris Hansgirg											X					
D. smithii Chodat and Chodat								X	X		X			X	X	X
D. spp. Hansgirg											X					
Gomphospaeria lacustris Chodat	X	X	X	X	X											X
Lyngbya contorta Lemmermann		X	X													
L. limnetica Lemmermann	X	X	X	X	X											
L. ochracea (Kutz.) Thuret											X		X		X	X
L. subtilis W. West	X	X	X		X											
L. tenue Agardh															X	
L. spp. Agardh	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Merismopedia tenuissima Lemmermann									X							
Microcystis aeruginosa Kutz. *emend* Elen.	X	X	X	X	X	X	X		X	X	X	X			X	X
Oscillatoria amoena (Kutz.) Gomont															X	
O. amphibia Agardh													X	X	X	
O. geminata Meneghini	X					X	X	X	X	X	X	X	X	X	X	X
O. limnetica Lemmermann						X	X	X	X	X	X	X	X	X	X	X
O. splendida Greville						X	X		X				X			
O. subtilissima Kutz.											X	X	X	X	X	X
O. spp. Vaucher					X							X		X		
Phormidium angustissimum West & West	X	X			X											
P. spp. Kutzing	X			X	X											
Raphidiopsis curvata Fritsch & Rich			X		X	X	X	X	X	X	X		X		X	
R. mediterranea Skuja										X						
Rhabdoderma sigmoidea Schm. & Laut. [1]																
Spirulina subsala Oersted													X			
Synecococcus lineare (Sch. & Lt.) Kom.	X	X	X	X	X	X	X		X	X	X	X		X	X	
CLASS: EUGLENOPHYCEAE																
Euglena acus Ehrenberg	X									X					X	X
E. deses Ehrenberg																X
E. minuta Prescott											X		X		X	X
E. polymorpha Dangeard							X					X	X		X	X
E. proxima Dangeard														X	X	X
E. spp. Ehrenberg	X	X		X	X	X	X		X	X		X			X	X
Lepocinclus acuta															X	
L. glabra Drezepolski														X		
L. ovum. (Ehr.) Lemm.											X				X	
L. spp. Perty									X							
Phacus cuvicauda Swirenko											X					
P. longicauda (Her.) Dujardin											X					
P. orbicularis Hubner			X													X
P. tortus (Lemm.) Skvortzow	X		X													
P. triquter Playfair															X	
P. spp. Dujardin [1]																
Trachelomonas abrupta v. *minor* Deflan.																X
T. acanthostoma (Stk.) Defl.												X			X	X
T. ensifera Daday														X		

Table 3-4. (Continued).

TAXON	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
T. hispida (Perty) Stein				X		X				X		X	X	X	X	X
T. lemmermanii v. *acuminata*																X
T. pulcherrima Playfair [1]																
T. pulcherrima v. *minor*															X	
T. volvocina Ehrenberg						X				X		X		X	X	X
T. spp. Ehrenberg	X	X			X											
CLASS: DINOPHYCEAE																
Ceratium hirundinella (OFM) Schrank	X		X		X	X		X	X	X	X					
C. hirundinella v. *brachyceras* (Day.) Est.																X
Glenodinium borgei (Lemm.) Schiller							X									
G. gymnodinium Penard	X	X	X	X				X							X	
G. palustre (Lemm.) Schiller [1]																
G. penardiforme (linde.) Schiller										X	X				X	
G. quadridens (Stein) Schiller	X				X											
G. spp. (Ehrenberg) Stein		X			X											
Gymnodinium aeruginosum Stein									X	X	X			X	X	X
G. spp. (Stein) Kofoid & Swezy	X	X	X	X	X	X		X	X		X	X	X	X	X	X
Peridinium aciculiferum Lemmermann [1]																
P. cinctum (Muller) Ehrenberg													X			
P. inconspicuum Lemmermann	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. intermedium Playfair									X	X	X	X	X	X	X	X
P. limbatum (Stokes0 Lemm.																X
P. pusillum (Lenard) Lemmermann	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
P. umbonatum Stein			X	X	X											
P. willei (Huitfeld-Kass															X	X
P. wisconsinense Eddy	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
P. spp. Ehrenberg	X	X	X	X	X											
CLASS: CHLOROMONADOPHYCEAE																
Gonyostomum depresseum Lauterborne						X			X	X			X	X	X	X
G. semen (Ehrenberg) Diesing	X															
G. spp. Diesing	X				X											

1 = taxa found during 1987-89 only

Table 3-5. Dominant classes, their most abundant species, and their percent composition (in parenthesis) at Lake Norman locations during each sampling period of 2005.

LOC	FEBRUARY	MAY
2.0	CRYPTOPHYCEAE (50.3)	BACILLARIOPHYCEAE (51.6)
	Rhodomonas minuta (45.3)	*Fragillaria crotonensis* (23.8)
5.0	CRYPTOPHYCEAE (45.3)	BACILLARIOPHYCEAE (46.2)
	R. minuta (42.1)	*F. crotonensis* (23.7)
9.5	CRYPTOPHYCEAE (41.3)	BACILLARIOPHYCEAE (63.5)
	R. minuta (39.0)	*F. crotonensis* (34.2)
11.0	CRYPTOPHYCEAE (44.1)	BACILLARIOPHYCEAE (55.3)
	R. minuta (35.4)	*F. crotonensis* (21.5)
15.9	CRYPTOPHYCEAE (42.4)	BACILLARIOPHYCEAE (49.8)
	R. minuta (38.1)	*Melosira ambigua* (35.6)
	AUGUST	NOVEMBER
2.0	CHLOROPHYCEAE (68.7)	BACILLARIOPHYCEAE (50.8)
	Cosmarium asphearosporum strig.(36.6)	*Synedra planktonica* (7.5)
5.0	CHLOROPHYCEAE (63.3)	BACILLARIOPHYCEAE (66.9)
	C. asphear. strigosum (29.2)	*Melosira granulata* v. *ang.*(13.6)
9.5	CHLOROPHYCEAE (73.1)	BACILLARIOPHYCEAE (47.6)
	C. asphear. strig. (40.9)	*Cyclotella stelligera* (10.7)
11.0	CHLOROPHYCEAE (61.2)	BACILLARIOPHYCEAE (49.4)
	C. asphear. strig. (33.7)	*Rhizosolenia* spp. (5.2)
15.9	CHLOROPHYCEAE (53.6)	BACILLARIOPHYCEAE (47.4)
	C. asphear. strig. (27.8)	*Tabellaria fenestrata* (11.1)

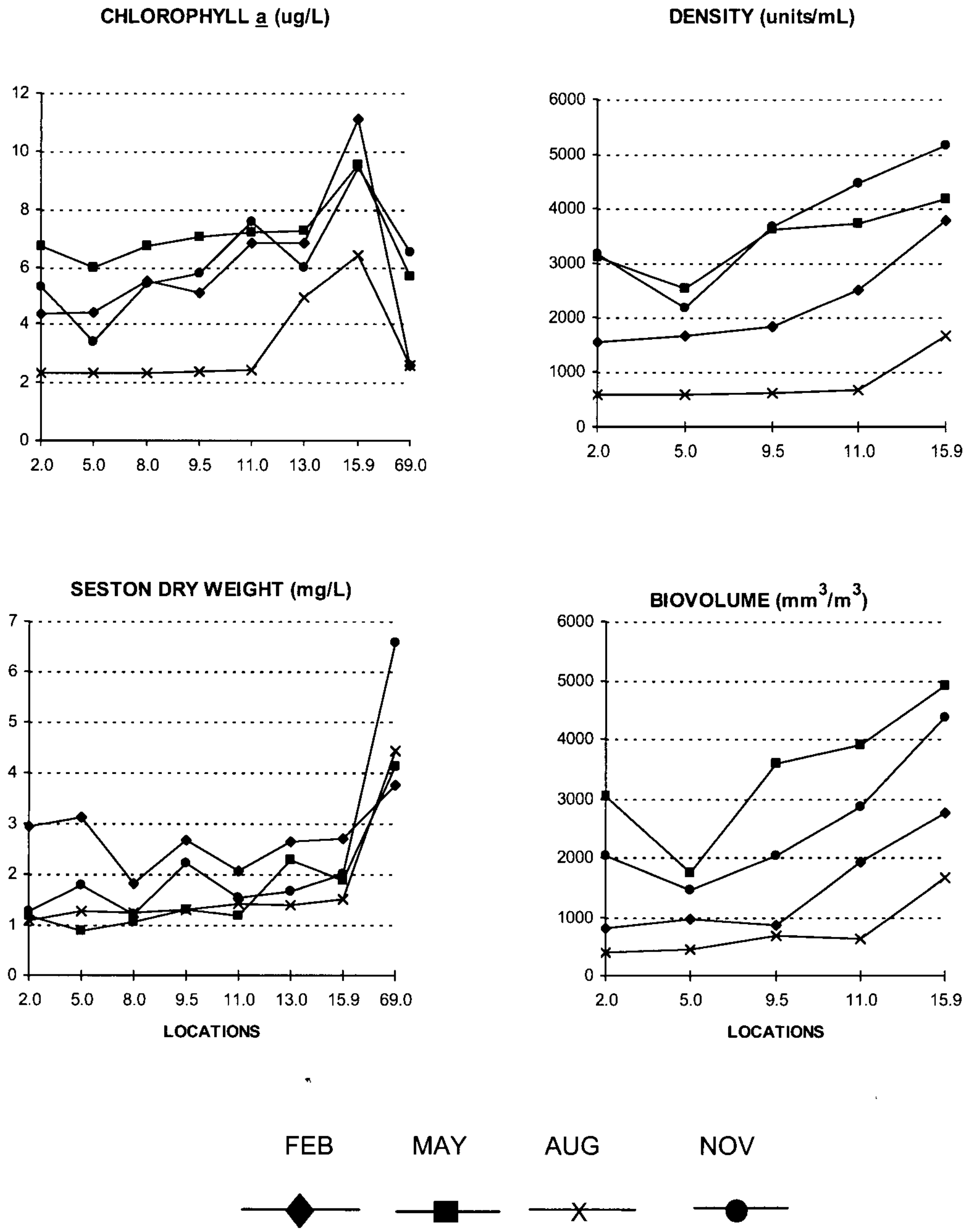


Figure 3-1. Phytoplankton chlorophyll *a*, densities, biovolumes, and seston weights at locations in Lake Norman in February, May, August, and November 2005.

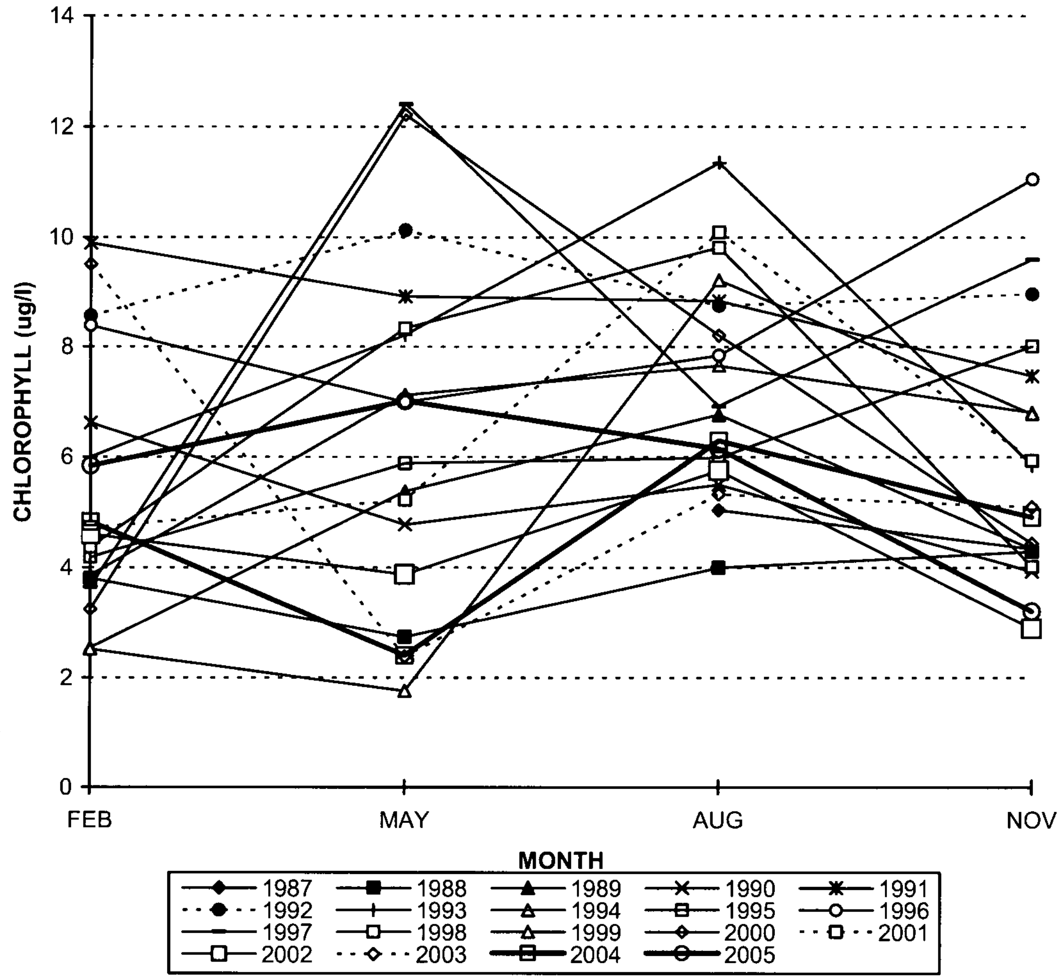


Figure 3-2. Total Phytoplankton chlorophyll *a* annual lake means from all locations in Lake Norman for each quarter since August 1987.

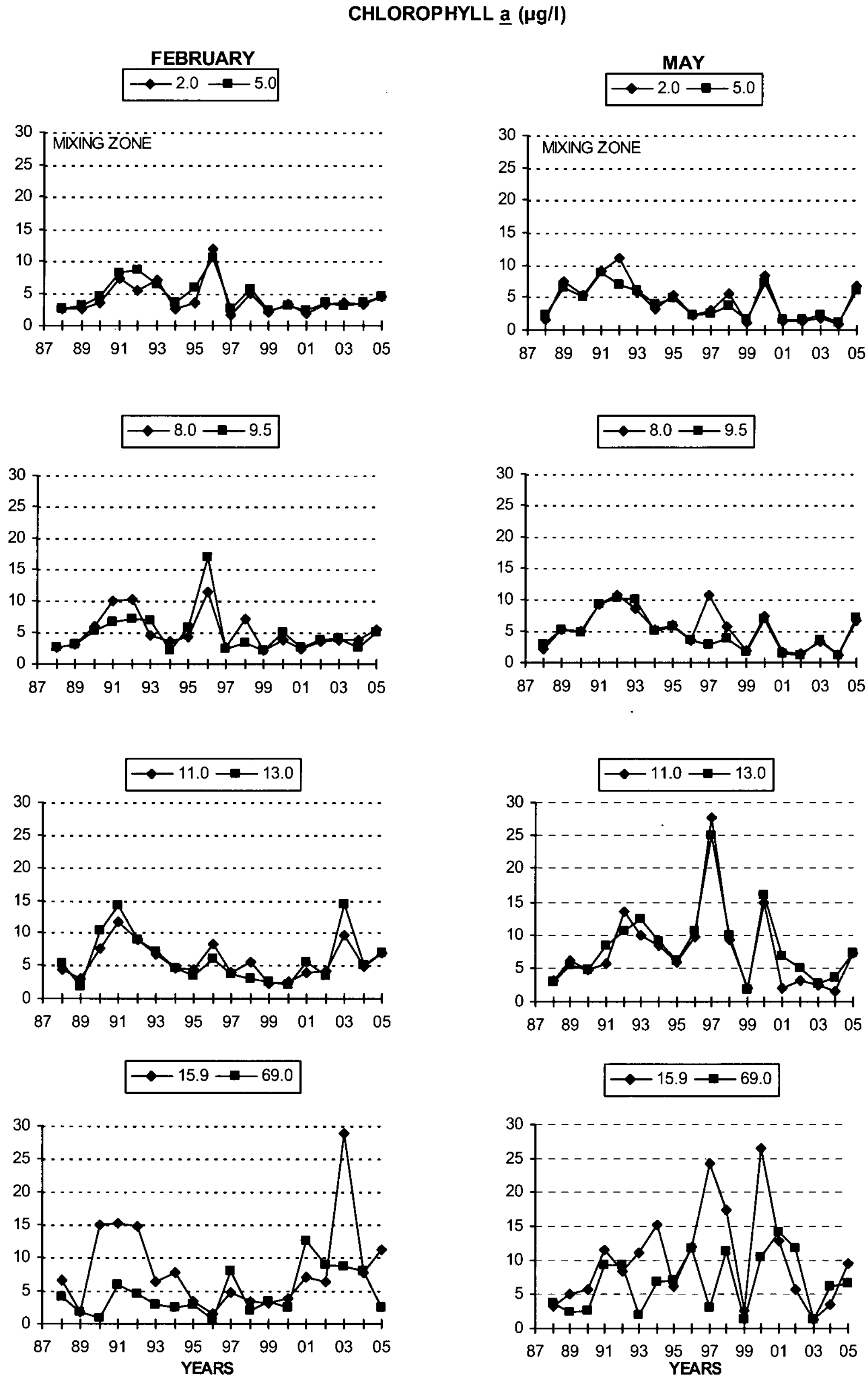


Figure 3-3. Phytoplankton chlorophyll *a* concentrations by location for samples collected in Lake Norman from February and May 1988 through 2005.

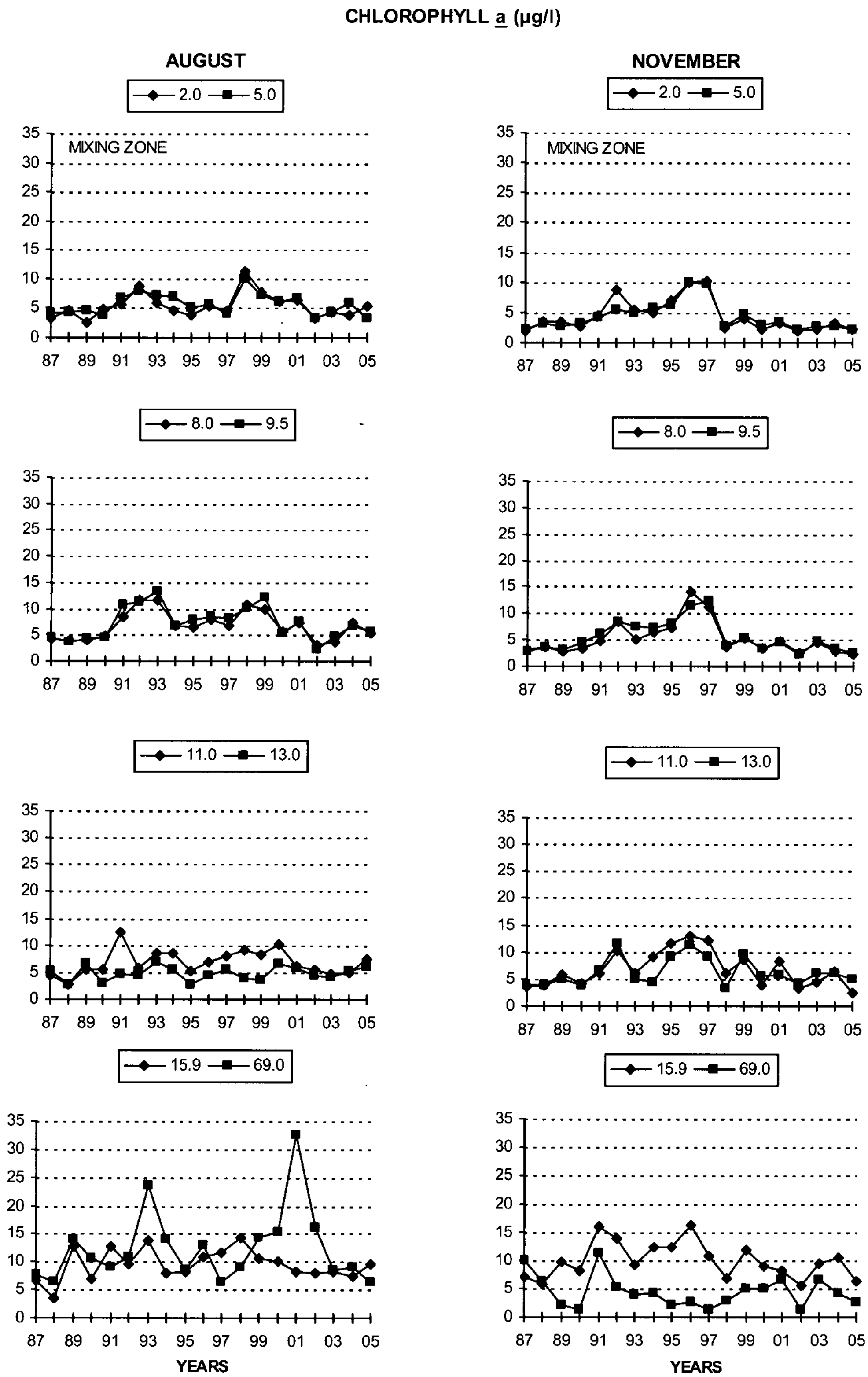


Figure 3-4. Phytoplankton chlorophyll *a* concentrations by location for samples collected in Lake Norman from August and November 1987 through 2005.

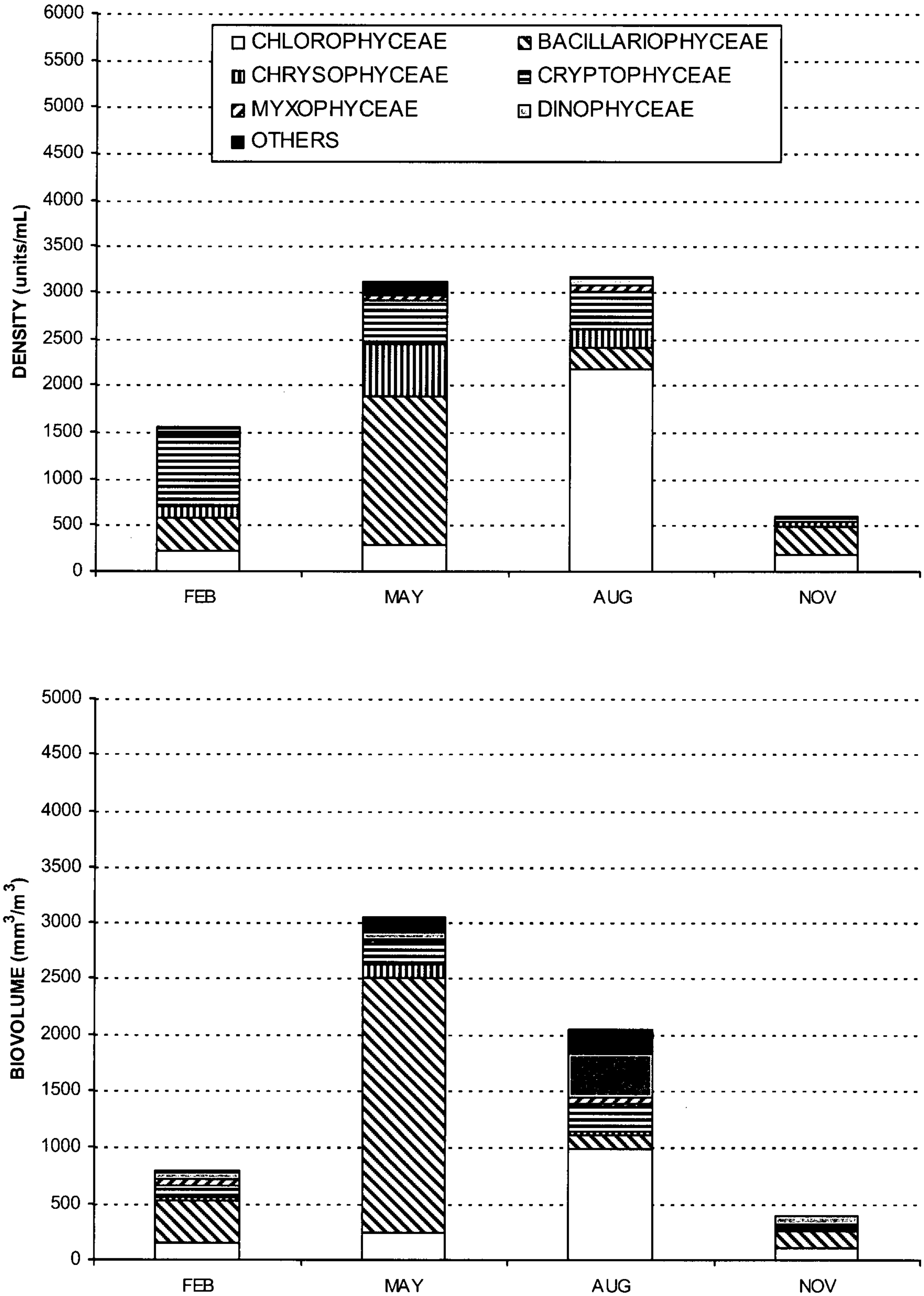


Figure 3-5. Class composition (mean density and biovolume) of phytoplankton from euphotic zone samples collected at Location 2.0 in Lake Norman during 2005.

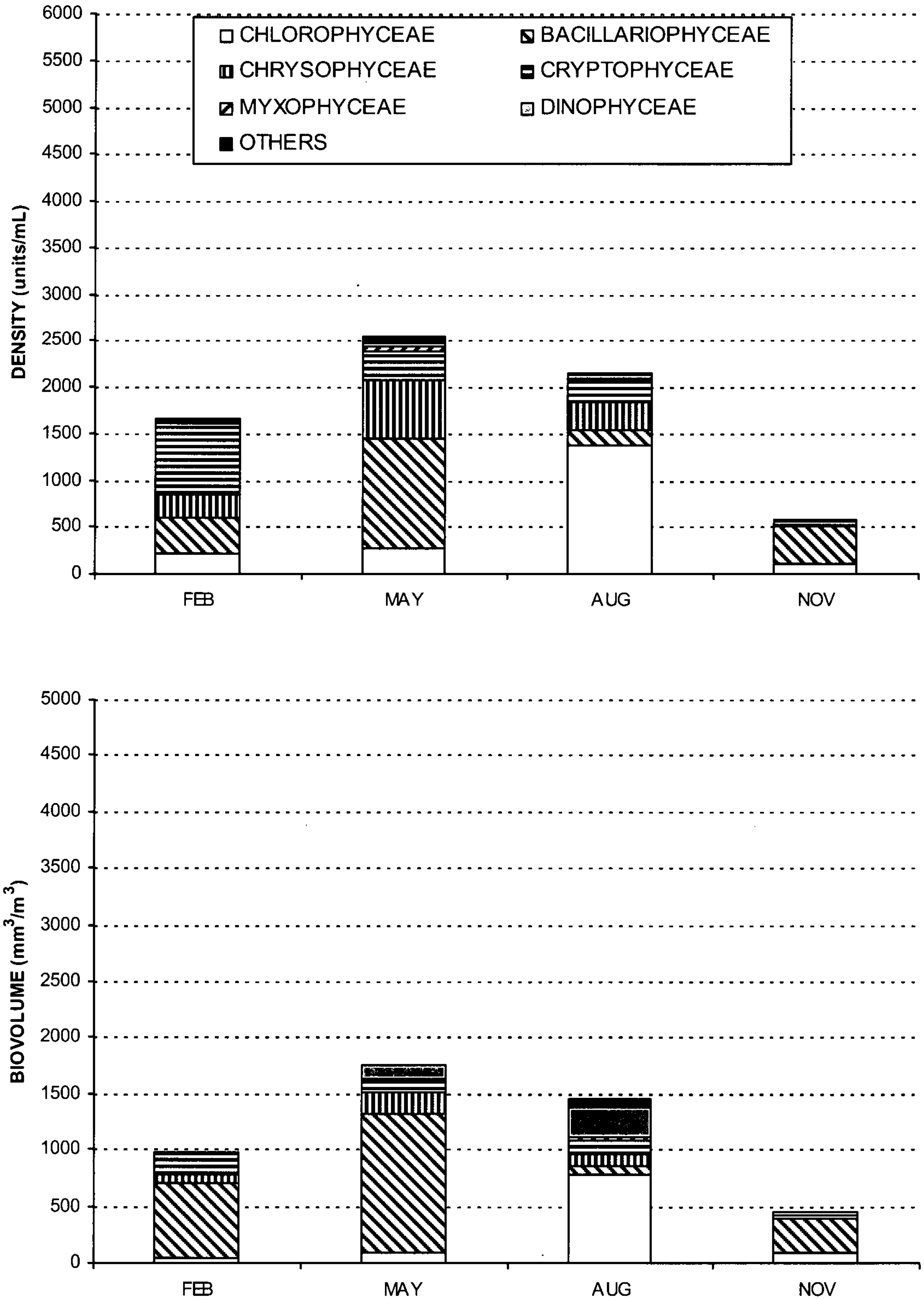


Figure 3-6. Class composition (mean density and biovolume) of phytoplankton from euphotic zone samples collected at Location 5.0 in Lake Norman during 2005.

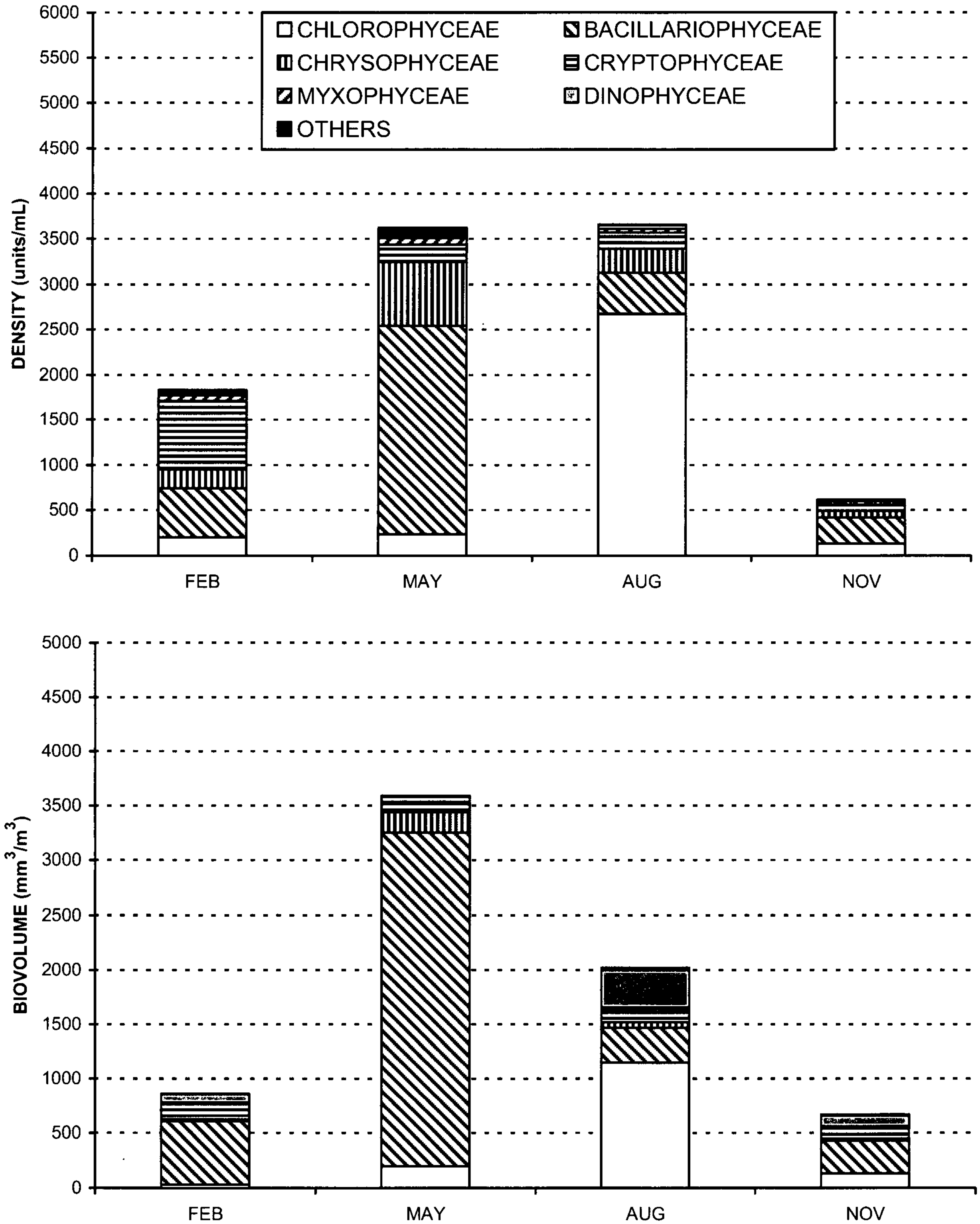


Figure 3-7. Class composition (mean density and biovolume) of phytoplankton from euphotic zone samples collected at Location 9.5 in Lake Norman during 2005.

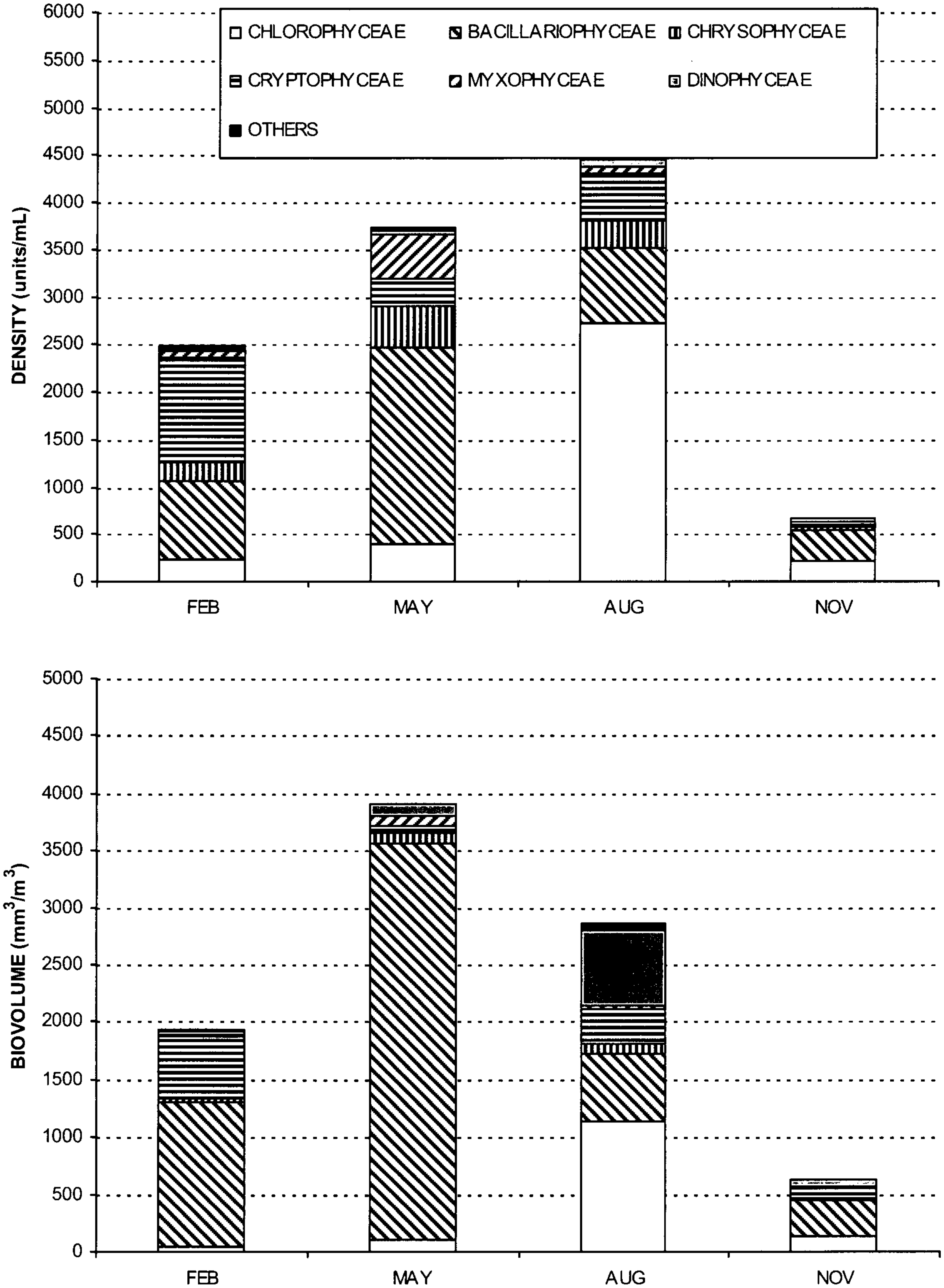


Figure 3-8. Class composition (mean density and biovolume) of phytoplankton from euphotic zone samples collected at Location 11.0 in Lake Norman during 2005.

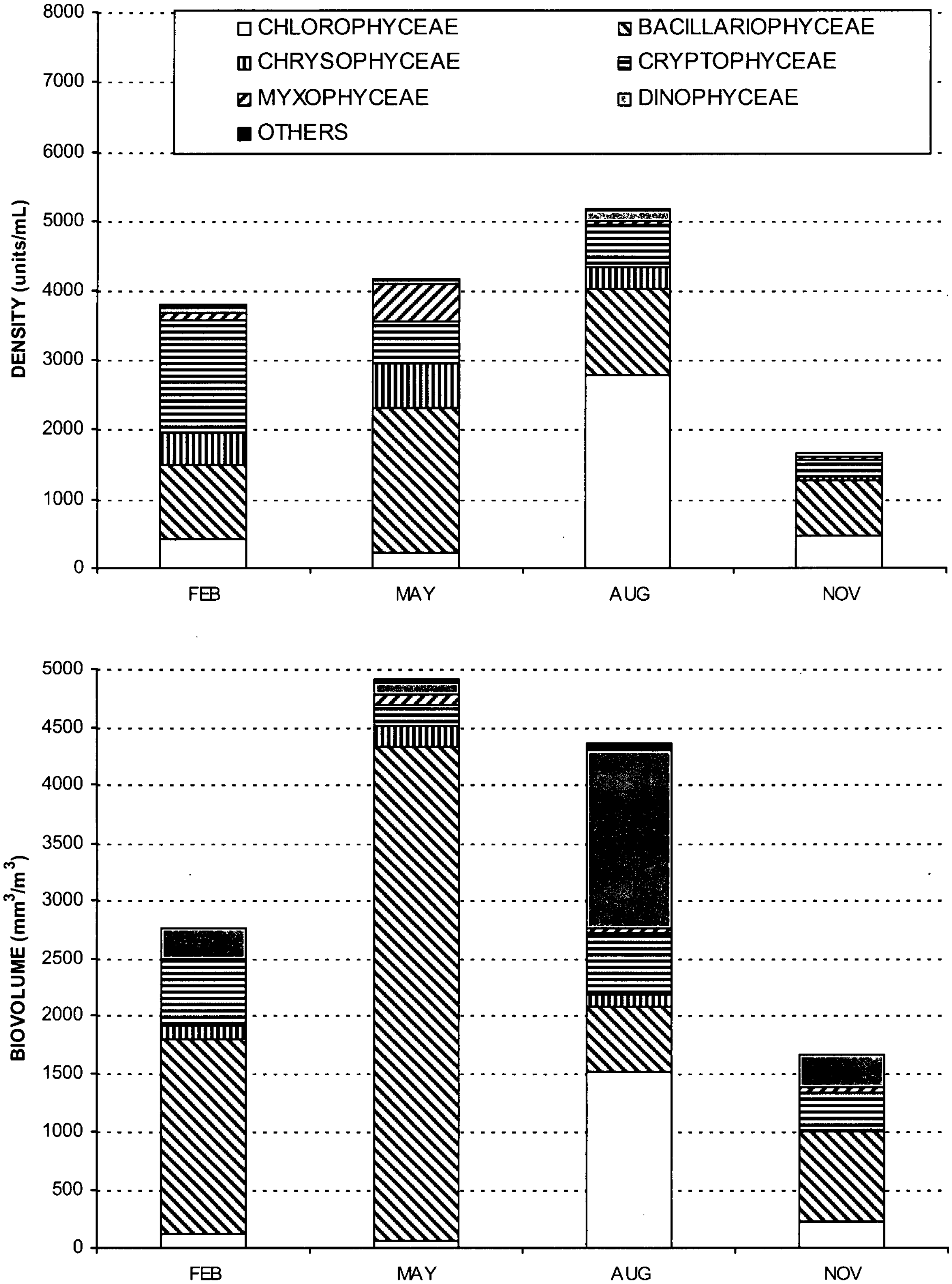


Figure 3-9. Class composition (mean density and biovolume) of phytoplankton from euphotic zone samples collected at Location 15.9 in Lake Norman during 2005.

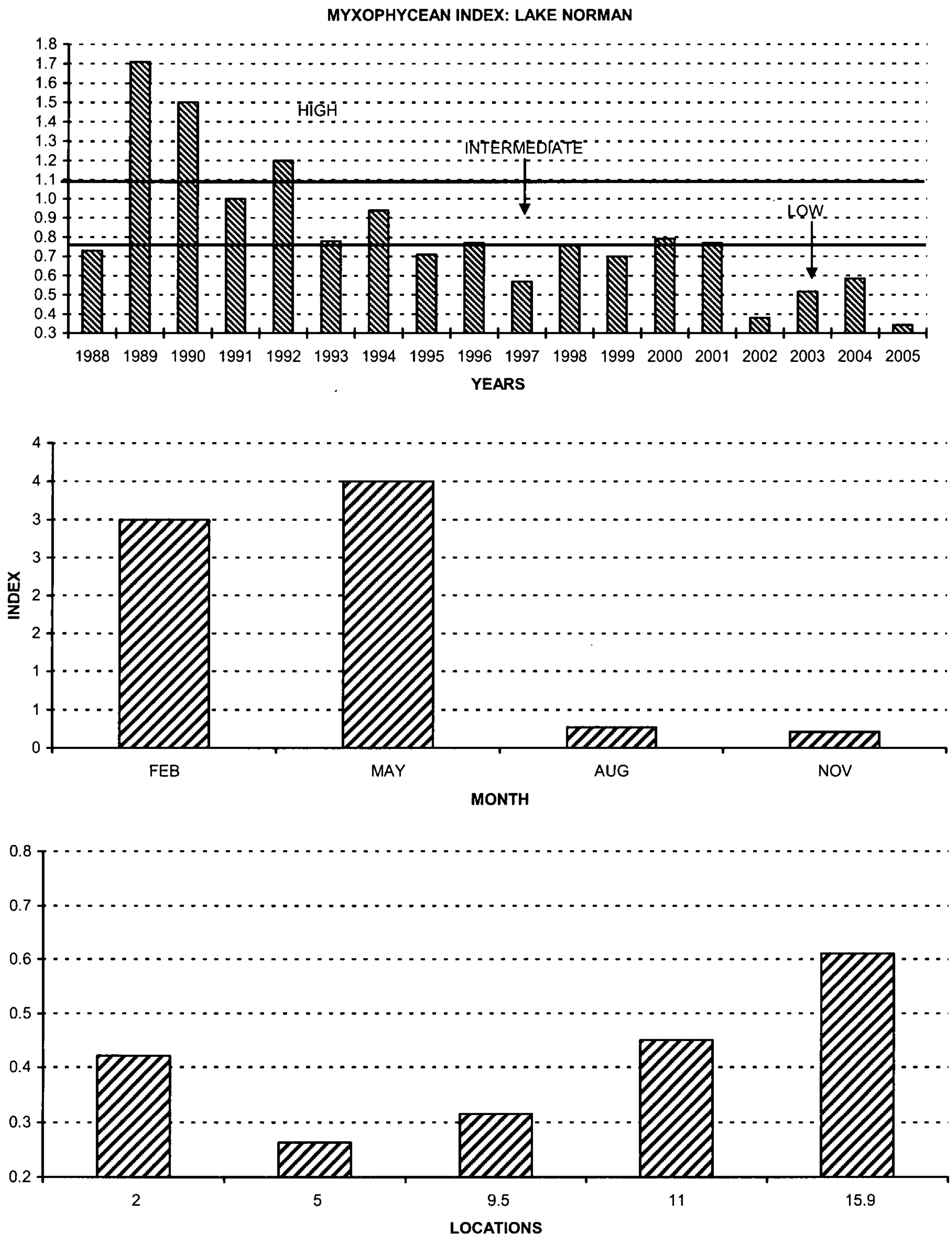


Figure 3-10. Myxophycean index values by year (top), each quarter in 2005 (mid), and each location in Lake Norman during 2005.

CHAPTER 4

ZOOPLANKTON

INTRODUCTION

The objectives of the Lake Norman Maintenance Monitoring Program for zooplankton are to:

1. Describe and characterize quarterly patterns of zooplankton standing crops at selected locations on Lake Norman and
2. compare and evaluate, where possible, zooplankton data collected during 2005 with historical data collected during the period 1987-2004.

Previous studies of Lake Norman zooplankton populations, using monthly data, have demonstrated a bimodal seasonal distribution with highest values generally occurring in the spring, and a less pronounced fall peak. Considerable spatial and year-to-year variability has been observed in zooplankton abundance in Lake Norman (Duke Power Company 1976, 1985; Hamme 1982; Menhinick and Jensen 1974). Since quarterly sampling was initiated in August 1987, distinct bimodal seasonal distribution has been less apparent due to lack of transitional data between quarters.

METHODS AND MATERIALS

Duplicate 10 m to surface, and bottom to surface net tows, were taken at Locations 2.0, 5.0, 9.5, 11.0, and 15.9 in Lake Norman (Figure 2-1) in April, May, September, and December 2005. Normally, zooplankton samples are collected during each season (winter: January-March; spring: April-June; summer: July-September; fall: October-December); however, due to scheduling, equipment problems, and inclement weather, sampling was not conducted during the winter season, and had to be delayed until early spring. Since in all previous years, winter samples were collected, it will not be possible to interpret April 2005 data in any detailed historical context. April 2005 data will be discussed primarily with respect to zooplankton results from 2005.

For discussion purposes the 10 m to surface tow samples are called "epilimnetic" samples and the bottom to surface net tow samples are called "whole-column" samples. Locations 2.0

and 5.0 are defined as the mixing zone and Locations 9.5, 11.0 and 15.9 are defined as background locations. Field and laboratory methods for zooplankton standing crop analysis were the same as those reported in Hamme (1982). Zooplankton standing crop data from 2005 were compared with corresponding data from quarterly monitoring begun in August 1987.

RESULTS AND DISCUSSION

Total Abundance

Maximum epilimnetic zooplankton densities at Lake Norman locations have most often been observed in the spring, with annual peaks observed in the winter about 25% of the time. Annual maxima have only occasionally been recorded for summer and fall (Duke Power 2005).

During 2005, typical seasonal variability was observed in epilimnetic samples. Maximum epilimnetic densities were observed in April at all but Location 2.0, which demonstrated its yearly maximum in May (Table 4-1, Figure 4-1). The lowest epilimnetic densities occurred in December at Locations 2.0 and 5.0, in September at Locations 9.5 and 11.0, and in May at Location 15.9. Epilimnetic densities ranged from a low of 29,379 no./m^3 at Location 5.0 in December, to a high of 1,042,954 no./m^3 at Location 15.9 in April. Maximum densities in all whole-column samples were also observed in April. Minimum whole-column densities were observed September at all but Locations 15.9, which exhibited its annual minimum in December. Whole-column densities ranged from 16,973 no./m^3 at Location 2.0 in September, to 535,956 no./m^3 at Location 15.9 in April.

Total zooplankton densities were most often higher in epilimnetic samples than in whole-column samples during 2005, as has been the case in previous years (Duke Power 2005). This is related to the ability of zooplankton to orient vertically in the water column in response to physical and chemical gradients and the distribution of food sources, primarily phytoplankton, which are generally most abundant in the euphotic zone (Hutchinson 1967).

Although spatial distribution varied among locations from season to season, a general pattern of lower average densities from the mixing zone as compared to background locations was observed during 2005 (Tables 4-1 and 4-2, Figures 4-1 and 4-2). Location 15.9, the uppermost location, had higher epilimnetic densities than mixing zone locations during all sampling periods except May, when zooplankton densities showed a marked decline from mixing zone to background locations (Table 4-1). In most previous years of the Program, background locations had higher mean densities than mixing zone locations (Duke Power Company 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997; Duke Power 1998, 1999, 2000, 2001, 2002, 2003, 2004a, 2005).

Historically, both seasonal and spatial variability among epilimnetic zooplankton densities have been much higher among background locations than among mixing zone locations. The uppermost location, 15.9, showed the greatest range of densities during 2005 (Table 4-1, Figures 4-3 and 4-4). Apparently epilimnetic zooplankton communities are more greatly influenced by environmental conditions at the up-lake locations than at the down-lake locations. Location 15.9 represents the transition zone between river and reservoir where populations would be expected to fluctuate due to the dynamic nature of this region of Lake Norman. At the locations nearest the dam (Locations 2.0 and 5.0), seasonal variations are dampened and the overall production would be lower due to the relative stability of this area (Thornton, et al. 1990). A similar trend was observed in the phytoplankton communities (Chapter 3).

Due to the lack of data from the winter period of 2005, comparisons with historical data could not be made. April samples were collected during monthly sampling in the 1970's and 1980's (Duke Power Company, 1976, 1985; Hamme 1982). Most often, annual maxima were observed during April and May periods of these past years. As stated earlier, annual maxima (both in the epilimnion and whole-column samples) occurred at most locations during April 2005; however, densities in excess of 1,000,000/m^3, as recorded from Location 15.9 in April, have rarely been reported in any previous Duke Power studies.

Epilimnetic zooplankton densities during 2005 were most often within historical ranges during spring (May), summer, and fall (Figures 4-3 and 4-4). The exceptions were Locations 2.0, 5.0, and 9.5, which had record high densities for May.

Long-term maximum densities for the spring period (May) at Locations 2.0, 5.0, and 9.5 were observed in 2005, while the highest spring values from Locations 11.0 and 15.9 occurred in 2002 (Figure 4-3). Long-term summer maxima occurred in 1988 at all but Location 15.9, which had its highest summer value in 2003 (Figure 4-4). Fall long-term maxima at

Locations 2.0, 5.0 and 9.5 occurred in 1988, and at Locations 11.0 and 15.9 in the fall of 1999.

Since 1990, the densities at mixing zone locations in the spring, summer, and fall have shown a moderate degree of year-to-year variability, and the long-term trend at mixing zone locations in the spring has been a gradual increase over the last fifteen years with long-term peaks recorded in 2005. The background locations continue to exhibit considerable year-to-year variability in all seasons (Figures 4-3 and 4-4).

Community Composition

One hundred twenty zooplankton taxa have been identified since the Lake Norman Maintenance Monitoring Program began in August 1987 (Table 4-2). Forty-one taxa were identified during 2005, as compared to 52 taxa recorded during 2004 (Duke Power 2005). Two previously unreported taxa were identified in 2005: One copepod (*Paracyclops limbricatus* v. *poppei*), and one rotifer (*Brachionus calyciflorus*) were added to the taxa list.

Copepods, which were most often dominant during 2001, showed a significant decline in relative abundance during 2002, when they were dominant in only seven August samples (Duke Power 2002 and 2003). During 2003, copepods rebounded considerably, and were dominant in 13 zooplankton samples collected during all four quarters (Duke Power 2004a). During 2004, copepod dominance and relative abundance declined slightly, and these microcrustaceans were dominant in 10 samples collected in the summer and fall (Duke Power 2005). During 2005, copepods were the least abundant forms, and were dominant in only two samples from Location 9.5, epilimnion, in the spring, and Location 5.0, whole column, in the summer (Table 4-1, Figures 4-2, and 4-6 through 4-8). Cladocerans, most often the least abundant forms in Lake Norman, were dominant in three epilimnetic samples from Locations 2.0, 5.0, and 9.5 in the summer, and two whole-column samples from Locations 2.0 and 9.5, also in the summer. Rotifers were dominant in over 82% of all zooplankton samples collected during 2005. During most years of the Program, microcrustaceans (copepods and cladocerans) dominated mixing zone samples, but were somewhat less important among background locations (Figures 4-6 through 4-8). From 1995 through 1998, a trend of increasing relative abundance among microcrustaceans was observed throughout Lake Norman. Since 2000, this trend has reversed, with a subsequent increase in relative abundances of rotifers to the extent that taxonomic composition since

2002 has been similar to that found during 1995. During 2005, microcrustaceans increased slightly in relative abundance in all areas of Lake Norman.

Copepoda

Copepod populations were consistently dominated by immature forms (primarily nauplii) during 2005, as has always been the case. Adult copepods rarely constituted more than 7% of the total zooplankton density at any location. *Tropocyclops* was the most important constituent of adult populations in both epilimnetic and whole-column samples, particularly during summer and fall (Table 4-3). This was also the case in previous years (Duke Power 2005).

Copepods tended to be more abundant at background locations than at mixing zone locations during 2005, and their densities peaked in the spring (May) at mixing zone locations, and at Location 11.0. The maximum annual copepod density at Location 15.9 was in the summer (Table 4-1). Copepods showed similar spatial and seasonal trends during 2004 (Figure 4-5). Historically, maximum copepod densities were most often observed during the spring.

Cladocera

Bosmina was the most abundant cladoceran observed in 2005 samples, as has been the case in most previous studies (Duke Power 2005, Hamme 1982). *Bosmina* often comprised greater than 5% of the total zooplankton densities in both epilimnetic and whole-column samples, and was the dominant zooplankter in two samples in the summer and fall (Table 4-3). *Bosminopsis* was also important among cladocerans in the summer when it dominated cladoceran populations in most samples. Similar patterns of *Bosminopsis* dominance have been observed in past years (Duke Power 2005).

Long-term seasonal trends of cladoceran densities were variable. From 1990 to 1993, peak densities occurred in the winter, while in 1994, 1995, 1997, 2000, 2004, and 2005, maxima were recorded in the spring (Figure 4-5). During 1996, 1999, and 2002, peak cladoceran densities occurred in the spring in the mixing zone, and in the summer among background locations. Maximum cladoceran densities in 1998 occurred in the summer. In 2001, maximum cladoceran densities in the mixing zone occurred in the winter, while background locations showed peaks in the fall. During 2003, maximum densities at background locations occurred in the summer, while peaks in the mixing zone were observed in the fall. Spatially, cladocerans were well distributed among most locations (Table 4-1, Figures 4-2 and 4-5).

Rotifera

Polyarthra was the most abundant rotifer in 2005 samples (Table 4-3). This taxon dominated rotifer populations in the epilimnion at Locations 2.0 and 15.9, and Location 15.9, whole-column, in April; was dominant at all but Location 15.9, epilimnion, in May, and in whole-column samples from Locations 11.0 and 15.9 in September. In December, *Polyarthra* was the dominant rotifer at all but Location 11.0, whole-column. *Conochilus* dominated rotifer populations at Locations 5.0, 9.5, and 11.0, eplilimnion, in April, as well as at Locations 2.0, 9.5 (both tows), and Location 11.0, epilimnion, in September. *Keratella* was the dominant rotifer in whole-column samples at all but Location 15.9 in April. It was also dominant in the epilimnion at Location 15.9 in May, and in the whole-column at Location 11.0 in May and December *Ptygura* was the dominant rotifer at Location 5.0 in September. All of these taxa have been identified as important constituents of rotifer populations, as well as zooplankton communities, in previous studies (Duke Power 2005; Hamme 1982).

Long-term tracking of rotifer populations indicated high year-to-year seasonal variability. Peak densities have most often occurred in the winter and spring, with an occasional peak in the summer (Figure 4-5). During 2005, peak densities were observed in the spring.

FUTURE STUDIES

No changes are planned for the zooplankton portion of the Lake Norman Maintenance Monitoring Program.

SUMMARY

Maximum zooplankton densities occurred in April at all but Location 2.0, which had its annual epilimnetic maximum in May. Minimum zooplankton densities were most often noted in September. As in past years, epilimnetic densities were higher than whole-column densities. Mean zooplankton densities tended to be higher among background locations than among mixing zone locations during 2005. In the mixing zone, a long-term trend of increasing year-to-year densities was observed for May. In addition, long-term trends showed much higher year-to-year variability at background locations than at mixing zone locations.

Epilimnetic zooplankton densities were generally within ranges of those observed in previous years. The exceptions were record high densities for spring (May) at Locations 2.0, 5.0, and 9.5.

One hundred twenty zooplankton taxa have been recorded from Lake Norman since the Program began in 1987 (41 were identified during 2005). Two previously unreported taxa (one copepod and one rotifer) were identified during 2005.

Overall relative abundance of copepods in 2005 had decreased since 2004, and they were dominant in only two samples collected during spring and fall. Cladocerans were dominant in five samples during the summer, while rotifers were dominant in over 82% of all samples. The relative abundance of microcrustaceans had increased slightly since 2004, and their relative abundances were somewhat similar to those of 1995. Historically, copepods and rotifers have most often shown annual peaks in the spring, while cladocerans continued to demonstrate year-to-year variability.

Copepods were dominated by immature forms with adults rarely accounting for more than 7% of zooplankton densities. The most important adult copepod was *Tropocyclops*, as was the case in previous years. *Bosmina* was the predominant cladoceran, as has also been the case in most previous years of the Program. *Bosminopsis* dominated most cladoceran populations during the summer. The most abundant rotifers observed in 2005, as in many previous years, were *Polyarthra*, *Conochilus*, and *Keratella*.

Lake Norman continues to support a highly diverse and viable zooplankton community. Zooplankton densities, as well as seasonal and spatial trends were generally consistent with historical precedent during 2005, and no impacts of plant operations were observed.

Table 4-1. Total zooplankton densities (Number X 1000/m^3), densities of major zooplankton taxonomic groups, and percent composition (in parentheses) of major taxa in 10 m to surface (10-S) and bottom to surface (B-S) net tow samples collected from Lake Norman in April, May, September, and December 2005.

Date	Sample Type	Taxon	Locations 2.0	5.0	9.5	11.0	15.9
4/7/05	10-S	COPEPODA	7.5	3.6	20.2	18.8	18.6
			(3.9)	(2.1)	(9.2)	(4.9)	(1.8)
		CLADOCERA	11.1	6.8	25.4	57.0	0
			(5.7)	(3.9)	(11.5)	(14.8)	(0)
		ROTIFERA	174.7	165.1	174.9	310.5	1,024.3
			(90.4)	(94.0)	(79.3)	(80.4)	(98.2)
		TOTAL	**193.3**	**175.5**	**220.5**	**386.3**	**1,042.9**
	B-S						
	Depth (m)						
	of tow	COPEPODA	7.7	7.2	29.0	7.5	15.2
	For each		(5.0)	(4.9)	(12.6)	(3.6)	(2.8)
	Location	CLADOCERA	9.0	7.0	21.5	24.7	7.0
	2.0=30		(5.8)	(4.8)	(9.3)	(11.7)	(1.3)
	5.0=19	ROTIFERA	138.1	133.0	180.3	178.1	513.7
	9.5=20		(89.2)	(90.3)	(78.1)	(84.7)	(95.9)
	11.0=25						
	15.9=21	**TOTAL**	**154.8**	**147.2**	**230.8**	**210.3**	**535.9**
5/9/05	10-S	COPEPODA	51.2	44.8	85.9	30.6	27.3
			(24.8)	(22.5)	(48.1)	(21.4)	(21.7)
		CLADOCERA	73.6	20.8	17.2	29.8	23.1
			(35.7)	(10.5)	(9.6)	(20.9)	(18.4)
		ROTIFERA	81.5	133.3	75.6	82.4	75.3
			(39.5)	(67.0)	(42.3)	(57.7)	(59.9)
		TOTAL	**206.3**	**198.9**	**178.7**	**142.8**	**125.7**
	B-S						
	Depth (m)						
	Of tow	COPEPODA	21.1	34.7	51.1	27.3	24.5
	for each		(29.4)	(24.1)	(44.0)	(30.9)	(27.8)
	Location	CLADOCERA	18.9	17.0	10.0	22.6	15.7
	2.0=30		(26.3)	(11.8)	(8.7)	(25.7)	(17.8)
	5.0=20	ROTIFERA	31.8	92.5	55.0	38.3	47.8
	9.5=21		(44.3)	(64.1)	(47.3)	(43.4)	(54.2)
	11.0=25						
	15.9=21	**TOTAL**	**71.8**	**144.2**	**116.1**	**88.2**	**88.2***

Table 4-1. (Continued).

Date	Sample Type	Taxon	Locations 2.0	5.0	9.5	11.0	15.9
9/8/05	10-S	COPEPODA	9.9	11.2	15.2	14.7	43.4
			(26.5)	(29.7)	(29.7)	(30.7)	(28.1)
		CLADOCERA	17.3	17.4	26.5	12.6	18.1
			(46.1)	(46.2)	(51.8)	(26.5)	(11.7)
		ROTIFERA	10.3	9.1	9.5	20.5	92.8
			(27.4)	(24.1)	(18.5)	(42.8)	(60.2)
		TOTAL	**37.5**	**37.7**	**51.2**	**47.8**	**154.3**
	B-S						
	Depth(m)						
	of tow	COPEPODA	8.9	12.5	12.5	20.4	27.2
	for each		(32.9)	(43.5)	(30.5)	(42.0)	(32.9)
	Location	CLADOCERA	11.4	10.1	22.3	7.7	14.5
	2.0=29		(42.5)	(35.0)	(54.5)	(15.8)	(17.5)
	5.0=18	ROTIFERA	6.6	6.1	6.1	20.6	41.0
	9.5=20		(24.6)	(21.2)	(15.0)	(42.2)	(49.6)
	11.0=25						
	15.9=20	**TOTAL**	**26.9**	**28.8***	**40.9**	**48.7**	**82.7**
12/20/04	10-S	COPEPODA	5.6	8.8	16.3	18.1	15.6
			(19.0)	(29.9)	(16.4)	(19.0)	(12.1)
		CLADOCERA	7.7	7.7	9.1	6.7	5.9
			(26.3)	(26.2)	(9.1)	(7.0)	(4.6)
		ROTIFERA	16.1	12.9	74.2	70.3	107.7
			(54.7)	(43.9)	(74.5)	(73.9)	(83.3)
		TOTAL	**29.4**	**29.4**	**99.6**	**95.1**	**129.2**
	B-S						
	Depth(m)						
	of tow	COPEPODA	10.7	5.3	19.1	23.2	12.8
	For each		(19.2)	(16.3)	(14.0)	(23.0)	(18.4)
	Location	CLADOCERA	11.6	7.1	10.2	12.1	0.9
	2.0=31		(20.9)	(21.8)	(7.4)	(11.9)	(1.2)
	5.0=16	ROTIFERA	33.4	20.2	107.5	65.9	55.6
	9.5=21		(59.9)	(61.9)	(78.6)	(65.1)	(80.4)
	11.0=26						
	15.9=22	**TOTAL**	**55.7**	**32.6**	**136.8**	**101.2**	**69.3**

* = *Chaoborus* (Insecta) observed in bottom to surface samples from 15.9 in May (196/m^3, 0.22%), and 5.0 in September (78/m^3, 0.27%).

Table 4-2. Zooplankton taxa identified from samples collected quarterly on Lake Norman from 1987 through 2005.

TAXON	87-91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
COPEPODA															
Cyclops thomasi Forbes	X			X	X		X	X	X	X	X	X	X	X	X
C. vernalis Fischer						X									
C. spp. O. F. Muller	X	X	X	X	X	X	X	X			X	X	X		
Diaptomus birgei Marsh	X		X							X					
D. mississippiensis Marsh	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
D. pallidus Herick	X		X		X	X	X		X				X		X
D. reighardi Marsh									X						
D. spp. Marsh	X	X	X	X	X	X	X	X	X	X		X	X		
Epishura fluviatilis Herrick					X	X	X	X	X	X	X	X	X	X	X
Ergasilus spp.						X									
Eucyclops agilis (Koch)								X							
Mesocyclops edax (S. A. Forbes)	X			X	X	X	X	X	X	X	X	X	X	X	X
M. spp. Sars	X	X	X	X	X	X	X				X	X	X		
Paracyclops limbricatus v. *poppei*															X
Tropocyclops prasinus (Fischer)	X				X	X	X	X	X	X	X	X	X	X	X
T. spp. (Fischer)	X	X	X	X	X	X	X				X	X		X	
Calanoid copepodites	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cyclopoid copepodites	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Harpacticoidea		X	X			X									X
Nauplii	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Parasitic copepods									X						
CLADOCERA															
Alona spp.Baird						X	X								
Alonella spp. (Birge)				X					X						
Bosmina longirostris (O. F. M.)	X		X				X	X	X	X	X	X	X	X	X
B. spp. Baird	X	X	X	X	X	X	X	X		X	X	X			
Bosminopsis dietersi Richard	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ceriodaphnia lacustris Birge	X						X	X	X	X	X		X	X	X
C. spp. Dana	X	X	X	X	X	X	X	X	X	X	X	X	X		
Chydorus spp. Leach	X		X	X	X	X	X		X		X	X		X	X
Daphnia ambigua Scourfield	X					X	X	X	X		X				X
D. catawba Coker						X	X				X				
D. galeata Sars						X									
D. laevis Birge						X							X		
D. longiremis Sars						X	X			X	X		X	X	
D. lumholzi Sars	X		X	X	X	X		X	X	X					X
D. mendotae (Sars) Birge							X	X	X	X			X		
D. parvula Fordyce	X				X	X	X	X	X	X	X	X	X	X	X
D. pulex (de Geer)						X	X								
D. pulicaria Sars						X	X								
D. retrocurva Forbes						X	X	X	X	X		X	X	X	X
D. schodleri Sars						X									
D. spp. Mullen	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Diaphanosoma brachyurum (Lievin)							X	X	X	X	X	X	X	X	X

Table 4-2. (Continued).

TAXON	87-91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
D. spp. Fischer	X	X	X	X	X	X	X	X		X	X	X	X	X	
Disparalona acutirostris (Birge)														X	
Eubosmina spp. (Baird)	X														
Holopedium amazonicum Stin..	X						X	X	X	X	X	X		X	X
H. gibberum Zaddach	X						X	X							
H. spp. Stingelin	X	X	X	X	X	X	X			X	X	X	X		
Ilyocryptus sordidus (Lieven)	X														
I. spinifer Herrick									X						
I. spp. Sars		X	X	X				X		X					
Latona setifera (O.F. Muller)	X														
Leptodora kindtii (Focke)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Leydigia acanthoceroides (Fis.)														X	
L. spp. Freyberg			X	X	X	X	X						X	X	
Moina spp. Baird	X														
Monospilus dispar Sars													X		
Oxurella spp. (Sars)														X	
Pleuroxus hamulatus Birge													X		
P. spp. Baird													X		
Sida crystallina O. F. Muller	X	X													
Simocephalus expinosus (Koch)		X													
Simocephalus spp. Schodler									X						
ROTIFERA															
Anuraeopsis fissa (Gosse)														X	
A. spp. Lauterborne	X	X	X		X		X		X					X	
Asplanchna brightwelli Gosse								X		X					
A. priodonta Gosse								X	X	X				X	
A. spp. Gosse	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Brachionus calyciflorus															X
Brachionus caudata Bar. & Dad.	X														
B. bidentata Anderson													X		
B. havanensis Rousselet	X						X								
B. patulus O. F. Muller	X							X							
B. spp. Pallas	X		X		X	X		X							
Chromogaster ovalis (Berg.)							X	X	X		X				X
C. spp. Lauterborne	X	X	X	X	X	X									
Collotheca balatonica Harring						X	X	X	X	X		X	X	X	X
C. mutabilis (Hudson)						X	X	X	X	X			X	X	X
C. spp. Harring	X	X	X	X	X	X	X	X		X	X	X	X		
Colurella spp. Bory de St. Vin.						X									
Conochiloides dossuarius Hud.							X	X	X	X	X	X	X	X	X
C. spp. Hlava	X	X	X	X	X	X	X				X		X		
Conochilus unicornis (Rouss.)	X						X	X	X	X	X	X	X	X	X
C. spp. Hlava	X	X	X	X	X	X	X				X	X			
Filinia spp. Bory de St. Vincent			X	X				X						X	
Gastropus stylifer Imhof								X	X	X	X			X	
G. spp. Imhof	X	X	X	X	X	X	X	X			X				
Hexarthra mira Hudson							X	X	X	X		X			
H. spp. Schmada	X	X	X	X	X	X	X				X				

Table 4-2. (Continued).

TAXON	87-91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Kellicottia bostoniensis (Rou.)	X			X	X	X	X	X	X	X	X	X	X	X	X
K. longispina Kellicott							X	X	X	X	X	X	X	X	X
K. spp. Rousselet	X	X	X	X	X	X	X				X	X	X	X	X
Keratella cochlearis									X	X				X	
K. taurocephala Myers							X		X					X	X
K. spp. Bory de St. Vincent	X	X	X	X	X	X	X	X	X	X	X	X		X	X
Lecane spp. Nitzsch	X	X		X	X		X	X		X		X	X		X
Macrochaetus subquadratus P.							X	X							
M. spp. Perty	X		X			X			X	X		X			X
Monostyla stenroosi (Meiss.)	X														
M. spp. Ehrenberg	X			X	X	X		X					X		
Notholca spp. Gosse				X		X		X							
Platyias patulus Harring												X			
Ploeosoma hudsonii Brauer	X			X	X	X	X	X	X	X	X	X	X	X	X
P. truncatum (Levander)	X			X	X	X	X	X	X	X	X	X	X	X	X
P. spp. Herrick	X	X	X	X	X	X		X			X				
Polyarthra euryptera (Weir.)	X							X						X	
P. major Burckhart							X		X	X		X	X	X	X
P. vulgaris Carlin	X						X		X	X	X	X	X	X	X
P. spp. Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Pompholyx spp. Gosse						X									
Ptygura libra Meyers							X	X		X		X	X	X	X
P. spp. Ehrenberg	X	X	X	X	X	X	X					X	X		
Synchaeta spp. Ehrenberg	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Trichocerca capucina (Weir.)	X			X	X	X	X	X				X			
T. cylindrica (Imhof)	X				X	X	X	X	X	X		X	X	X	X
T. longiseta Schrank							X								
T. multicrinis (Kellicott)								X	X	X		X	X	X	X
T. porcellus (Gosse)					X	X	X		X	X		X		X	
T. pusilla Jennings							X								
T. similis Lamark					X										
T. spp. Lamark	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Trichotria spp. Bory de St. Vin.						X						X		X	
Unidentified Bdelloida	X	X	X	X			X	X	X					X	
Unidentified Philodinidae														X	
Unidentified Rotifera	X	X	X	X	X	X	X	X	X	X					
INSECTA															
Chaoborus spp. Lichtenstein	X	X	X					X	X		X	X		X	X
OSTRACODA (unidentified)								X					X	X	

Table 4-3. Dominant taxa among copepods (adults), cladocerans, and rotifers, and their densities as percent composition (in parentheses) of their taxonomic groups in Lake Norman samples during 2005.

	APRIL	MAY	SEPTEMBER	DECEMBER
		COPEPODA	**EPILIMNION**	
2.0	*Tropocyclops* (4.3)*	*Epishura* (7.9)*	*Tropocyclops* (9.6)*	*Tropocyclops* (4.0)*
5.0	*Epishura* (8.4)*	*Epishura* (3.9.)	*Tropocyclops* (3.8)*	*Tropocyclops* (11.8)
9.5	*Epishura* (3.5)	*Tropocyclops* (4.1)	*Tropocyclops* (11.0)*	*Tropocyclops* (3.6)*
11.0	*Cyclops* (3.7)*	*Tropocyclops* (3.6)	*Tropocyclops* (6.5)	*Tropocyclops* (9.1)
15.9	No adults	*Cyclops* (2.8)	*Tropocyclops* (3.8)	*Tropocyclops* (1.8)*
		COPEPODA	**WHOLE-COLUMN**	
2.0	*Tropocyclops* (3.5)	*Epishura* (5.9)	*Tropocyclops* (17.4)	*Tropocyclops* (9.4)
5.0	*Tropocyclops* (7.7)	*Epishura* (4.4)	*Tropocyclops* (8.7)*	*Tropocyclops* (11.2)
9.5	*Epishura* (2.5)	*Epishura* (9.8)	*Tropocyclops* (7.9)	*Tropocyclops* (1.7)*
11.0	*Epishura* (4.0)*	*Epishura* (5.0)	*Mesocyclops* (9.2)	*Mesocyclops* (19.4)
15.9	*Cyclops* (2.0)*	*Cyclops* (9.4)	*Mesocyclops* (13.0)	*Tropocyclops* (3.3)
		CLADOCERA	**EPILIMNION**	
2.0	*Bosmina* (100.0)	*Bosmina* (98.9)	*Bosminopsis* (90.3)	*Bosmina* (100.0)
5.0	*Bosmina* (100.0)	*Bosmina* (96.0)	*Bosminopsis* (96.7)	*Bosmina* (96.7)
9.5	*Bosmina* (98.7)	*Bosmina* (67.0)	*Bosminopsis* (75.5)	*Bosmina* (97.1)
11.0	*Bosmina* (98.8)	*Bosmina* (82.2)	*Bosminopsis* (44.3)	*Bosmina* (95.7)
15.9	No cladocerans	*Daphnia* (92.1)	*Bosmina* (42.1)	*Bosmina* (100.0)
		CLADOCERA	**WHOLE-COLUMN**	
2.0	*Bosmina* (97.0)	*Bosmina* (96.6)	*Bosminopsis* (73.2)	*Bosmina* (100.0)
5.0	*Bosmina* (97.2)	*Bosmina* (89.7)	*Bosminopsis* (88.4)	*Bosmina* (100.0)
9.5	*Bosmina* (96.6)	*Bosmina* (52.8)	*Bosminopsis* (64.0)	*Bosmina* (100.0)
11.0	*Bosmina* (95.0)	*Bosmina* (65.6)	*Bosmina* (12.9)	*Bosmina* (94.9)
15.9	*Bosmina* (100.0)	*Daphnia* (75.3)	*Bosmina* (42.3)	*Bosmina* (100.0)

Table 4-3. (Continued).

	APRIL	MAY	SEPTEMBER	DECEMBER
		ROTIFERA	**EPILIMNION**	
2.0	*Polyarthra* (38.9)	*Polyarthra* (60.1)	*Conochilus* (46.4)	*Polyarthra* (48.2)
5.0	*Conochilus* (41.5)	*Polyarthra* (66.2)	*Ptygura* (29.9)	*Polyarthra* (76.3)
9.5	*Conochilus* (43.5)	*Polyarthra* (71.0)	*Conochilus* (43.8)	*Polyarthra* (58.7)
11.0	*Conochilus* (42.8)	*Polyarthra* (62.2)	*Conochilus* (41.9)	*Polyarthra* (46.6)
15.9	*Polyarthra* (73.5)	*Keratella* (26.3)	*Conochilus* (49.0)	*Polyarthra* (39.6)
		ROTIFERA	**WHOLE-COLUMN**	
2.0	*Keratella* (41.3)	*Polyarthra* (70.1)	*Conochilus* (55.6)	*Polyarthra* (55.1)
5.0	*Keratella* (36.4)	*Polyarthra* (76.8)	*Ptygura* (30.7)	*Polyarthra* (57.4)
9.5	*Keratella* (44.7)	*Polyarthra* (69.0)	*Conochilus* (29.5)	*Polyarthra* (55.1)
11.0	*Keratella* (48.5)	*Polyarthra* (52.2)	*Polyarthra* (41.0)	*Keratella* (39.0)
15.9	*Polyarthra* (75.6)	*Polyarthra* (28.8)	*Polyarthra* (45.0)	*Polyarthra* (38.5)

* = Only adults present in samples.

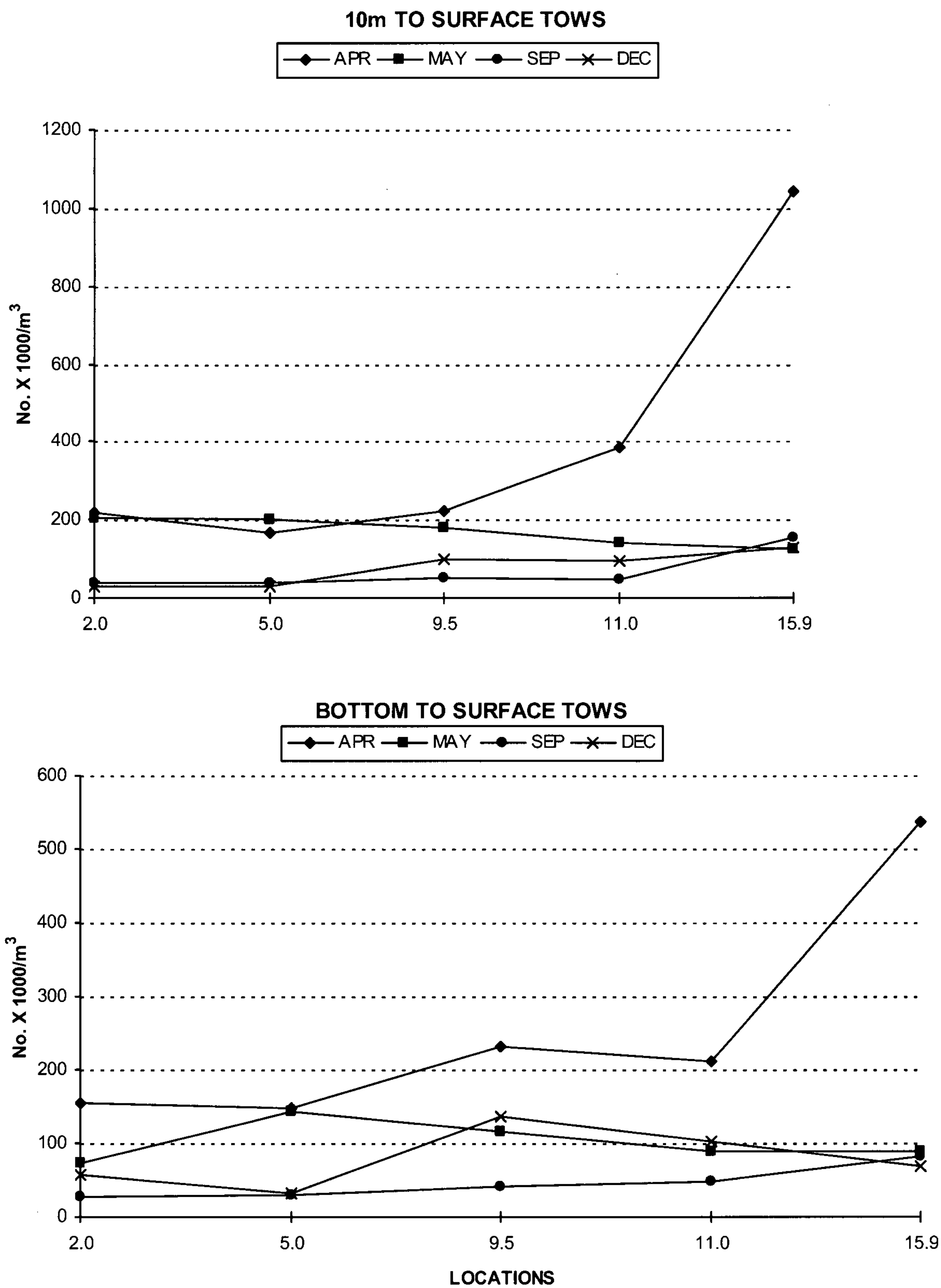


Figure 4-1. Total zooplankton density by location for samples collected in Lake Norman in 2005.

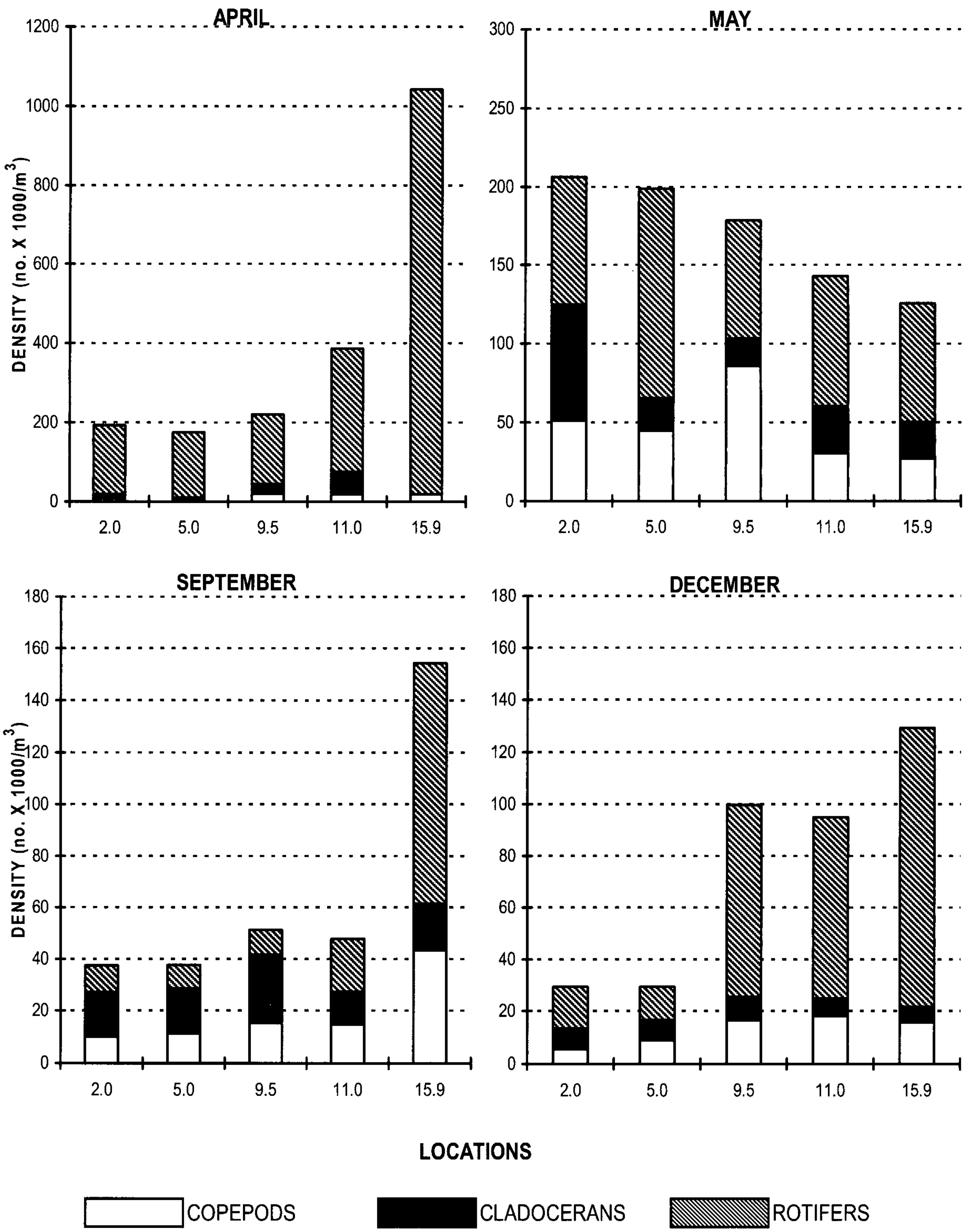
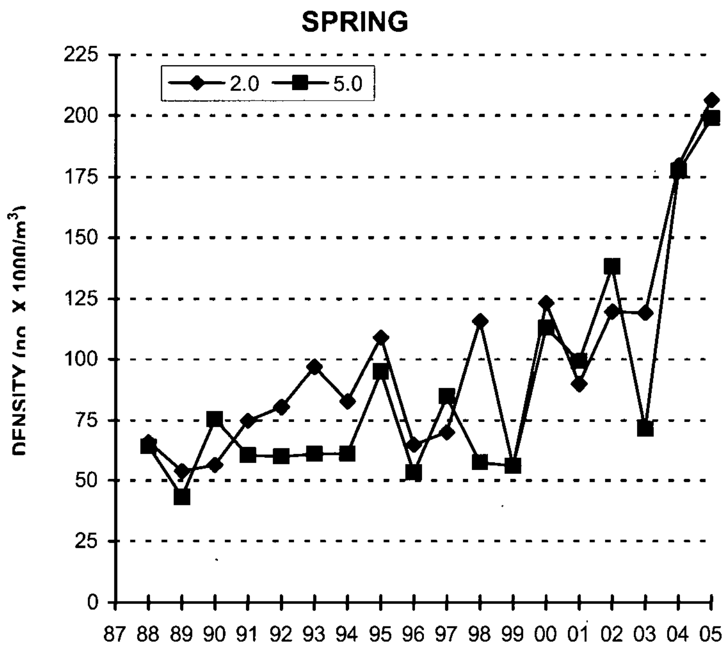


Figure 4-2. Zooplankton community composition by month for epilimnetic samples collected in Lake Norman in 2005.

MIXING



BACKGROUND

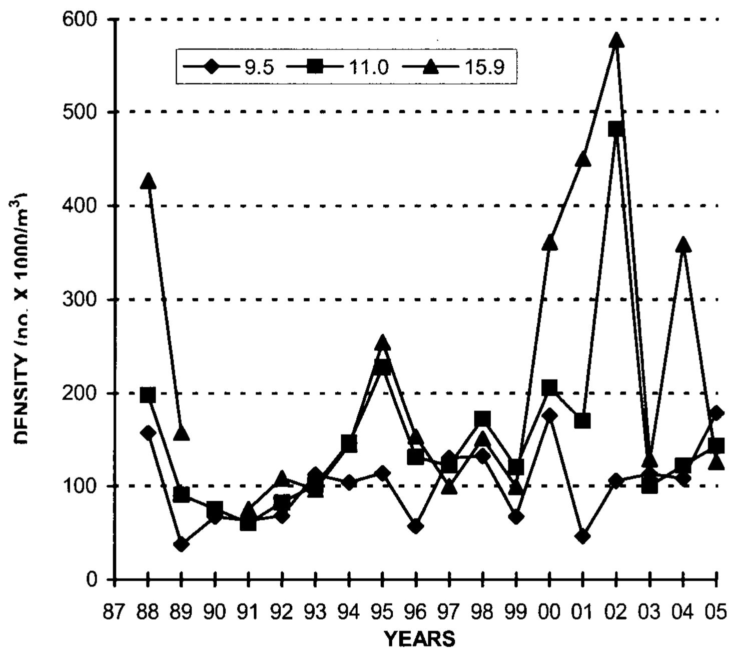


Figure 4-3. Total zooplankton densities by location for epilimnetic samples collected in Lake Norman in spring periods of 1988 through 2005.

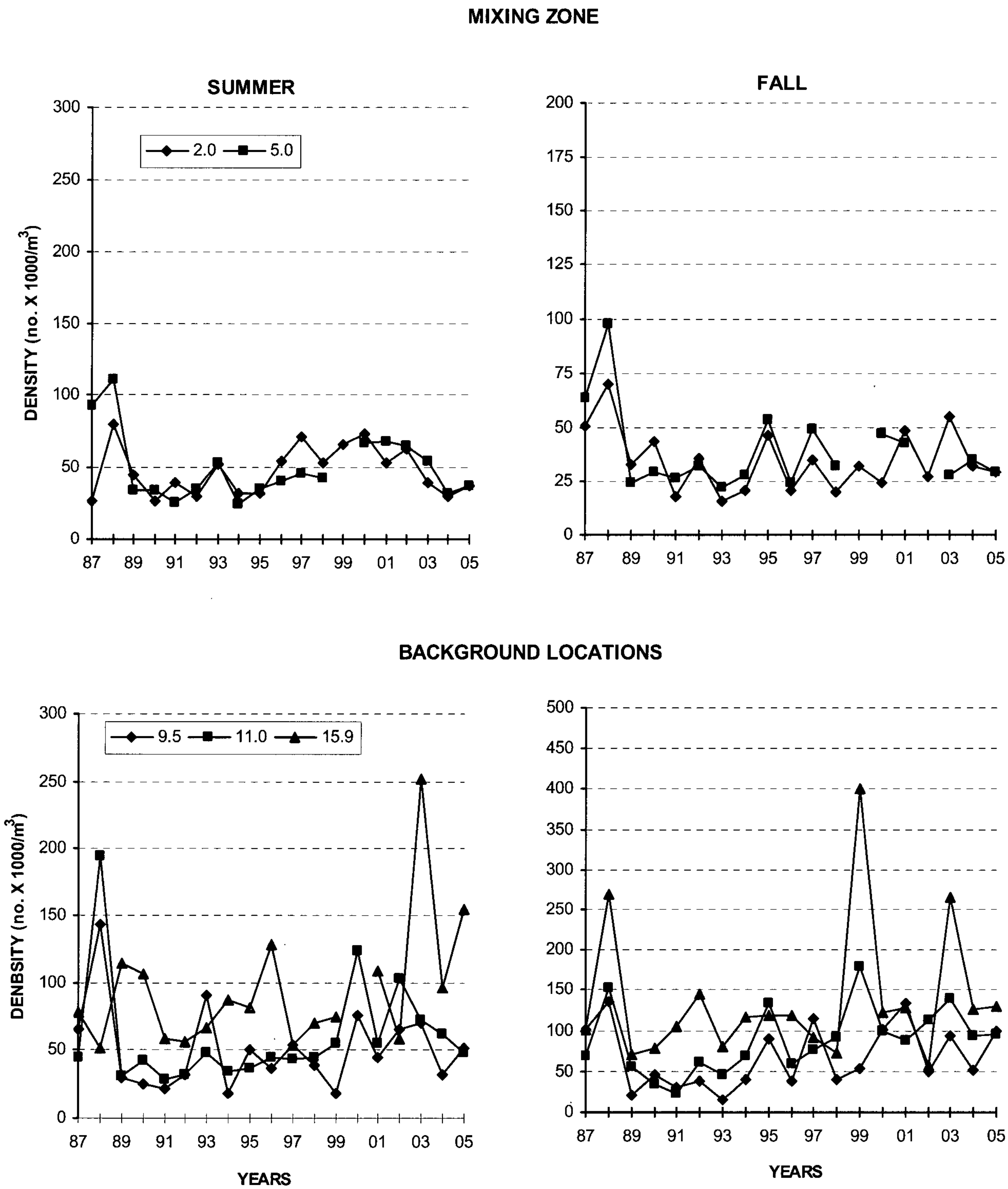


Figure 4-4. Total zooplankton densities by location for epilimnetic samples collected in Lake Norman in summer and fall periods of 1987 through 2005.

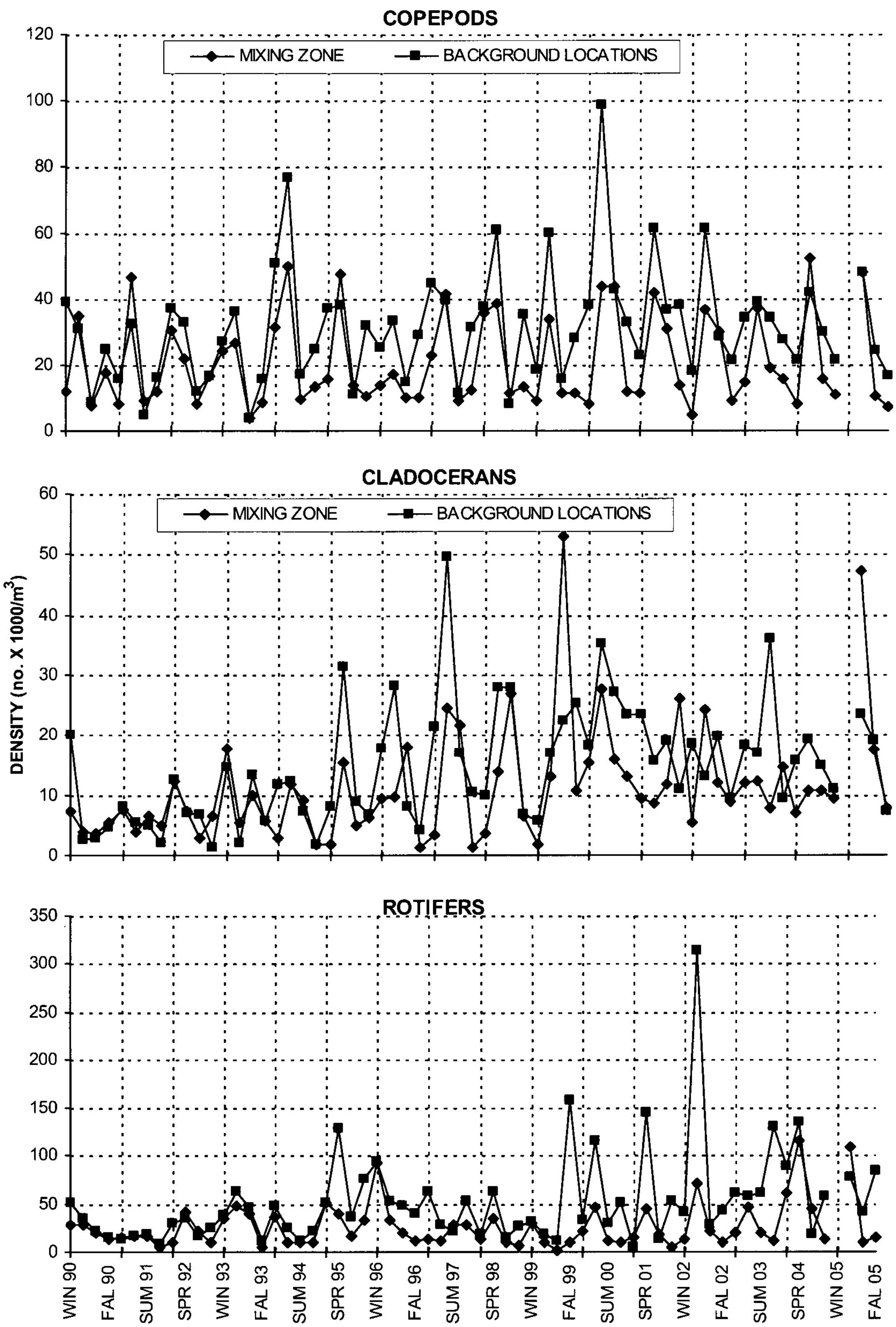
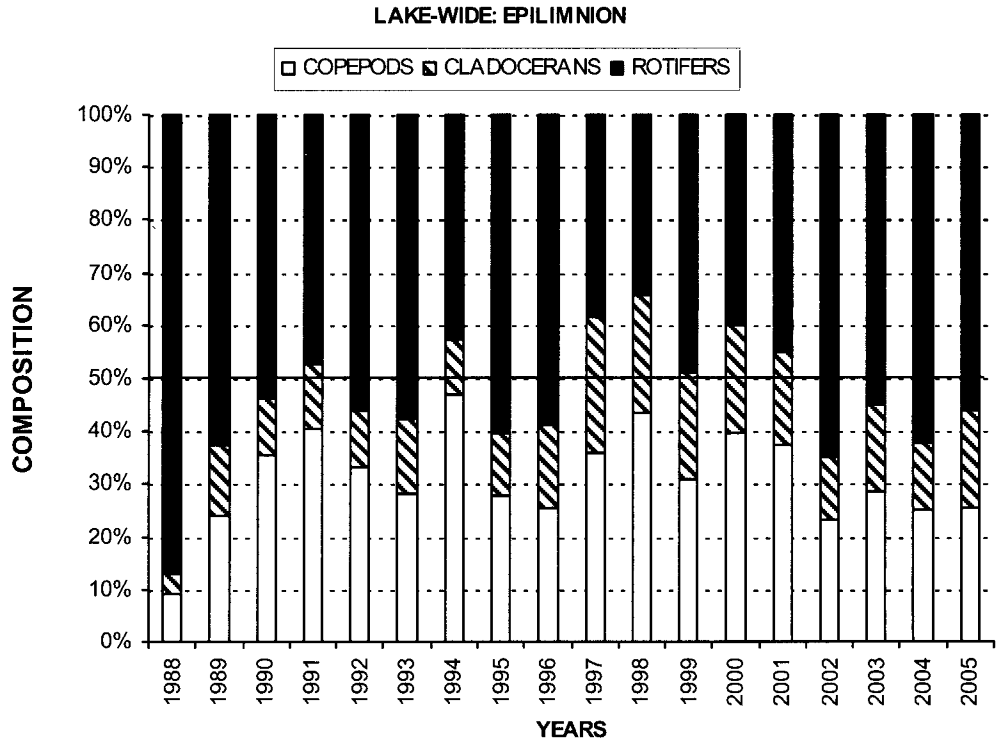


Figure 4-5. Zooplankton composition by quarter for epimlimnetic samples collected in Lake Norman from 1990 through 2005.



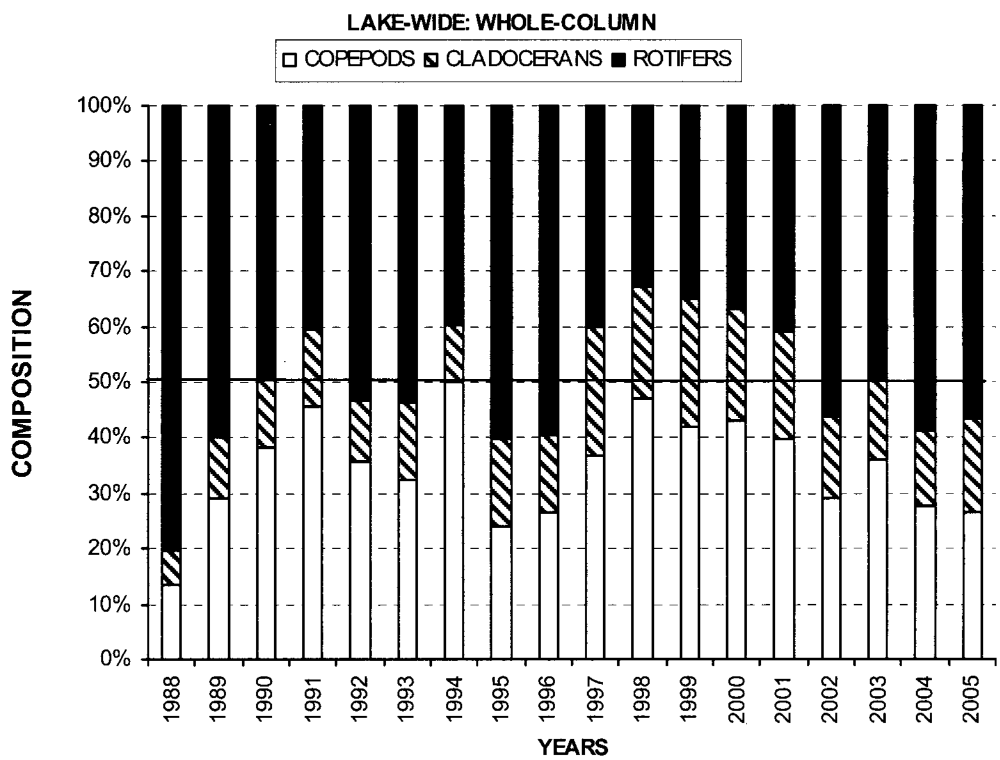
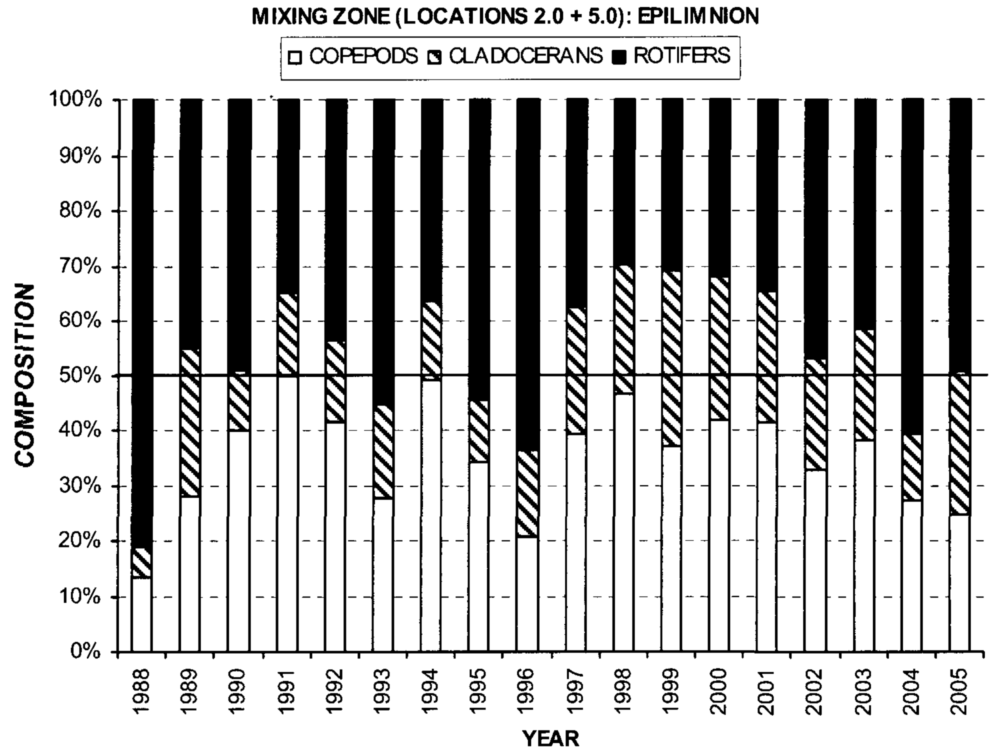


Figure 4-6. Annual lake-wide percent composition of major zooplankton taxonomic groups from 1988 through 2005 (Note: Does not include Locations 5.0 in November 2002 or winter samples from 2005).



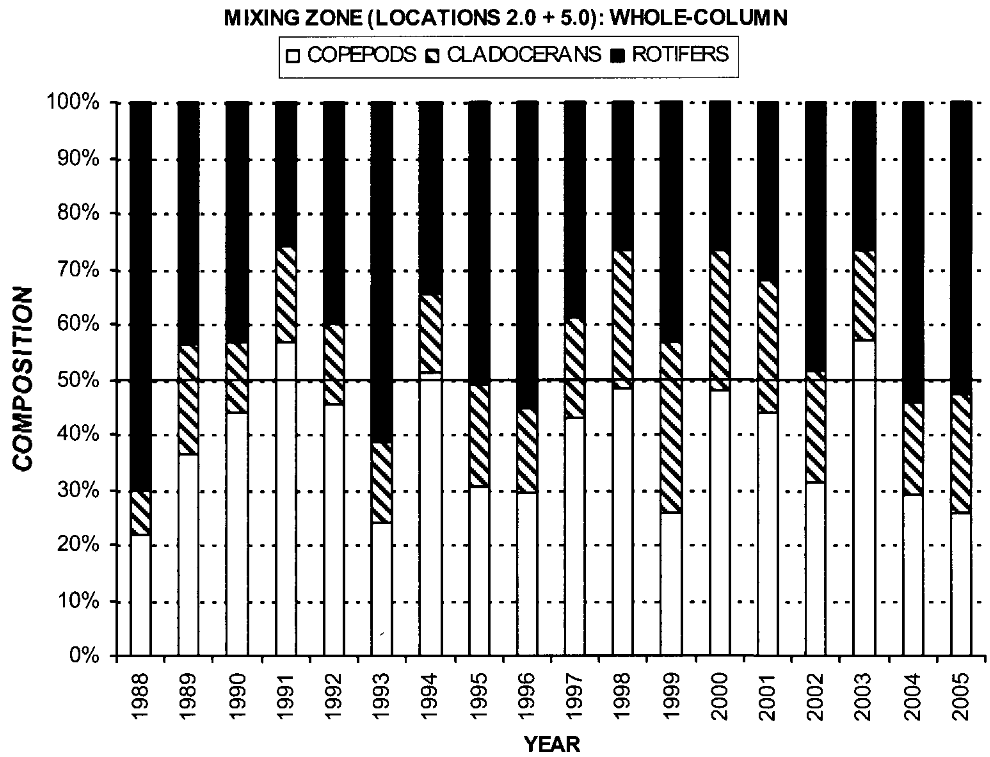
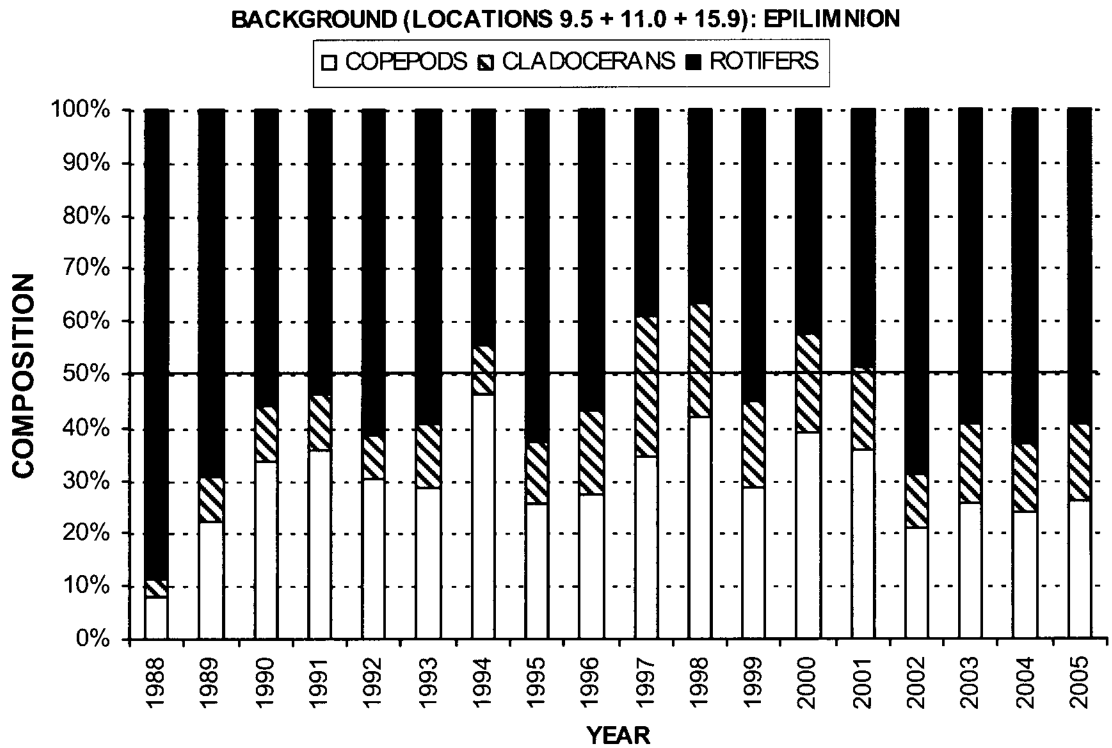


Figure 4-7. Annual percent composition of major zooplankton taxonomic groups from mixing zone locations: 1988 through 2005 (Note: Does not include Location 5.0 in November 2002 or winter samples from 2005).



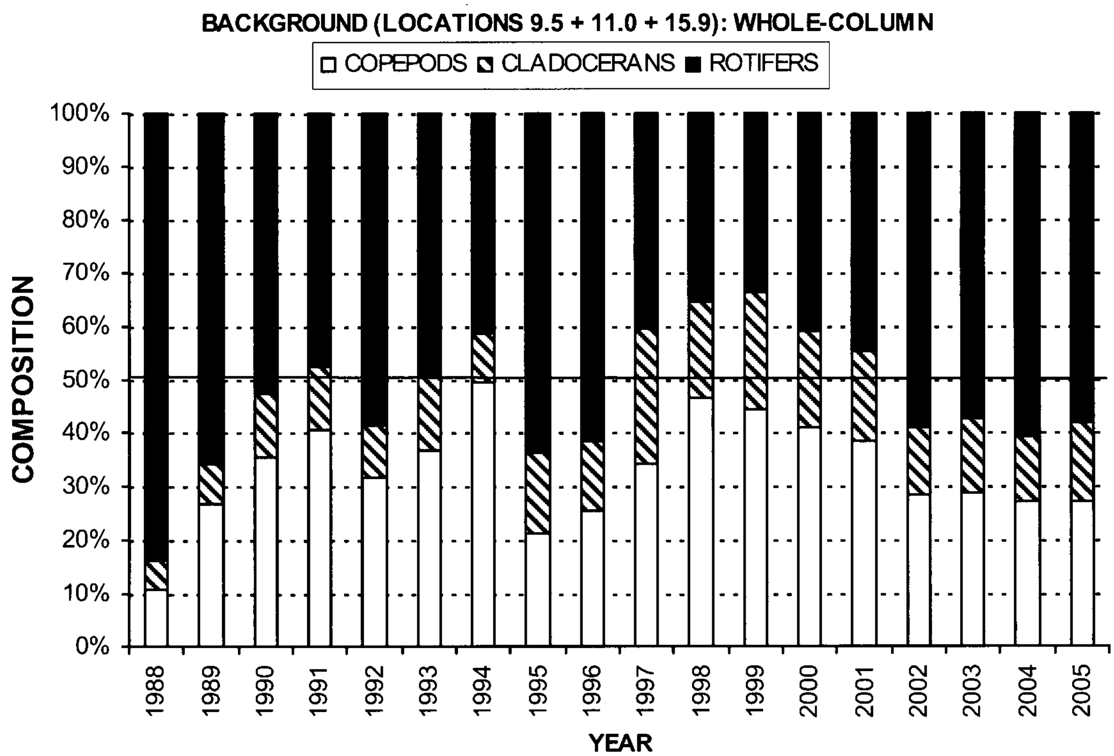


Figure 4-8. Annual percent composition of major zooplankton taxonomic groups from background locations: 1988 through 2005 (Note: Does not include winter samples from 2005).

CHAPTER 5

FISHERIES

INTRODUCTION

In accordance with the NPDES permit for McGuire Nuclear Station (MNS), monitoring of specific fish population parameters in Lake Norman continued during 2005. The components of this portion of the Lake Norman Maintenance Monitoring Program were:

1. spring electrofishing surveys of littoral fish populations with emphasis on age, growth, size distribution, and relative weight (W_r) of spotted bass and largemouth bass. Scientific names of fish mentioned in this chapter are listed in Table 5-1.
2. summer striped bass mortality monitoring;
3. cooperative striped bass study with the North Carolina Wildlife Resources Commission (NCWRC) with emphasis on age, growth, and W_r;
4. exploration of the potential for collecting population data on catfish in conjunction with the striped bass study;
5. cooperative trap-net surveys with NCWRC for white crappies and black crappies, with emphasis on age and growth;
6. fall hydroacoustic and purse seine surveys of pelagic prey fish to determine their abundance and species composition.

METHODS AND MATERIALS

Spring Electrofishing Surveys

Spring electrofishing surveys were conducted in March at three locations: (1) near Marshall Steam Station (MSS) in Zone 4, (2) a reference (REF) area located between MNS and MSS in Zone 3, and (3) near MNS in Zone 1 (Figure 5-1). The locations sampled in 2005 were identical to historical sites sampled since 1993 and consisted of ten 300-m shoreline transects at each location. All transects included the various types of fish habitat found in Lake Norman. The only areas excluded were shallow flats where the boat could not access the area within 3-4 m of the shoreline. All sampling was conducted during daylight, when water temperatures generally ranged from 15 to 20 °C (59 to 68 °F). All stunned fish were collected and identified to species. Except for spotted bass and largemouth bass, all other fish were counted and weighed (g) in aggregate by taxon. Individual total lengths (mm) and weights were obtained for all spotted and largemouth bass collected. Sagittal otoliths were removed from all bass > 125 mm long (all fish < 125 mm were assumed to be age 1 because young-of-year bass are not collected in these spring samples) and sectioned for age determination (Devries and Frie 1996). Growth rates were calculated as the mean length for all fish of the same age. Relative weight was calculated for spotted bass $\geq$100 mm long and largemouth bass $\geq$150 mm long, using the formula $W_r = (W/W_s) \times 100$, where W = weight of the individual fish (g) and W_s = length-specific mean weight (g) for a fish as predicted by a weight-length equation for that species (Anderson and Neumann 1996).

Striped Bass Netting Survey

Striped bass for age, growth, and W_r determinations were collected in early December by NCWRC and Duke Energy (DE) personnel. Four monofilament nets (76.2 m long x 6.1 m deep), two each containing two 38.1 m panels of 38- and 51-mm mesh (square measure) and two each containing similar panels of 63- and 76 mm mesh, were set overnight in areas where striped bass had been previously located. Individual total lengths and weights were obtained for all striped bass collected and sagittal otoliths were removed from a randomly selected subsample of the total catch. Age, growth, and W_r were determined for these subsampled fish as well as W_r for all collected fish as described earlier for largemouth bass. In addition, all catfish collected in these gill nets were identified to species and enumerated.

Crappie Trap-net Study

White crappie and black crappie populations in Lake Norman were sampled cooperatively by the NCWRC and DE in late October and early November using trap nets as described by Nelson and Dorsey (2005). Personnel from DE sampled downlake (below the Highway 150 bridge) and NCWRC personnel sampled uplake. Total length and weight were obtained for all collected white and black crappies and sagittal otoliths were removed from all crappies for age and growth determinations.

Fall Hydroacoustics and Purse Seine

The abundance and distribution of pelagic prey fish in Lake Norman was determined using mobile hydroacoustic (Brandt 1996) and purse seine (Hayes et al. 1996) techniques. The mobile hydroacoustic survey of the entire lake was conducted in September to estimate forage fish populations. Hydroacoustic surveys employed multiplexing, side-scan and down-looking transducers to detect surface-oriented fish and deeper fish (from 2.0 m below the water surface to the bottom), respectively. Both transducers were capable of determining target strength directly by measuring fish position relative to the acoustic axis. The lake was divided into six zones (Figure 5-1) due to its large size, spatial heterogeneity, and multiple power generation facilities.

Purse seine samples were also collected in September from the lower (Zone 1), mid (Zone 2), and uplake (Zone 5) areas of the reservoir. The purse seine measured 118 x 9 m with a mesh size of 4.8-mm. A subsample of forage fish collected from each area was used to determine taxa composition and size distribution.

RESULTS AND DISCUSSION

Spring Electrofishing Surveys

Electrofishing resulted in the collection of 1,814 fish (21 species and 1 hybrid complex) weighing 116 kg from the MSS area, 2,397 fish (19 species and 2 hybrid complexes) weighing 99 kg from the REF area, and 2,442 fish (16 species and 2 hybrid complexes) weighing 69 kg from the MNS area (Table 5-2). A variety of species including alewives, threadfin shad, whitefin shiners, spottail shiners, white perch, redbreast sunfish, warmouth, bluegills, redear sunfish, hybrid sunfish, spotted bass, and largemouth bass dominated samples numerically while alewives, threadfin shad, common carp, redbreast sunfish, bluegills, redear sunfish, spotted bass, and largemouth bass dominated samples gravimetrically.

Overall, total numbers of fish collected in spring 2005 were highest in the REF and MNS areas and lowest in the MSS area. This appeared to be primarily related to the higher numbers of threadfin shad (and alewives in the MNS area) collected in these areas compared to the MSS area. Fish biomass was highest, however, in the MSS area, intermediate in the REF area, and lowest in the MNS area. Since 1993, the numbers and biomass of fish collected in the sampled areas have varied annually with no apparent trend in area catch rates (Figure 5-2).

While numbers of fish collected in the electrofishing samples have fluctuated among areas and years, fish biomass has remained fairly stable among years. An exception was noted in 2003 when large numbers of common carp were collected in the MSS area that greatly inflated total fish biomass here over what has been normally observed. Biomass was generally highest in the MSS area, intermediate in the REF area, and lowest in the MNS area during most years. This trend in fish biomass continued to support the spatial heterogeneity theory noted by Siler et al. (1986) for fish biomass in Lake Norman. They reported that fish biomass was higher uplake than downlake due to higher levels of nutrients and productivity in the uplake area compared to the downlake area. Additional support for spatial heterogeneity is evidenced by higher concentrations of chlorophyll *a*, greater phytoplankton standing crops, and elevated epilimnetic zooplankton densities in uplake compared to downlake regions of Lake Norman (Chapters 3 and 4).

Spotted bass in Lake Norman were thought to have originated from angler introductions and were first collected here in the 2001 spring electrofishing samples. They have generally increased in abundance (both numbers and biomass) in all sampled areas since 2001 (Figure 5-3) and are presently most abundant in the MNS area, intermediate in the MSS area, and least abundant in the REF area. In 2005, small spotted bass (< 150 mm) was the dominant size range collected in all areas sampled (Figure 5-4) and their growth rate was generally similar among all areas sampled (Table 5-3). Spotted bass W_r ranged from 66 for fish 100-149 mm long in the MNS area to 93 for fish 300-349 mm long in the REF area (Figure 5-5). Values of W_r for most sizes of spotted bass collected in 2005 appeared similar among the three sampling areas.

The numbers of largemouth bass collected in 2005 were similar in the MSS and REF areas, and considerably higher than noted in the MNS area (Table 5-2). Largemouth bass biomass was, however, highest in the MSS area, intermediate in the REF area, and lowest in the MNS area. Overall, largemouth bass abundance (numbers and biomass) in 2005 was generally similar to that noted over the past several years (Figure 5-6), with one exception. A decline was noted in the numbers of largemouth bass collected at the MSS area from 2004 to 2005.

Since about 2000, larger fish (e.g., 300-349, 350-399, and 400-449 mm size groups) have dominated the largemouth bass population in all three sampling areas (Duke Power 2001, 2002, 2003, 2004a, 2005), and this continued in 2005 (Figure 5-4). The low abundance of small or young fish in the population appears to indicate that largemouth bass recruitment continues to be a concern in 2005. While displacement of largemouth bass by spotted bass in the lower lake is apparent, it remains difficult to determine if largemouth bass recruitment has been impacted solely by spotted bass or in combination with introduced alewives and white perch.

It is also difficult to determine if these introductions have affected growth or W_r for largemouth bass in 2005. In 2005, age 1 largemouth bass growth was highest for fish in the MSS area and somewhat lower but similar in the REF and MNS areas (Table 5-3). At age 2, mean lengths for fish in the MNS area were much higher than noted in the MSS and REF areas, but these differences were not as noticeable in older fish. Mean lengths for age 1 largemouth bass from the MSS and REF areas in 2005 were similar to previously collected data from these areas (Table 5-4). However, mean length for age 1 fish from the MNS area was the lowest noted since 1971-78 (Table 5-4). Mean lengths for ages 2, 3, and 4 largemouth bass collected from the MSS and REF areas in 2005 were similar to that noted in 2003-2004, but were somewhat higher than noted in these areas in 1974-78 and 1993-94. Mean lengths for age 2, 3, and 4 fish from the MNS area were higher than noted here previously. Largemouth bass W_r was similar for all sizes of fish in all sampled areas in 2005 (Figure 5-5) and similar to that noted in 2003 and 2004 (Duke Power 2004a, 2005).

Summer Striped Bass Mortality Surveys

In 2005, a total of 20 dead striped bass were collected during the July-August surveys (Table 5-5). This total was less than 1% of the 2,610 dead striped bass that were collected during this same period in 2004 (Duke Power 2005), but similar to that noted in 2003 when 10 fish were reported (Duke Power 2004). Most of the dead fish in 2005 were collected in Zone 1 from August 3 to August 16.

Striped Bass (and Catfish) Netting Survey

In December 2005, 224 striped bass were collected for age, growth, and W_r determinations and 131 of these fish were aged by sectioned otolith. Mean total length at age was 518, 542, 549, 526, 564, 613, and 533 mm at ages 1-8, respectively (Figure 5-7). Growth of Lake Norman striped bass was slow after age 3 as noted previously (Duke Power 2004a, 2005) and W_r for the aged fish was generally highest for young fish and lowest for older fish. Overall, mean W_r for all fish (224) in 2005 was 84 and was slightly higher than the 81 noted in 2003 (Duke Power 2004a) and the 79 in 2004 (Duke Power 2005).

In addition to the collection of striped bass in the December gillnetting, 34 catfish were collected. Blue catfish (19) dominated the catch, followed by flathead catfish (9), and channel catfish (6). These data were shared with the NCWRC.

Crappie Trap-net Study

Duke Energy personnel collected 162 crappies (2 white and 160 black crappies) in 59 trap-net sets from Lake Norman in 2005. These data and the collected otoliths were delivered to the NCWRC for summarization.

Fall Hydroacoustics and Purse Seine

Average forage fish densities in the six zones of Lake Norman ranged from 367 to 7,584 fish/ha in September 2005 (Table 5-6). Forage fish densities were highest in Zone 5, intermediate in Zones 1, 2, 3 and 4, and lowest in Zone 6. The limited amount of available habitat for sampling (i.e., shallow water where physical damage to the transducers by collision with the bottom is a high probability) in Zone 6 complicated any discussion of fish densities in this uppermost zone of Lake Norman. The lakewide population estimate in September 2005, approximately 73.2 million fish, was comparable to values measured from 1997 to 2003 when estimates ranged from 64.3 to 91.3 million fish (Figure 5-8). The 2005 population estimate was well above the low estimate of 47.1 million recorded in 2004. No trends have been noted in zonal or lakewide population pelagic fish estimates in Lake Norman from 1997 through 2005.

Purse seine sampling in 2005 indicated that the forage fish sampled by hydroacoustics were 98.1% threadfin shad and 1.9% alewives (Table 5-7). No gizzard shad were collected in the purse seine samples. Threadfin shad lengths primarily ranged from 31 to 70 mm while alewife lengths averaged approximately 75 mm (Figure 5-9). The modal length of threadfin shad was between 36 and 45 mm in 2005. Results from purse seining have undergone a dramatic shift in recent years (Table 5-7). From 1993 through 1999, purse seine samples were dominated by small threadfin shad (typically ≤ 55 mm long). Alewives were first detected in 1999 in low numbers and increased to approximately 25% of the open water forage fish community in 2002, and their presence was accompanied by a concurrent wider size range of individuals with a larger modal length class. The percent contribution from alewives has declined since 2002 and was approximately 1.9% of the forage fish catch in 2005. The decline in the percent composition of alewife has been accompanied by a progressively narrower size range of fish and a decline in modal length class of forage individuals towards value measured prior to the alewife invasion.

FUTURE STUDIES

The only suggested change to the fish portion of the Lake Norman Maintenance Monitoring Program is to implement a cooperative fall electrofishing program with the NCWRC to sample young-of-year black bass.

SUMMARY

In accordance with the Lake Norman Maintenance Monitoring Program for the NPDES permit for MNS, specific fish monitoring programs were coordinated with the NCWRC and continued during 2005. Spring electrofishing indicated that 16 to 21 species of fish and 2 hybrid complexes comprised fish populations in the 3 sampling areas, and numbers and biomass of fish in 2005 were generally similar to those noted since 1993. Declines in largemouth bass numbers, which were first observed in 2000, appear to be an exception. During summer 2005, low numbers (20) of striped bass mortalities were observed; this was a significant decline from the 2,610 fish observed during summer 2004 but similar to historical observations. Mean W_r for Lake Norman striped bass collected in November and December 2005 was 84 and slightly higher compared to values measured in 2003 and 2004. Trapnetting indicated little change in the crappie populations in Lake Norman in 2003-2004. Hydroacoustic sampling resulted in a prey fish population estimate comparable to values measured from 1997 to 2003. Purse seine sampling has continued to show declining percentages of alewife to the forage fish species composition and a shift in threadfin shad lengths back to the smaller size ranges observed prior to the alewife invasion.

Table 5-1. Common and scientific names of fish collected in Lake Norman, 2005.

Common name	Scientific name
Alewife	*Alosa pseudoharengus*
Gizzard shad	*Dorosoma cepedianum*
Threadfin shad	*Dorosoma petenense*
Greenfin shiner	*Cyprinella chloristia*
Whitefin shiner	*Cyprinella nivea*
Common carp	*Cyprinus carpio*
Spottail shiner	*Notropis hudsonius*
Quillback	*Carpiodes cyprinus*
White catfish	*Ameiurus catus*
Blue catfish	*Ictalurus furcatus*
Channel catfish	*Ictalurus punctatus*
Flathead catfish	*Pylodictis olivaris*
White perch	*Morone americana*
Striped bass	*Morone saxatilis*
Redbreast sunfish	*Lepomis auritus*
Green sunfish	*Lepomis cyanellus*
Warmouth	*Lepomis gulosus*
Bluegill	*Lepomis macrochirus*
Redear sunfish	*Lepomis microlophus*
Hybrid sunfish	*Lepomis* hybrid
Spotted bass	*Micropterus punctulatus*
Largemouth bass	*Micropterus salmoides*
Hybrid black bass	*Micropterus* hybrid
White crappie	*Pomoxis annularis*
Black crappie	*Pomoxis nigromaculatus*
Yellow perch	*Perca flavescens*

Table 5-2. Numbers and biomass of fish collected from electrofishing ten 300-m transects near Marshall Steam Station (MSS), the reference (REF) area between MSS and McGuire Nuclear Station (MNS), and MNS in Lake Norman, 2005.

	MSS		REF		MNS	
Taxa	N	Kg	N	Kg	N	Kg
Alewife			4	0.032	368	3.051
Gizzard shad	9	0.943	9	4.247	15	2.603
Threadfin shad	127	0.296	328	1.082	465	1.506
Greenfin shiner	7	0.055	1	0.003	9	0.025
Whitefin shiner	92	0.503	116	0.503	12	0.101
Common carp	7	18.741	4	8.527	3	7.205
Spottail shiner	30	0.281	57	0.491	10	0.101
Quillback	1	1.830	2	3.279		
White catfish	1	0.316				
Channel catfish	5	1.732	7	4.764	1	0.531
Flathead catfish	1	0.076	3	0.267	2	0.076
White perch	6	0.324	17	0.798	46	1.651
Striped bass	1	1.032				
Redbreast sunfish	193	4.178	344	6.937	343	5.322
Green sunfish	2	0.036				
Warmouth	41	0.321	59	0.391	46	0.300
Bluegill	925	9.889	1,024	11.070	800	7.153
Redear sunfish	133	13.528	188	8.516	111	3.121
Hybrid sunfish	75	2.373	93	2.712	82	1.763
Spotted bass	58	8.577	39	6.002	95	11.523
Largemouth bass	90	47.933	92	35.450	33	21.599
Hybrid black bass			1	0.018	1	0.910
Black crappie	8	2.724	8	3.774		
Yellow perch	2	0.028	1	0.029		
Total	1,814	115.716	2,397	98.892	2,442	68.541

Table 5-3. Mean total lengths (mm) at age for spotted bass (SPB) and largemouth bass (LMB) collected from electrofishing ten transects near Marshall Steam Station (MSS), the reference (REF) area between MSS and McGuire Nuclear Station (MNS), and MNS in Lake Norman, March 2005.

		Age								
Taxa	Location	1	2	3	4	5	6	7	8	9
SPB	MSS	128	322	352						
	REF	128	325	378						
	MNS	118	317	376	442					
LMB	MSS	190	314	358	396	395	398	447		
	REF	139	307	357	386	392	430	461		
	MNS	136	342	359	429	437	419	414		447

Table 5-4. Mean total length (mm) at age for largemouth bass collected from an area near Marshall Steam Station (MSS), the reference (REF) area between MSS and McGuire Nuclear Station (MNS), and MNS in Lake Norman. Data from 1971-78, 1993-94, and 2003-04 are from Siler (1981), Duke Power unpublished data, and Duke Power (2004a, 2005), respectively.

	Age			
Location and year	1	2	3	4
MSS 1974-78	170	266	310	377
MSS 1993	170	277	314	338
MSS 1994	164	273	308	332
MSS 2003	216	317	349	378
MSS 2004	176	309	355	367
MSS 2005	190	314	358	396
REF 1993	157	242	279	330
REF 1994	155	279	326	344
REF 2003	139	296	358	390
REF 2004	143	288	364	415
REF 2005	139	307	357	386
MNS 1971-78	134	257	325	376
MNS 1993	176	256	316	334
MNS 1994	169	256	298	347
MNS 2003	197	315	248	389
MNS 2004	170	276	335	370
MNS 2005	136	342	359	429

Table 5-5. Dead or dying striped bass observed in Lake Norman, July-August 2005.

Date	Number	Zone	Range in total length (mm)
6-Jul	1	1	593
	1	2	675
14-Jul	1	1	502
20-Jul	1	4	402
21-Jul	1	1	540
29-Jul	1	3	602
3-Aug	5	1	536-621
11-Aug	3	1	484-559
	1	3	366
	2	4	562-635
16-Aug	3	1	512-519

Table 5-6. Lake Norman forage fish densities (Number/hectare) and population estimates from hydroacoustic surveys in September 2005.

Zone	Density (N/ha)	Population Estimate
1	5,167	11,785,927
2	5,783	17,823,784
3	5,955	20,577,622
4	5,540	6,819,740
5	7,584	15,971,904
6	367	175,426
Lakewide total		73,154,403
95% LCL		68,207,036
95% UCL		78,101,769

Table 5-7. Numbers (N), species composition, and modal lengths (mm) of threadfin shad collected in purse seine samples from Lake Norman during late summer or fall, 1993 – 2005.

		Species Composition			Threadfin shad modal
Year	N	Threadfin	Gizzard	Alewife	length class (mm)
1993	13063	100.00%	0.00%	0.00%	31-35
1994	1619	99.94%	0.06%	0.00%	36-40
1995	4389	99.95%	0.05%	0.00%	31-35
1996	4465	100.00%	0.00%	0.00%	41-45
1997	6711	99.99%	0.01%	0.00%	41-45
1998	5723	99.95%	0.05%	0.00%	41-45
1999	5404	99.26%	0.26%	0.48%	36-40
2000	4265	87.40%	0.22%	12.37%	51-55
2001	9652	76.47%	0.01%	23.52%	56-60
2002	10134	74.96%	0.00%	25.04%	41-45
2003	33660	82.59%	0.14%	17.27%	46-50
2004	21158	86.55%	0.24%	13.20%	51-55
2005	23147	98.10%	0.00%	1.90%	36-45

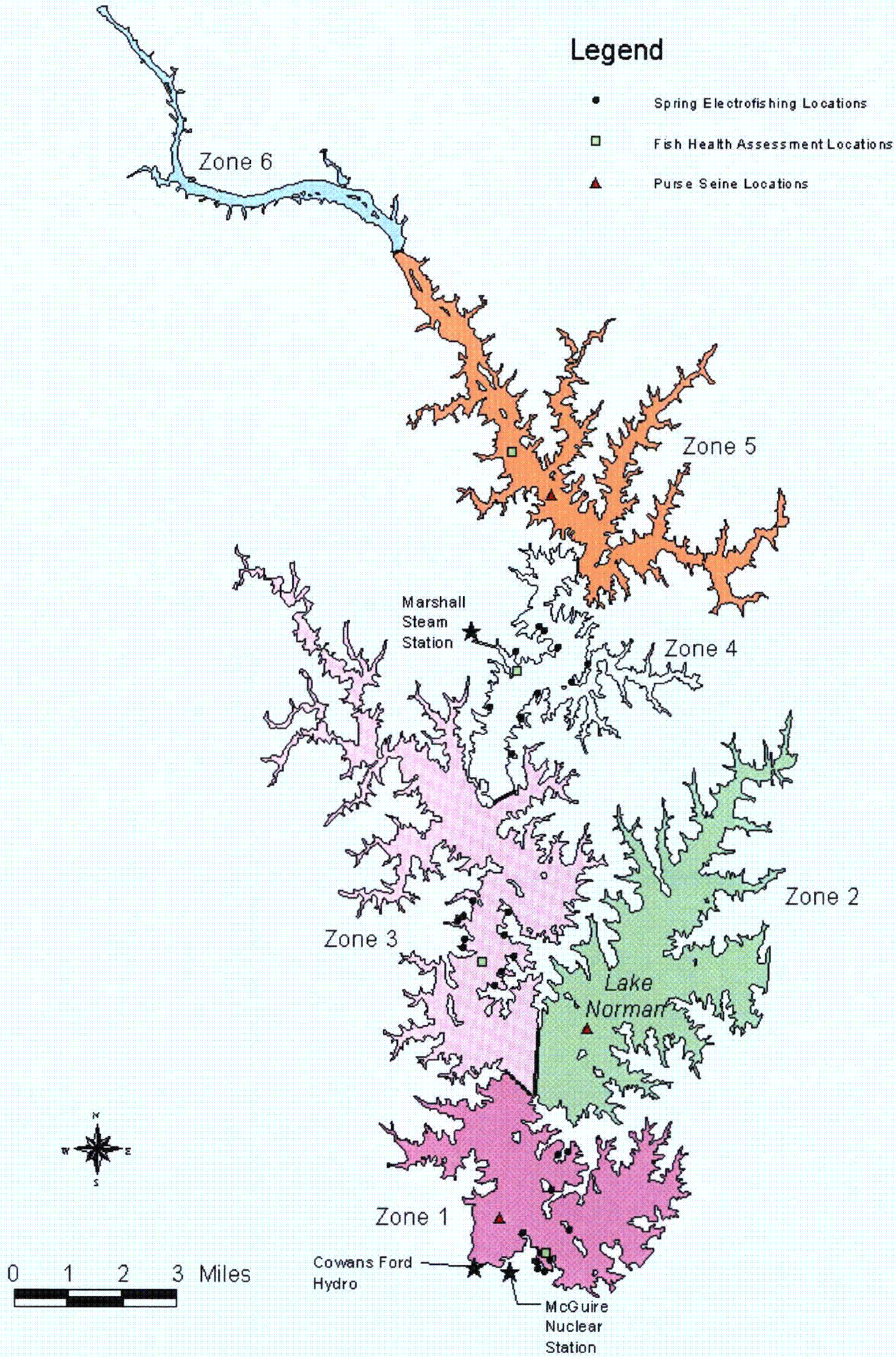


Figure 5-1. Sampling locations and zones in Lake Norman associated with fishery assessments.

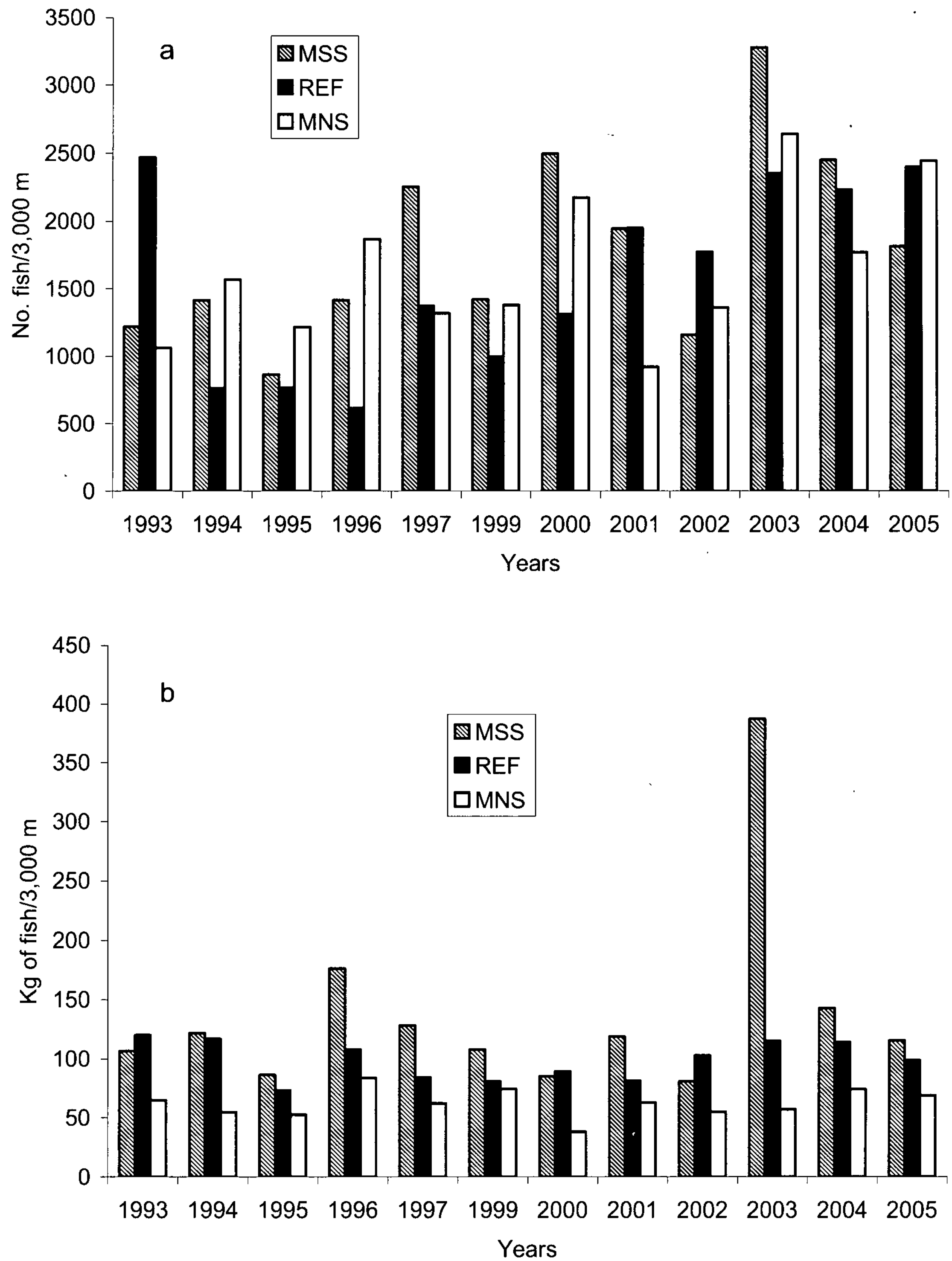


Figure 5-2. Sampling numbers (a) and biomass (b) of fish collected from electrofishing ten 300-m transects near Marshall Steam Station (MSS), the reference (REF) area between MSS and McGuire Nuclear Station (MNS), and MNS in Lake Norman, 1993-1997 and 1999-2005.

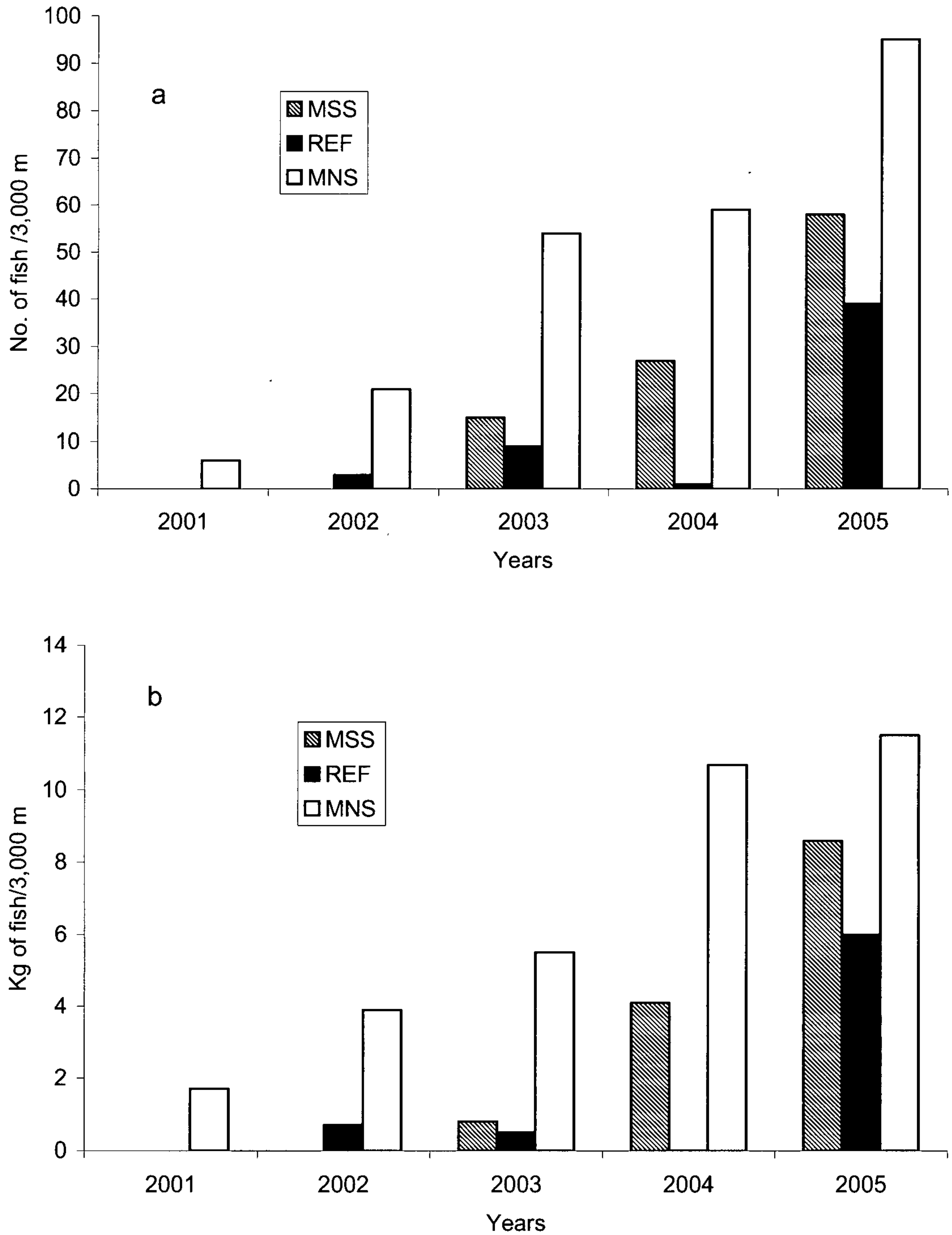


Figure 5-3. Numbers (a) and biomass (b) of spotted bass collected from electrofishing ten 300-m transects near Marshall Steam Station (MSS), the reference (REF) area between MSS and McGuire Nuclear Station (MNS), and MNS in Lake Norman, 2001-2005.

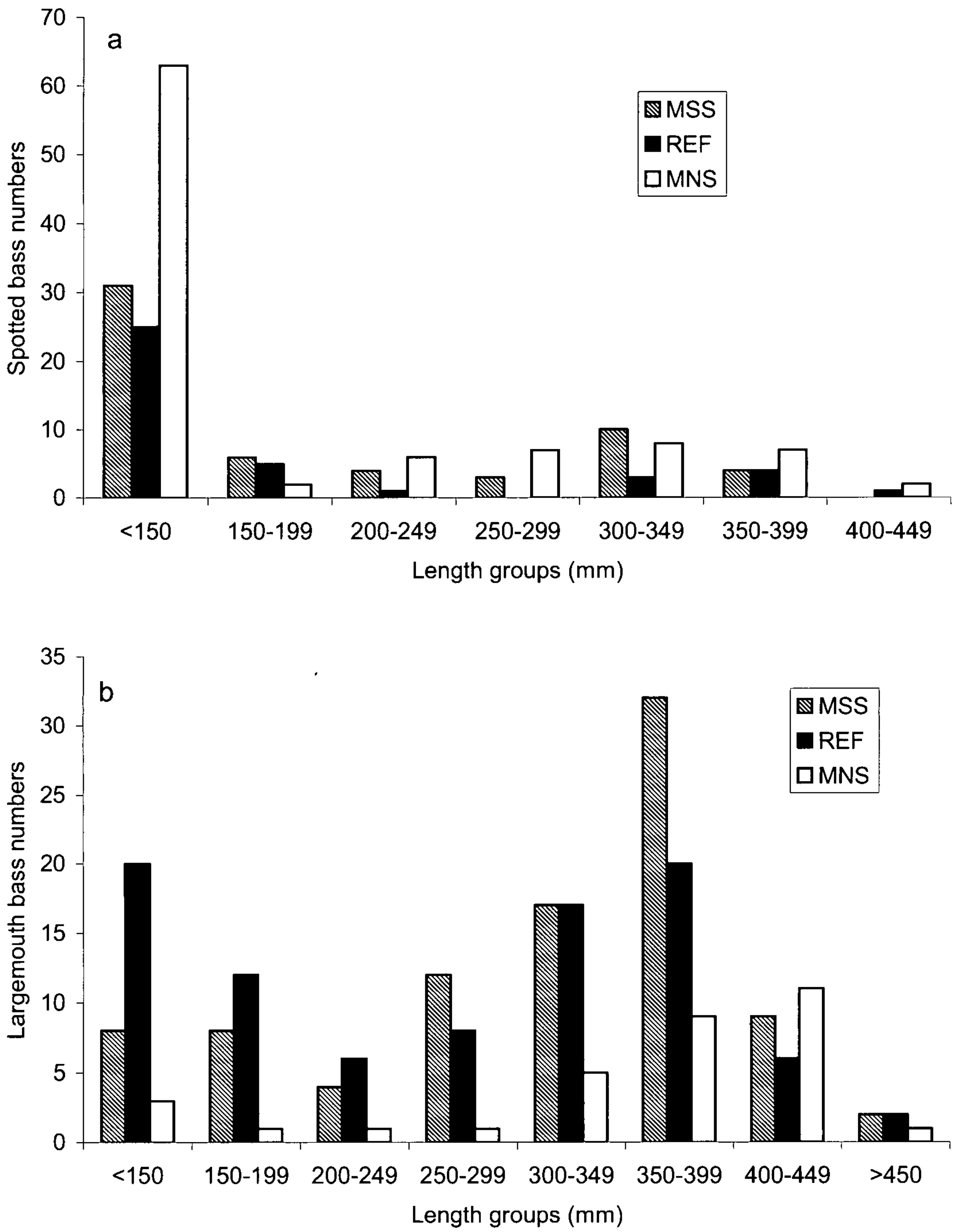


Figure 5-4. Size distributions of spotted bass (a) and largemouth bass (b) collected from electrofishing ten 300-m transects near Marshall Steam Station (MSS), the reference (REF) area between MSS and McGuire Nuclear Station (MNS), and MNS in Lake Norman, 2005.

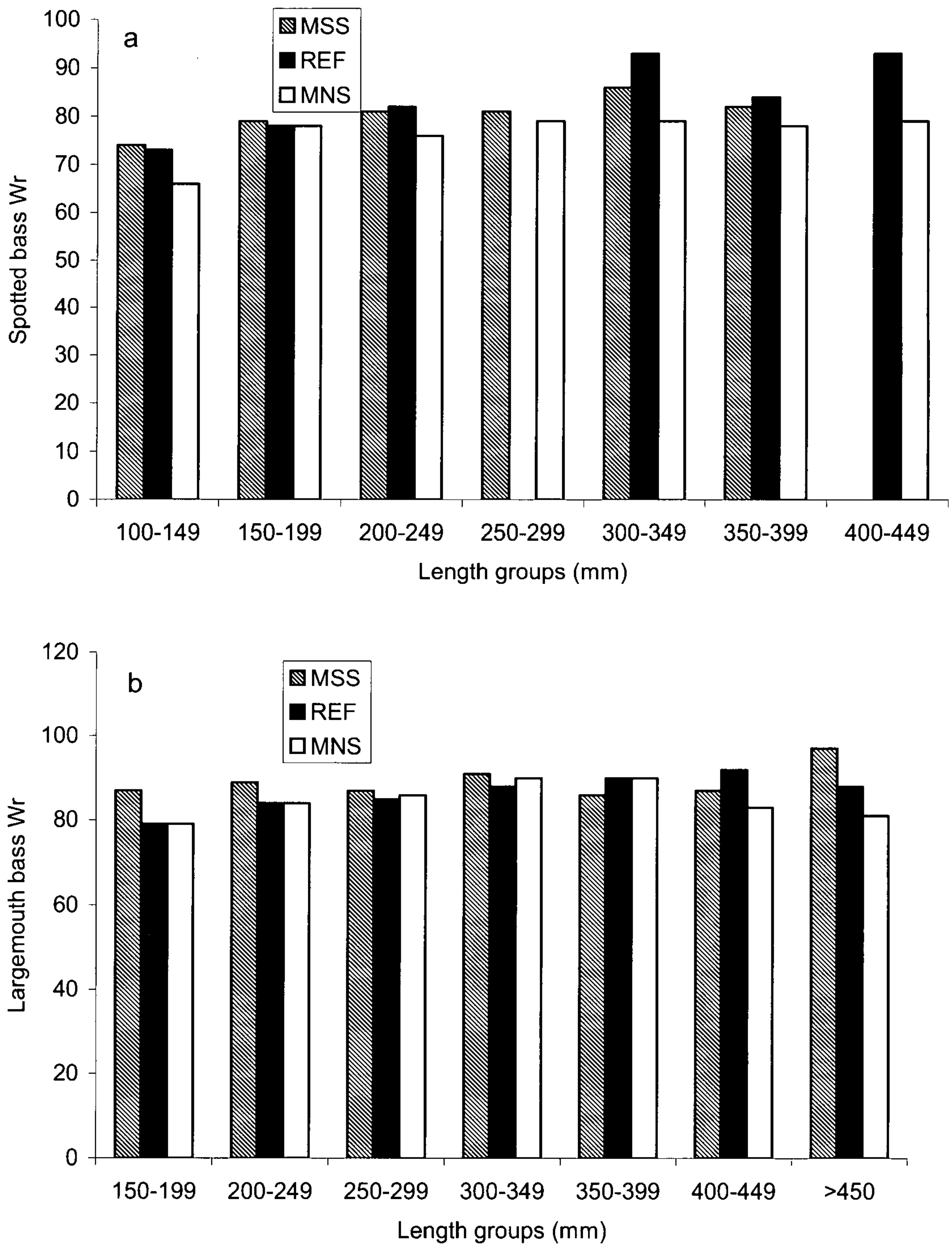


Figure 5-5. Mean relative weights (W_r) for spotted bass (a) and largemouth bass (b) collected from electrofishing ten 300-m transects near Marshall Steam Station (MSS), the reference (REF) area between MSS and McGuire Nuclear Station (MNS), and MNS in Lake Norman, 2005.

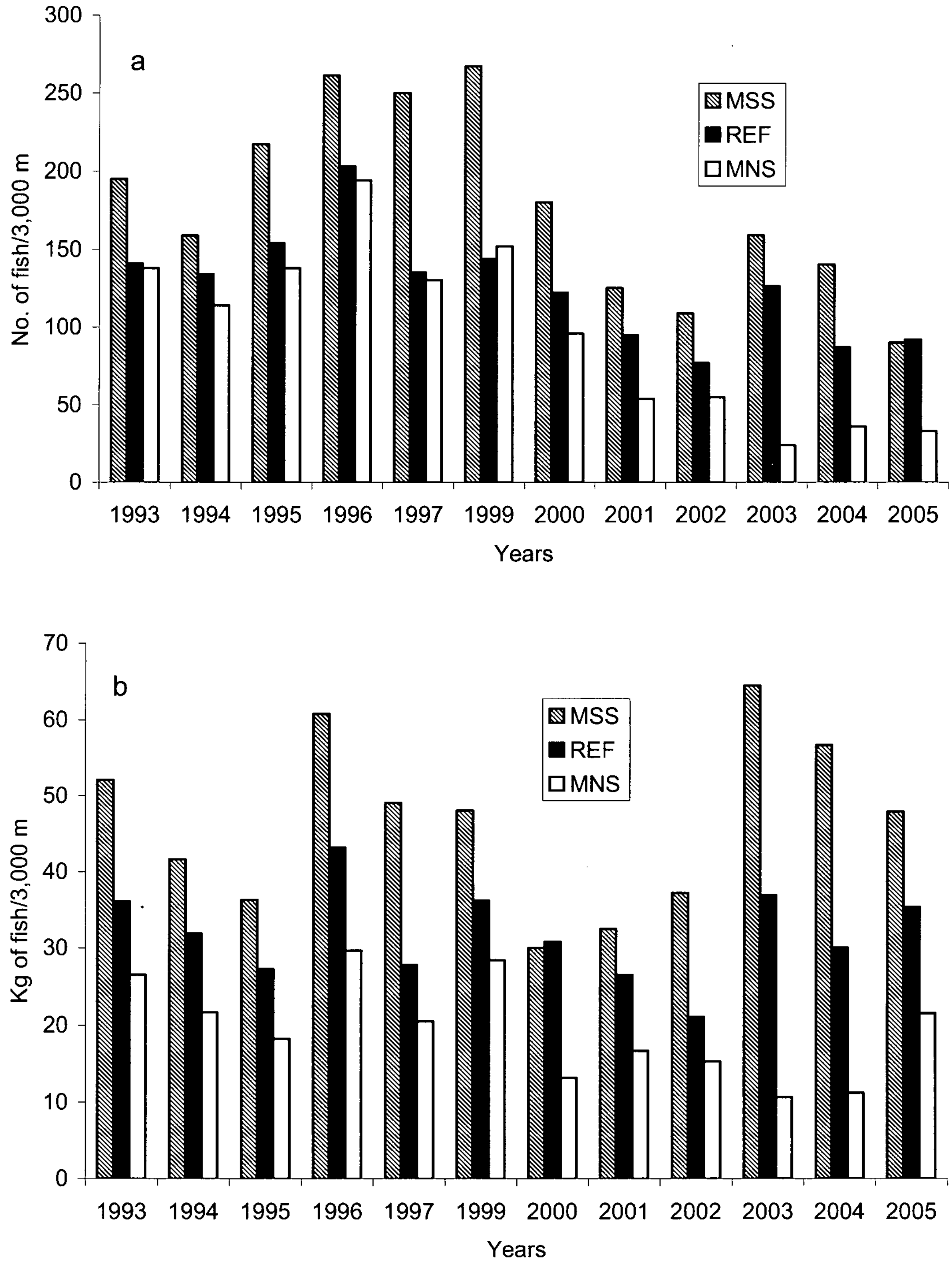


Figure 5-6. Numbers (a) and biomass (b) of largemouth bass collected from electrofishing ten 300-m transects near Marshall Steam Station (MSS), the reference (REF) area between MSS and McGuire Nuclear Station (MNS), and MNS in Lake Norman, 1993-1997 and 1999-2005.

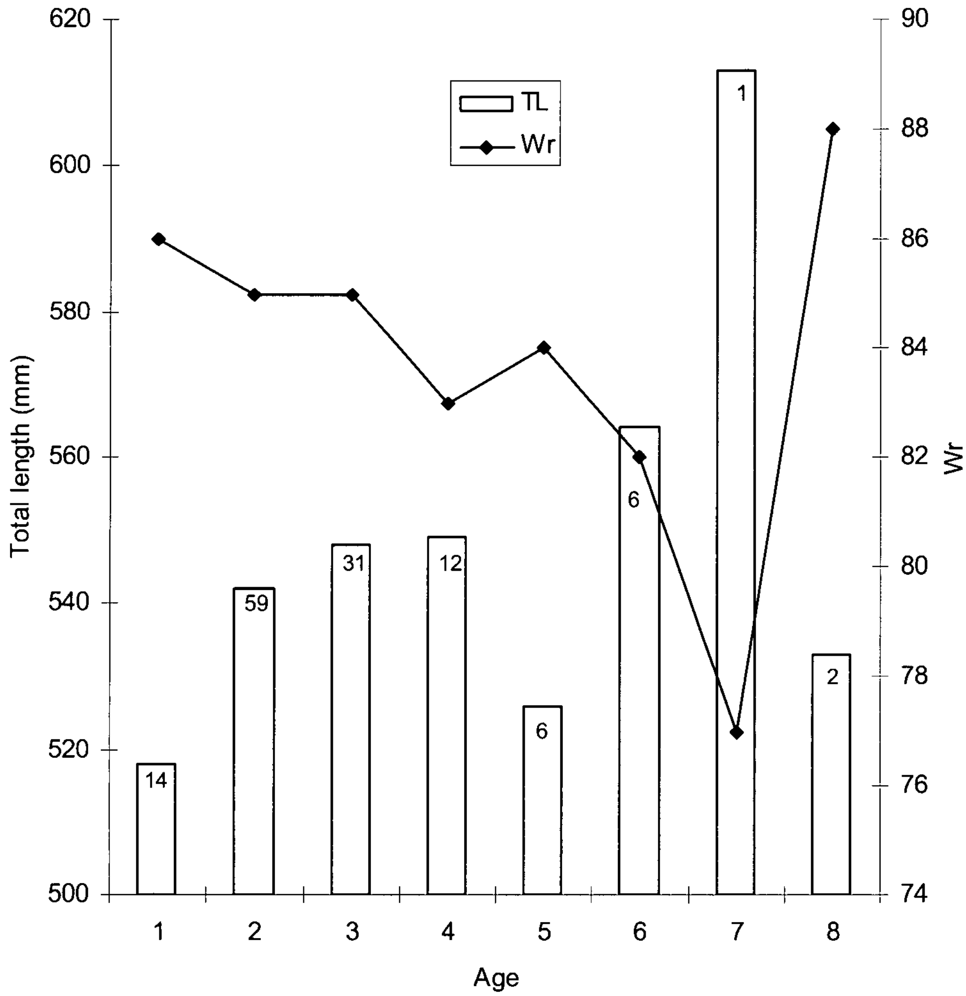


Figure 5-7. Mean total length and mean relative weight (W_r) for striped bass collected from Lake Norman, December 2005. Numbers of fish associated with mean length are inside the bars.

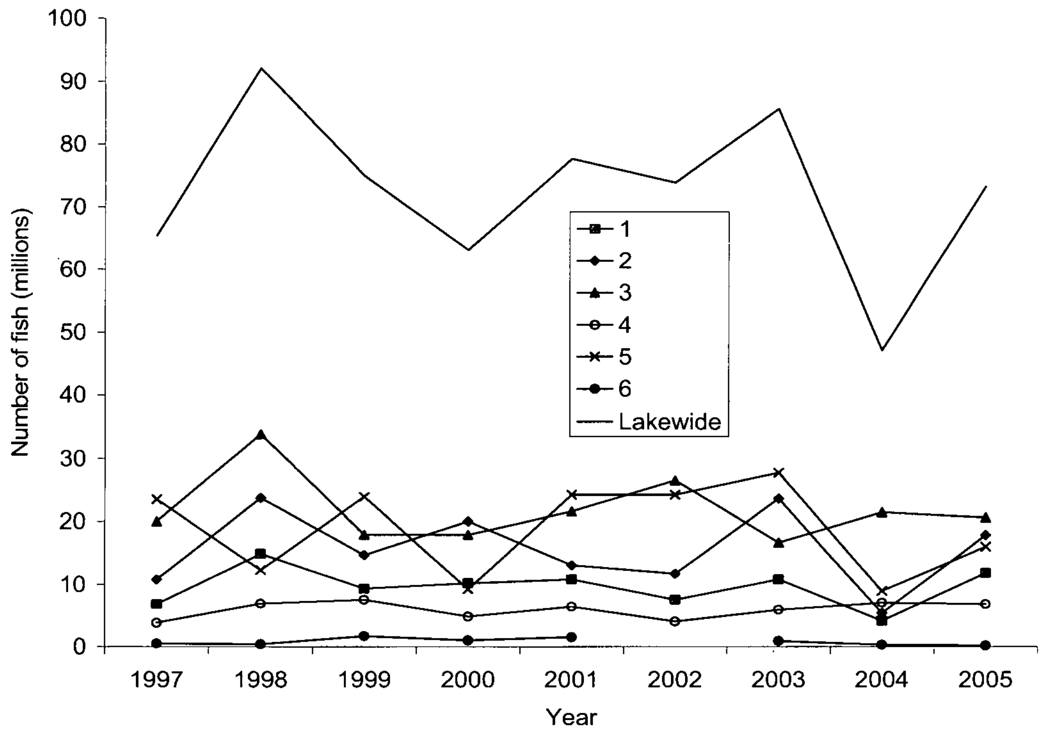


Figure 5-8. Zonal and lakewide population estimates of pelagic fish in Lake Norman.

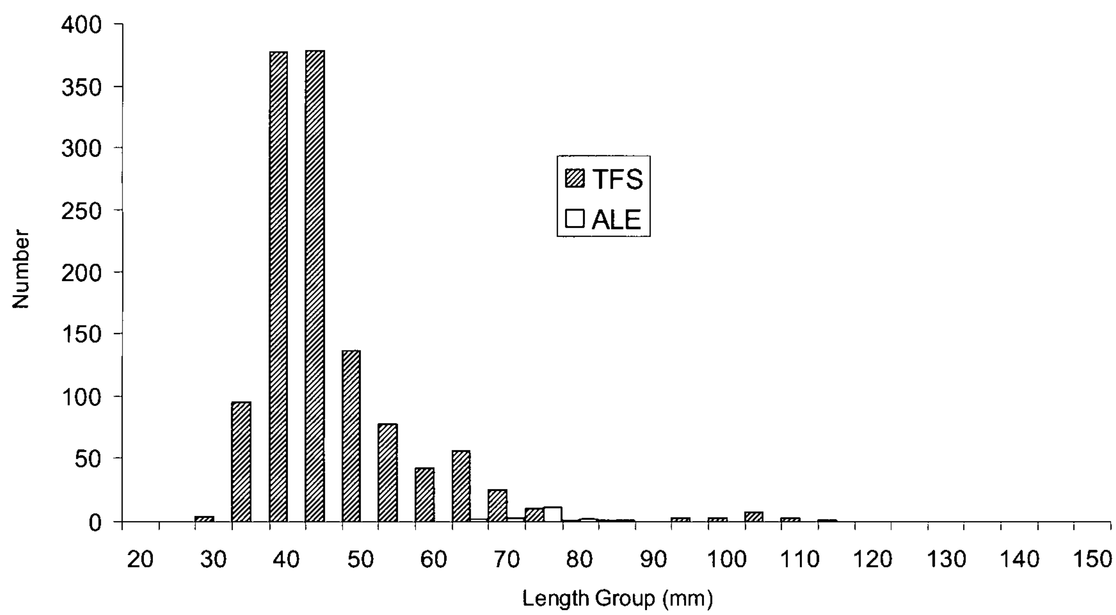


Figure 5-9. Size distributions of threadfin shad (TFS) and alewives (ALE) collected in purse seine surveys of Lake Norman, 2005.

LITERATURE CITED

American Public Health Association (APHA). 1995. Standard Methods for the Examination of Water and Wastewater. 19th Edition. APHA, Washington, DC.

Anderson, R. A., and R. M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-482 *in* B. R. Murphy and D. W. Willis, (ed.). Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Brandt, S. B. 1996. Acoustic assessment of fish abundance and distribution. Pages 385-432. *in* B. R. Murphy and D. W. Willis, (ed.). Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Cole, T. M. and H. H. Hannan. 1985. Dissolved Oxygen Dynamics. *in* Reservoir Limnology: Ecological Perspectives. K. W. Thornton, B. L. Kimmel and F. E. Payne (ed.). John Wiley & Sons. New York.

Coutant, C. C. 1985. Striped Bass, Temperature, and Dissolved Oxygen: A Speculative Hypothesis for Environmental Risk. Trans. Amer. Fisher. Soc. 114:31-61.

Derwort, J. E. 1982. Periphyton, p 279-314. *in* J. E. Hogan and W. D. Adair (eds.). Lake Norman Summary, vol. II. Duke Power Company, Technical Report DUKE PWR/82-02. Duke Power Company, Production Support Department, Production Environmental Services, Huntersville, NC.

Devries, D. R., and R. V. Frie. 1996. Determination of age and growth. Pages 483-512 *in* Duke Energy Company. *in* B. R. Murphy and D. W. Willis, (eds.). Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Duke Power. 1997. Lake Norman Maintenance Monitoring Program. 1996 Summary. Duke Energy Corporation, Charlotte, NC.

Duke Power. 1998. Lake Norman Maintenance Monitoring Program: 1997 Summary. Duke Energy Corporation, Charlotte, NC.

Duke Power. 1999. Lake Norman Maintenance Monitoring Program: 1998 Summary. Duke Energy Corporation, Charlotte, NC.

Duke Power. 2000. Lake Norman Maintenance Monitoring Program: 1999 Summary. Duke Energy Corporation, Charlotte, NC.

Duke Power. 2001. Lake Norman Maintenance Monitoring Program: 2000 Summary. Duke Energy Corporation, Charlotte, NC.

Duke Power. 2002. Lake Norman Maintenance Monitoring Program: 2001 Summary. Duke Energy Corporation, Charlotte, NC.

Duke Power. 2003. Lake Norman Maintenance Monitoring Program: 2002 Summary. Duke Energy Corporation, Charlotte, NC.

Duke Power. 2004a. Lake Norman Maintenance Monitoring Program: 2003 Summary. Duke Energy Corporation, Charlotte, NC.

Duke Power. 2004b. McGuire Nuclear Station. Updated Final Safety Analysis Report. Duke Energy Corporation, Charlotte, NC.

Duke Power. 2005. Lake Norman Maintenance Monitoring Program: 2004 Summary. Duke Energy Corporation, Charlotte, NC.

Duke Power Company. 1976. McGuire Nuclear Station, Units 1 and 2, Environmental Report, Operating License Stage. 6th rev. Volume 2. Duke Power Company, Charlotte, NC.

Duke Power Company. 1985. McGuire Nuclear Station, 316(a) Demonstration. Duke Power Company, Charlotte, NC.

Duke Power Company. 1987. Lake Norman Maintenance Monitoring Program: 1986 Summary. Duke Power Company, Charlotte, NC.

Duke Power Company. 1988. Lake Norman Maintenance Monitoring Program: 1987 Summary. Duke Power Company, Charlotte, NC.

Duke Power Company. 1989. Lake Norman Maintenance Monitoring Program: 1988 Summary. Duke Power Company, Charlotte, NC.

Duke Power Company. 1990. Lake Norman Maintenance Monitoring Program: 1989 Summary. Duke Power Company, Charlotte, NC.

Duke Power Company. 1991. Lake Norman Maintenance Monitoring Program: 1990 Summary. Duke Power Company, Charlotte, NC.

Duke Power Company. 1992. Lake Norman Maintenance Monitoring Program: 1991 Summary. Duke Power Company, Charlotte, NC.

Duke Power Company. 1993. Lake Norman Maintenance Monitoring Program: 1992 Summary. Duke Power Company, Charlotte, NC.

Duke Power Company. 1994. Lake Norman Maintenance Monitoring Program: 1993 Summary. Duke Power Company, Charlotte, NC.

Duke Power Company. 1995. Lake Norman Maintenance Monitoring Program: 1994 Summary. Duke Power Company, Charlotte, NC.

Duke Power Company. 1996. Lake Norman Maintenance Monitoring Program: 1995 Summary. Duke Power Company, Charlotte, NC.

Duke Power Company. 1997. Lake Norman Maintenance Monitoring Program: 1996 Summary. Duke Power Company, Charlotte, NC.

Ford, D. E. 1985. Reservoir Transport Processes. *in* Reservoir Limnology: Ecological Perspectives. K. W. Thornton, B. L. Kimmel and F. E. Payne (eds.). John Wiley & Sons. New York.

Hamme, R. E. 1982. Zooplankton, *in* J. E. Hogan and W. D. Adair (eds.). Lake Norman Summary, Technical Report DUKEPWR/82-02. p. 323-353, Duke Power Company, Charlotte, NC.

Hannan, H. H., I. R. Fuchs and D. C. Whittenburg. 1979 Spatial and Temporal Patterns of Temperature, Alkalinity, Dissolved Oxygen and Conductivity in an Oligo-mesotrophic, Deep-storage Reservoir in Central Texas. Hydrobiologia 51 (30); 209-221.

Hayes, D. B., C. P. Ferrier, and W. W. Taylor. 1996. Active fish capture methods. Pages 193-220 *in* B. R. Murphy and D. W. Willis, (eds.). Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Higgins, J. M. and B. R. Kim. 1981. Phosphorus Retention Models for Tennessee Valley Authority Reservoirs. Water Resources Research, 17:571-576.

Higgins, J. M., W. L. Poppe, and M. L. Iwanski. 1980. Eutrophication Analysis of TVA Reservoirs. *in* Surface Water Impoundments. H. G. Stefan, (ed.). Am. Soc. Civ. Eng., NY, pages 412-423.

Hutchinson, G. E. 1938. Chemical Stratification and Lake Morphometry. Proc. Nat. Acad. Sci., 24:63-69.

Hutchinson, G. E. 1957. A Treatise on Limnology, Volume I Geography, Physics and Chemistry. John Wiley & Sons, Inc. NY.

Hutchinson, G. E. 1967. A Treatise on Limnology. Vol. II. Introduction to Lake Biology and the Limnoplankton. John Wiley and Sons, Inc. NY, 1115 pp.

Hydrolab Corporation. 1986. Instructions for Operating the Hydrolab Surveyor Datasonde. Austin, TX. 105p.

Lee, R. E. 1989. Phycology (2nd. Ed.). Cambridge University Press. 40 West 20th. St., New York, NY.

Matthews, W. J., L. G. Hill, D. R. Edds, and F. P. Gelwick. 1985. Influence of Water Quality and Season on Habitat use by Striped Bass in a Large southwestern Reservoir. Trans. Amer. Fisher. Soc 118: 243-250.

Menhinick, E. F. and L. D. Jensen. 1974. Plankton populations, p. 120-138 *in* L. D. Jensen (ed.). Environmental responses to thermal discharges from Marshall Steam Station, Lake Norman, NC. Electric Power Research Institute, Cooling Water Discharge Project (RP-49) Report No. 11. Johns Hopkins Univ., Baltimore MD.

Mortimer, C. H. 1941. The Exchange of Dissolved Substances Between Mud and Water in Lakes (Parts I and II). J. Ecol., 29:280-329.

Nelson, C., and L. Dorsey. 2005. Population characteristics of black crappies in Lake Norman 2004. Survey Report, Federal Aid in Fish Restoration Project F-23-S. North Carolina Wildlife Resources Commission, Raleigh, North Carolina.

North Carolina Department of Environment, and Natural Resources, Division of Environmental Management (DEM), Water Quality Section. 1991. 1990 Algal Bloom Report.

North Carolina Department of Environment and Natural Resources. 2004. Red Book. Surface Waters and Wetland Standards. NC Administrative Code. 15a NCAC 02B.0100, .0200 and .0300. August 1, 2004. 133pp.

Nygaard, G. 1949. Hydrological studies of some Danish ponds and lakes II. K. danske Vilensk. Selsk. Biol. Skr.

Petts G. E., 1984. Impounded Rivers: Perspectives For Ecological Management. John Wiley and Sons. New York. 326pp.

Rodriguez, M. S. 1982. Phytoplankton, p. 154-260 *in* J. E. Hogan and W. D. Adair (eds.). Lake Norman summary. Technical Report DUKEPWR/82-02 Duke Power Company, Charlotte, NC.

Siler, J. R. 1981. Growth of largemouth bass, bluegill, and yellow perch in Lake Norman, North Carolina--A summary of 1975 through 1979 collections. Research Report PES/81-6. Duke Power Company, Huntersville, NC.

Siler, J. R., W. J. Foris, and M. C. McInerny. 1986. Spatial heterogeneity in fish parameters within a reservoir. Pages 122-136 *in* G. E. Hall and M. J. Van Den Avyle, (eds.). Reservoir Fisheries Management: Strategies for the 80's. Reservoir Committee, Southern Division American Fisheries Society, Bethesda, Maryland.

Soballe, D. M., B. L. Kimmel, R.H. Kennedy, and R. F. Gaugish. 1992. Reservoirs. *in* Biodiversity of the Southeastern United States Aquatic Communities. John Wiley & Sons, Inc. New York.

Stumm, W. and J. J. Morgan. 1970. Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters. Wiley and Sons, Inc. New York, NY. 583pp.

Thornton, K. W., B. L. Kimmel, F. E. Payne. 1990. Reservoir Limnology. John Wiley and Sons, Inc. New York, NY.

U.S. Environmental Protection Agency (USEPA). 1983. Methods for the Chemical Analysis of Water and Wastes. Environmental Monitoring and Support Lab. Office of Research and Development, Cincinnati, Ohio.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Company, Philadelphia, Pennsylvania, 743pp.