DUKE
ENERGY®

**Steven D. Capps**
Vice President
McGuire Nuclear Station

**Duke Energy**
MG01VP | 12700 Hagers Ferry Road
Huntersville, NC 28078

o: 980.875.4805
f: 980.875.4809
Steven.Capps@duke-energy.com

January 29, 2015
Serial No. MNS-15-007

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20555-0001

SUBJECT: Duke Energy Carolinas, LLC
McGuire Nuclear Station
Docket No. 50-369, 370
Lake Norman Maintenance Monitoring Program:
2013 Summary

Please find attached a copy of the annual "Lake Norman Maintenance Monitoring Program: 2013 Summary," as required by the National Pollutant Discharge Elimination System (NPDES) permit NC0024392. This 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 26, 2015.

Questions regarding the attached report should be directed to Kay L. Crane at (980) 875-4306.

Jimmy [illegible]
for
Steven D. Capps

IE25
NRR

Mr. V. M. McCree, Regional Administrator
U.S. Nuclear Regulatory Commission, Region II
Marquis One Tower
245 Peachtree Center Ave., NE Suite 1200
Atlanta, Georgia 30303-1257

Mr. Ed Miller, Project Manager
U. S. Nuclear Regulatory Commission
Mail Stop O-8 G9A
Washington, DC 20555-0001

John Zeiler
NRC Senior Resident Inspector
McGuire Nuclear Station

# LAKE NORMAN

# MAINTENANCE MONITORING PROGRAM

## 2013 SUMMARY

**DUKE ENERGY**
**ENVIRONMENTAL SERVICES**
**WATER RESOURCES**
**13339 HAGERS FERRY ROAD**
**HUNTERSVILLE NC 28078**

DUKE ENERGY.

**Duke Energy Carolinas LLC**
McGuire Nuclear Station
12700 Hagers Ferry Road
Huntersville, NC 28078

January 26, 2015

Ms Dianne Reid
North Carolina Department of Environment
and Natural Resources
Environmental Sciences Section
1621 Mail Service Center
Raleigh, NC 27699-1621

Subject: McGuire Nuclear Station
Lake Norman Environmental Monitoring Program: 2013 Summary Report

Dear Ms Reid

Enclosed are three copies of the annual Lake Norman Environmental Monitoring Program: 2013 Summary Report, as required by NPDES Permit NC0024392.

Results of the 2013 data were comparable with that of previous years. No obvious short-term or long-term impacts of station operations were observed in water quality, phytoplankton, zooplankton, and fish communities. Additionally, 2013 station operation data demonstrates compliance with permit thermal limits and cool water management requirements.

Fishery studies continue to be coordinated with the Division of Inland Fisheries of the North Carolina Wildlife Resource Commission to address Lake Norman's fishery management issues.

If you have any questions concerning this report, please contact John Williamson by phone at (980) 875-5894 or by email at John.Williamson@duke-energy.com

Sincerely,

SD Capps

Steven D. Capps
Site Vice President
Duke Energy Carolinas, LLC
McGuire Nuclear Station

DUKE ENERGY.

**Duke Energy Carolinas LLC**
McGuire Nuclear Station
12700 Hagers Ferry Road
Huntersville, NC 28078

January 26, 2015

Mr. Corey Oakley
NC Wildlife Resources Commission
5600 pine meadow lane
Mebane, NC 27302

Subject: McGuire Nuclear Station
Lake Norman Environmental Monitoring Program: 2013 Summary Report

Dear Mr. Oakley

Enclosed is a copy of the annual Lake Norman Environmental Monitoring Program: 2013 Summary Report, as required by NPDES permit NC0024392.

Results of the 2013 data were comparable with that of previous years. No obvious short-term or long-term impacts of station operations were observed in water quality, phytoplankton, zooplankton, and fish communities. Additionally, 2013 station operation data demonstrates compliance with permit thermal limits and cool water management requirements.

Fishery studies continue to be coordinated with the Division of Inland Fisheries of the North Carolina Wildlife Resource Commission to address Lake Norman's fishery management issues.

If you have any questions concerning this report, please contact John Williamson by phone at (980) 875-5894 or by email at John.Williamson@duke-energy.com

Sincerely,

SD Capps

Steven D. Capps
Site Vice President
Duke Energy Carolinas, LLC
McGuire Nuclear Station

# LAKE NORMAN

# MAINTENANCE MONITORING PROGRAM

# 2013 SUMMARY

## McGuire Nuclear Station: NPDES No. NC0024392

**Principal Investigators:**

**Michael A. Abney**
**John E. Derwort**
**William J. Foris**

**DUKE ENERGY**
**Environmental Services**
**McGuire Environmental Center**
**13339 Hagers Ferry Road**
**Huntersville, NC 28078**

**January 2015**

# TABLE OF CONTENTS

# EXECUTIVE SUMMARY

Annual monitoring of physicochemical characteristics and assessments of phytoplankton, zooplankton and fish populations in Lake Norman continued through 2013, in accordance with the National Pollutant Discharge Elimination System (NPDES) permit number NC0024392 for McGuire Nuclear Station (MNS), and Duke Energy's agreement with the North Carolina Department of Environment and Natural Resources covering the Lake Norman Maintenance Monitoring Program. This report presents operational and environmental data most recently collected in 2013 and compares this information to one or more prior years, with the primary objective of continually assessing the impact of MNS's thermal discharge on the water quality and plankton and fish populations in Lake Norman, as required under the 316(a) thermal discharge variance provision of the Clean Water Act.

The MNS operational data (% capacity factor) in 2013 were similar to 2012 and other recent years, with an annual average of 95.5%. Also, MNS continues to demonstrate complete compliance with monthly thermal discharge limits, as well as coolwater conservation requirements.

Cumulatively, water quality data collected in 2013 reaffirmed that Lake Norman, both near and distant from MNS's thermal discharge, continues to provide a suitable physicochemical environment necessary for sustaining a balanced and indigenous aquatic biological community. Natural variations from average in meteorology and hydrology in 2013 impacted water quality in Lake Norman. Meteorological conditions in 2013 were primarily cooler and wetter than normal, which translated into below average water temperatures and higher than average reservoir flow though rates. In response to the elevated precipitation levels, reservoir inflow and outflow rates increased by as much as 400%, compared to 2012 rates, resulting in the decline of the reservoir hydraulic retention time from an average of 210 days to 85 days.

In addition to water temperature, dissolved oxygen (DO) concentrations and coolwater fish habitat were also impacted by these atypical 2013 physical forcing metrics, with the enhanced rate of reservoir flow through having a governing influence on vertical and horizontal mixing and reaeration, especially during the spring and summer stratified period. Water temperatures in spring 2013 were as much as 6 - 8 °C cooler and DO values were almost 5.0 mg/L higher at comparable depths than measured in 2012, with a somewhat greater impact observed in the uplake background locations than at the downlake mixing

The most abundant diatoms during 2013 were *Tabellaria fenestrate* in February and November, *Fragillaria crotonensis* in May, and *Anomoeoneis vitrea* in August. All of these taxa have been common and abundant throughout the Lake Norman Maintenance Monitoring Program.

Seston dry and ash-free weights were most often higher in 2013 than in 2012. Maximum dry and ash-free weights were generally observed uplake while minimum values were observed most often downlake.

Secchi depths often reflected suspended solids, with shallow depths loosely related to high dry weights. The lakewide mean Secchi depth in 2013 was lower than that of 2012, but well within historical ranges.

Zooplankton monitoring continued in 2013. Seasonal mean zooplankton densities were below the long-term mean density and the mean density in winter was the lowest winter mean yet recorded. As in past years, epilimnetic densities were often within the ranges of those observed in previous years, however some record low zooplankton densities were observed. Spatial trends of zooplankton populations were generally similar to those of phytoplankton, with increasing densities from downlake to uplake during spring and fall and variable in winter and summer. Mean zooplankton densities tended to be higher among background locations than among mixing zone locations during 2013, but to a lesser degree than in previous years.

Copepods were dominant in most zooplankton samples and their overall relative abundances increased since 2012. Adults rarely accounted for more than 7% of zooplankton densities. The overall relative abundance of rotifers decreased from 2012 to 2013. The relative abundance of all microcrustaceans (copepods and cladocerans) increased throughout the lake in 2013 and their percent compositions were within historical ranges. The most abundant rotifer observed in 2013 was *Polyarthra* as in many previous years. The most important adult copepod was *Epishura*, as in most years of the Program. *Bosmina* was the predominant cladoceran. Lake Norman continues to support highly diverse and viable phytoplankton and zooplankton communities.

Spring electrofishing indicated that numbers and biomass of fish in 2013 were generally similar to those noted since 1993. The littoral fish populations in the three sampling areas were comprised of 13 to 19 species of fish and two hybrid complexes. Fish collections were

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF FIGURES, Continued

differences, including below average air temperatures and higher than normal rainfall, between these two years (see Chapter 2). The volume of cool water in Lake Norman was additionally tracked throughout the year to ensure that an adequate cooling-volume was available to comply with both the Nuclear Regulatory Commission Technical Specification requirements and the NPDES discharge water temperature limits.

# CHAPTER 2

# WATER QUALITY

## INTRODUCTION

The objectives of the water quality portion of the McGuire Nuclear Station (MNS) National Pollutant Discharge Elimination System (NPDES) Maintenance Monitoring Program (MMP) are to:

1. maintain continuity in the water quality 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 South.

This report focuses primarily on 2012 and 2013 data. Where appropriate, reference to data collected prior to 2012 will be made by citing reports previously submitted to the North Carolina Department of Environment and Natural Resources (NCDENR).

## METHODS AND MATERIALS

The complete water quality monitoring program for 2013, including specific variables, locations, depths, and frequencies is outlined in Table 2-1. Sampling locations are identified in Figure 2-1. Sampling locations were selected at the initiation of the Lake Norman MMP in 1986 to provide a thorough assessment of water quality throughout the reservoir and include sites within the area projected to be impacted by the thermal discharge from MNS, and in a non-impact zone. Physicochemical data collected at these locations also serve to track the temporal and spatial variability in striped bass habitat in the reservoir during the stratified period. Many of the water quality monitoring locations were additionally used for the collection of phytoplankton and zooplankton samples (Chapters 3 and 4). A number of these locations also corresponded closely with areas of the reservoir sampled in the MNS fishery assessment program (Chapter 5; Figure 5-1).

to the *in situ* data, emphasized a much broader lakewide investigation and encompassed the plotting of monthly isotherms and isopleths, and summer striped bass (*Morone saxatilis*) habitat. Several quantitative calculations were also performed on the *in situ* data; these included 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 (maximum - minimum heat content).

Heat and oxygen content were expressed on an area and volume basis for the entire water column, the epilimnion, and the hypolimnion. Heat and dissolved oxygen mass calculations provide a convenient approach of integrating the influence of various physical, chemical, and biological processes on the thermal and DO structure of a waterbody. Heat and oxygen mass were calculated at one meter intervals within the water column employing the *in situ* profile data, bathymetric (area and volume) data for Lake Norman and the following equation, modified after Hutchinson (1957):

$$Lt = A_0^{-1} \bullet \int_{z_0}^{z_m} TO \bullet Az \bullet dz$$

where;
$Lt$ = reservoir heat ($Kcal/cm^2$) or oxygen ($mg/cm^2$) content
$A_0$ = 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)
$z_0$ = 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 Energy 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. Lake level and hydroelectric flow data were obtained from within Duke Energy.

Seasonal degree-day calculations, a method frequently employed by meteorologists to quantify the temporal cumulative fluctuations in air temperatures, provides a convenient metric of also quantifying the temporal cumulative influence of air temperatures on water temperatures in aquatic ecosystems. Degree-day calculations were performed for Lake Norman's winter cooling and summer heating periods, defined as January – March and May – September, respectively, from 1975 – 2013. The winter cooling period is especially important because of its influence on the magnitude of heat loss from the reservoir, and therefore determines the minimum water column temperatures and maximum reoxygenation that the reservoir achieves prior to the genesis of lake stratification, which usually is observed in March. Since Lake Norman is classified as a warm monomictic reservoir that mixes and reoxygenates only once a year, the magnitude of winter reaeration, which can vary by as much as 25%, is of critical importance in determining the availability of DO in the middle and lower portions of the water column for the susbsequent stratified period.

The degree-days total for the 2013 cooling period was approximately 33% less (cooler) than 2012 and 9% cooler than the long-term mean. Similarly, the degree-days total for the 2013 heating period was also cooler than both 2012 and the long-term, but somewhat less so than the winter period, averaging approximately 4% cooler (1.5 °C).

Annual precipitation in the vicinity of MNS in 2013 totaled 137.6 cm (Figures 2-2a and 2-2b), or about 57% greater than measured in 2012 and 16% greater than the long-term average (117.6 cm), based on Charlotte, NC airport data. It was also the fourth wettest year measured at the MNS site since rainfall monitoring was initiated in 1975. Monthly rainfall was the highest in June and July with a combined total of 45.7 cm, or approximately one-third of the yearly rainfall, and was almost 2.5 times greater than the long-term average. The June 2013 rainfall total of 28.37 cm was also the highest for the month of June over the 1975 – 2013 period. Additionally, on 28 June a total of 13.6 cm of precipitation was recorded over a 24 hour period, or almost 50% of the monthly total. It is also the highest daily total ever recorded at this site and provides insight into the daily intensity of the June 2013 rainfall pattern.

The effects of elevated levels of seasonal and annual rainfall in 2013 versus 2012 resulted in significant differences in inflows into the reservoir from the upstream watershed and outflows at the Cowans Ford Hydroelectric Station (CFHS) at the lower end of the reservoir between the two years (Figures 2-2d and 2-2e). Hydrologic inputs into Lake Norman are dominated by releases from the Lookout Shoals Hydroelectric Station (LSHS), which is

$m^3/s$) and just the May 1 – August 31 period (168.9 $m^3/s$), the average retention time decreased to 135 days and 85 days, respectively.

Water Temperature

Water temperatures in reservoirs are influenced by a host of physical factors, including incident solar thermal energy, inflows from the watershed, thermal inputs from industrial and municipal discharges, and physical characteristics such as depth, clarity and reservoir inflow and outflow rates, all of which can be temporally and spatially variable in large reservoirs like Lake Norman (Hannan et al. 1979; Ford 1987; Cole and Hannan 1985). Analysis of historical thermal data for Lake Norman over the years has illustrated that temporal (interannual and seasonal) and spatial (horizontal and vertical) variations in water temperatures are largely governed by seasonal differences in air temperatures, water movement into, within and out of the reservoir, and thermal discharges from MNS and Marshall Steam Station (MSS), which are primarily localized effects (Duke Power Company 1985, 1987, and 1988; Duke Power 2004a, and 2005; Duke Energy 2011, 2012, and 2013).

Lake Norman 2013 water temperatures were, for the most part, cooler than measured in 2012 throughout the reservoir for the majority of the year, with differences somewhat more pronounced in the background versus the mixing zone, but well within seasonal historical ranges in both zones. Historical data illustrates that interannual differences in water temperatures generally parallel differences in air temperatures, but because lake sampling is routinely performed in the first week of each month, the observed data often reflects the cumulative influences of meteorology and hydrology prior to that date (Duke Power 2002; Duke Energy 2011, 2012, and 2013).

Interannual differences in water temps between 2012 and 2013 were observed in both zones throughout the year but were most pronounced in April and May (Figures 2-3 and 2-4), with 2013 upper water column temperatures ranging from approximately 6-8 °C cooler than measured in 2012. These differences were likely linked to the cumulative influence of three factors that varied between the two years: (1) cooler 2013 air temperatures than 2012 from February – April; (2) higher precipitation levels in 2013 than 2012 over this period, which resulted in greater inflows into and outflows out of the reservoir, and would have exerted an advective mixing and cooling impact on the reservoir; and (3) the occurrence of a maintenance outage at MNS of Unit 1 in spring 2013 that resulted in less heat being discharged from MNS into the mixing zone, compared to 2012 (Duke Energy 2013). As the

Late-summer, fall, and early winter (September – December) water temperatures in both zones indicated that the process known as "lake turnover", which involves cooling, convectively mixing and reaeration of the water column, was generally slower in 2013 than observed in 2012, although some variability existed (Figures 2-3 and 2-4). The slightly warmer November epilimnion temperatures in the mixing zone in 2013 compared to 2012 were likely related to station operational differences at that time between the two years (Table 1-1; Duke Energy 2013).

Overall, the 2013 water temperature profile data, especially the spring data, suggest that the thermal regime of Lake Norman, including the genesis and seasonal development of thermal stratification and formation of the thermocline, was not as pronounced within the reservoir as observed in 2012, and the majority of other years (Duke Power Company 1985, 1987, and 1988; Duke Power 2004a, and 2005; Duke Energy 2011, 2012, and 2013). Several factors likely contributed to the 2013 conditions, the most important of which involved higher than normal 2013 precipitation levels, and the corresponding impact of this additional water source on both inflows into and outflows from the reservoir. Spring 2013 (January 1 – March 31) inflows averaged approximately double the 2012 rate and undoubtedly this increased flow served to promote water column mixing and cooling during this period. A similar hydraulic mixing effect of increased water movement on reservoir temperatures likely also occurred during the period May 1 – August 31 when inflows averaged about three times greater, and outflows close to four times greater, than observed in 2012.

Surface (0.3 m) temperature data collected in 2013 at the discharge location in concert with the monthly in-situ lake sampling were, for the most part, cooler than observed in 2012 except for early winter and late fall (Figure 2-5). The maximum discharge temperature measured at Location 4.0 in 2013 (35.7 °C) was recorded in August and was 3.4 °C less than the historical maxima of 39.1 °C measured in 2011. Temperatures for all months in 2013 were within historical ranges (Duke Power Company 1985, 1987, and 1988; Duke Power 2004a, and 2005; Duke Energy 2011, 2012, and 2013).

### Dissolved Oxygen

Historically, the annual DO regime in Lake Norman follows a fairly consistent spatial and temporal pattern. Cooling, mixing and reoxygenation of the water columns begins in mid-September, concurrent with declining air temperatures, and generally continues into early winter, reaching maximum cooling and reoxygenation in February. With the genesis of oxygenated waters into the reservoir and weakened thermal stratification, resulting in enhanced vertical mixing within the water column. This phenomenon is common in reservoirs (Ford 1987; Hannan et al 1979; Cole and Hannan 1985). By September, 2013 DO levels were, for the most part, similar between years.

The 2013 late summer and autumn DO data indicate that convective reaeration of the water column proceeded slower than in corresponding months in 2012 (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 well with interannual differences in air temperatures (Figures 2-2c, 2-3, and 2-4). The November DO profiles for the background and mixing zones illustrated that reoxygenation of the entire water column in 2012 was complete by early November, whereas in 2013 portions of the lower water column in both zones still had not been reaerated. Interannual differences in DO patterns are common within the Catawba River Basin and other Southeastern reservoirs and can reflect yearly differences in hydrologic, meteorologic, and limnologic forcing variables (Hannan et al. 1979; Cole and Hannan 1985; Petts 1984).

The seasonal pattern of DO in 2013 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). Overall, the DO differences between years generally followed the trend observed for temperature, with the higher DO concentrations measured in those months when temperatures were cooler than the prior year. The lowest DO concentration measured at the discharge location in 2013 (4.9 mg/L) occurred in early September and was well within the range of previously measured annual low values (Duke Power Company 1985, 1987, and 1988; Duke Power 2004a, and 2005; Duke Energy 2011, 2012, and 2013).

## Reservoir-Wide Temperature and Dissolved Oxygen

The plotting of reservoir-wide isotherm and isopleth data offers a simple and illustrative tool to easily visualize the spatial and temporal dynamics of temperature and DO regimes in reservoirs (Hannan et al. 1979). Thermal and DO regimes in 2013 were considerably different in time and space than observed in 2012 (Figures 2-8 and 2-9), due primarily to cooler than normal air temperatures, coupled with precipitation-driven hydrologic events that resulted in increased reservoir inflows and outflows, as discussed previously. Overall, temperatures were cooler and DO levels higher throughout most of the reservoir, especially historically observed in Lake Norman. This observation is directly linked to the mixing and reoxygenation impact of reservoir flow rates, as discussed earlier in this chapter.

Hutchinson (1938 and 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 ≤ 0.025 $mg/cm^2/day$, mesotrophic 0.026 $mg/cm^2/day$ to 0.054 $mg/cm^2/day$, and eutrophic ≥ 0.055 $mg/cm^2/day$. Employing these limits, Lake Norman should be classified as mesotrophic based on the calculated AHOD value of 0.034 $mg/cm^2/day$ for 2013, which is similar to 2012 and prior years (Duke Energy 2013). The oxygen-based mesotrophic classification also agrees well with the mesotrophic classification based on chlorophyll *a* levels (Chapter 3). The 2013 AHOD value is also similar to that found in other Southeastern reservoirs of comparable depth, chlorophyll *a* status, and Secchi depth (Table 2-4), which illustrates that the trend is for progressively greater AHOD values with increasing mean depth, which is at least partially an indicator of increased potential for a greater vertical mixing and reaeration influence in lakes with shallower depths.

### Striped Bass Habitat and Fish Mortalities

Striped bass, a coolwater predator often introduced in Southeastern reservoirs to enhance and diversify the sport fishery, were first stocked in Lake Norman by the North Carolina Wildlife Resources Commission (NCWRC) in the late 1960's. These annual introductions were successful for the most part; however, in recent years periodic summertime mortalities of adult striped bass have occurred (Duke Energy 2013). Coutant (1985) hypothesized that summertime mortalities of adult striped bass could be explained by a temperature-dissolved oxygen "squeeze" within the water column. As thermal stratification intensified throughout the summer, continued epilimnion warming and deepening, coupled with mid and bottom water deoxygenation, would ultimately force fish to occupy water layers that lack the appropriate physicochemical conditions critical for survival, and eventually would lead to mortalities. Coutant (1985) proposed that suitable physicochemical habitat critical for survival of adult striped bass included water temperatures of about 18-25 °C and DO concentrations above about 2-3 mg/L. Duke Energy has been monitoring summertime pelagic coolwater fish habitat in Lake Norman, described as waters with temperatures ≤ 26 °C and DO levels ≥ 2.0 mg/L, since MNS became operational (Duke Energy 2011, 2012, and 2013).

declining air temperatures gradually expanded habitat from the surface downward, resulting in a lakewide habitat thickness of approximately 15 m on September 3. By early October, habitat was present both vertically and horizontally throughout most of the reservoir, and continued to expand further as the reservoir cooled and mixed.

In contrast to prior years, coolwater fish habitat in 2013 was present continuously throughout a large portion of the reservoir during the summer, due mainly to the higher DO levels observed in the middle and lower portions of the water column, particularly in the upper reaches. This year-round availability of coolwater habitat in the upper portions of the reservoir appears to have altered the annual downlake migration of both adult alewives (*Alosa pseudoharengus*), and striped bass into the hypolimnion of lower Lake Norman, where the last remaining habitat attracted and concentrated these fish. As microbial respiration processes exhausted the remaining oxygen supplies in these deeper waters, striped bass became "trapped" and eventually died due to asphyxiation. No mortalities of striped bass were observed in 2013 likely because few adult alewives, a coolwater forage fish, and striped bass actually migrated downlake into the hypolimnion. Weekly hydroacoustic surveys performed in lower Lake Norman in summer 2013 identified few "targets" within the water column, in striking contrast to prior years, adding corroborative evidence to this migration hypothesis.

Turbidity and Specific Conductance

Turbidity values were relatively low at the MNS discharge, mixing, and background zone locations during 2013, and well below the NC water quality standard of 25 NTU's, although some spatial and temporal variability was observed (Table 2-5). Surface readings ranged from 1.1 to 3.8 NTUs, whereas bottom values were slightly higher, ranging from 1.0 to 5.9 NTUs with the higher values being more frequently reported at the uplake locations. Turbidity values observed in 2013 were well within the historical range (Duke Power Company 1985, 1987, 1988, and 1996; Duke Power 2004a, and 2005; Duke Energy 2009, 2010, 2011, 2012, and 2013).

Specific conductance in Lake Norman in 2013 ranged from 50 to 95 µmhos/cm and was within historical ranges, with the annual mean slightly lower than observed in 2012, likely reflecting a dilution effect of the high reservoir flow through for 2013 (Table 2-5, Duke Power Company 1985, 1987, 1988, and 1996; Duke Power 2004a, and 2005; Duke Energy 2009, 2010, 2011, 2012, and 2013). Conductance values in surface and bottom waters in historically (Duke Power Company 1985, 1987, 1988, and 1996; Duke Power 2004a, and 2005; Duke Energy 2009, 2010, 2011, 2012, and 2013). Nitrite-nitrate and ammonia nitrogen levels in 2013 did exhibit some longitudinal variability, probably influenced by reservoir flow throughs, but all values were relatively low at all locations in both surface and bottom samples, and generally similar to values measured in 2012 and historically (Duke Energy 2009, 2010, 2011, 2012, and 2013). For total phosphorus (TP), all 44 water samples analyzed in 2013 exceeded 5 µg/L, the analytical reporting limit (ARL), and values were slightly higher than observed in 2012, but within the historical range. Somewhat higher TP values were observed in the middle section of the reservoir (Location 11.0) than in the lower segment. These higher TP values were likely linked to the influx into the reservoir of organic and inorganic particulates associated with the precipitation-driven inflows observed in 2013, as discussed earlier. The impact of hydrologic effects of rainfall runoff on reservoir water quality have been documented by numerous researchers across the world, as well as reservoirs in the Southeast (Cole and Hannan 1985; Hannan et al. 1979; Petts 1984). All measurements (N = 44) of orthophosphorus in 2013, the soluble form of phosphorus, were ≤ 5 µg/L, the ARL, and similar to historical observations (Duke Energy 2009, 2010, 2011, 2012, and 2013).

### Metals

Metal concentrations in the discharge, mixing, and background zones of Lake Norman for 2013 were similar to those measured in 2012 (Table 2-5) and historically (Duke Power Company 1985, 1987, 1988, and 1996; Duke Power 2004a, and 2005; Duke Energy 2009, 2010, 2011, 2012, and 2013). Iron concentrations in surface and bottom waters were generally low (≤ 0.2 mg/L) during 2013, with only five of 44 samples exceeding 0.20 mg/L, which was similar to the 2012 data. The highest 2013 iron values were measured in the bottom waters in the lower portion of the reservoir in early November, prior to complete water column mixing. The maximum iron value in 2013 was 2.12 mg/L, a bottom sample collected at Location 2.0 near the dam, and no surface sample collected in 2013 exceeded the North Carolina water quality action level for iron (1.0 mg/L; NCDENR 2004).

Manganese concentrations in the surface and bottom waters in 2013 were also generally low (≤ 100 µg/L), except during the summer stratified period when bottom waters were anoxic (Table 2-5). Manganese concentrations in surface waters at all locations in 2013 were low and well below the North Carolina water quality action level (200 µg/L; NCDENR 2004) and similar to historical conditions (Duke Power Company 1985, 1987, 1988, and 1996; Duke compared to 2012 rates, resulting in the decline of the reservoir hydraulic retention time from an average of 210 days to 85 days.

Water temperatures, dissolved oxygen concentrations and coolwater fish habitat were also impacted by these atypical 2013 phyical forcing metrics, with the enhanced rate of reservoir flow through having a dominant influence on vertical and horizontal mixing and reaeration, especially during the spring and summer stratified period. Water temperatures in spring 2013 were as much as 6 - 8 °C cooler and DO values were almost 5.0 mg/L higher at comparable depths than measured in 2012, with a somewhat greater impact observed in the uplake background locations than at the downlake mixing zone locations. This pattern of cooler than average temperatures and above average DO conditions were observed until the genesis of fall cooling and lake turnover.

In contrast to prior years, coolwater fish habitat was present continuously throughout a large portion of the reservoir during the summer, due mainly to the higher DO levels observed in the middle and lower portions of the water column, particularly in the upper reaches. No mortalities of striped bass were observed in 2013, likely because few adult alewives and striped bass actually migrated downlake into the hypolimnion during the summer, compared to prior years, due to the availability of uplake habitat.

Impacts of the atypical 2013 meterology and hydrology on other warter quality parameters were less extreme and mostly neglible. Specific conductance, alkalinity, and several major ions (calcium, sodium, chloride, and sulfate) were slightly lower than measured in than 2012 and average, likely related to dilution effects associated with the high inflow and outflow rates observed in 2013. Total phosphorus, and to some degree nitrite-nitrate and ammonia nitrogen levels, exhibited some temporal and longitudinal variability, also attributed to 2013 hydrology influences, but all values were relatively low at all locations in both surface and bottom samples, and within historical ranges. Metal concentrations in 2013 were, for the most part, unaffected by 2013 hydrology with concentratons often measured below the analytical reporting limit for that element. Elevated levels of iron and manganese above the North Carolina water quality action levels for these elements were measured in the bottom waters during late summer in 2013, but this phenomenon is consistent with historical data for Lake Norman and other Southeatern reservoirs.

Cumulatively, water quality data collected in 2013 reaffirmed that Lake Norman, both near and distant from MNS's thermal discharge, continues to provide a suitable physicochemical

## Table 2-1. Water quality 2013 program for the MNS NPDES Maintenance Monitoring Program on Lake Norman.

2013 McGUIRE NPDES SAMPLING PROGRAM

| PARAMETERS | LOCATIONS | 1 | 2 | 4 | 5 | 8 | 9.5 | 11 | 13 | 14 | 15 | 15.9 | 62 | 69 | 72 | 80 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DEPTH (m) | 33 | 33 | 5 | 20 | 32 | 23 | 27 | 21 | 10 | 23 | 23 | 15 | 7 | 5 | 4 |
| | | 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 at all locations except 5 & 9.5. | | | | | | | | | | | | | | |
| Conductivity | Hydrolab | | | | | | | | | | | | | | | |
| | | NUTRIENT ANALYSES | | | | | | | | | | | | | | |
| Ammonia | C_NH3 | 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 | | |
| Nitrate+Nitrite | C_NO2NO3 | 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 | | |
| Orthophosphate | C_OPO4 | 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 | | |
| Total Phosphorus | C_TP | 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 | | |
| Silica | C_SIO2 | 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 | | |
| Cl | C_CL | 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 | | |
| | | ELEMENTAL ANALYSES | | | | | | | | | | | | | | |
| Aluminum | ICP Undigested | 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 | | |
| Calcium | ICP Undigested | 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 | | |
| Iron | IMS_TRM | 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 | | |
| Magnesium | ICP Undigested | 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 | | |
| Manganese | IMS_TRM | 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 | | |
| Potassium | ICP Undigested | 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 | | |
| Sodium | ICP Undigested | 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 | | |
| Zinc | IMS_TRM | 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 | | |
| | | | | | | | | | | | | | | | | |
| Cadmium | IMS_TRM | 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 | | |
| Copper (Total Recoverable) | IMS_TRM | 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 | | |
| Copper (Dissolved) | IMS Dissolved | 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 | | |
| Lead | IMS_TRM | 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 | | |
| | | ADDITIONAL ANALYSES | | | | | | | | | | | | | | |
| Alkalinity | ALK_FIX5.1 | 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 | | |
| Turbidity | 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 | | |
| Sulfate | DIONEX | 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 | | |

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

Table 2-3. Heat content calculations for the thermal regime in Lake Norman for 2012 and 2013.

| | 2013 | 2012 |
|---|---|---|
| Maximum Areal Heat Content (Kcal/cm$^2$) | 26.953 | 28.785 |
| Minimum Areal Heat Content (Kcal/cm$^2$) | 9.344 | 11.521 |
| Birgean Heat Budget (Kcal/cm$^2$) | 17.609 | 17.264 |
| Epilimnion (above 11.5 m) Heating Rate (°C/day) | 0.12 | 0.11 |
| Hypolimnion (below 11.5 m) Heating Rate (°C/day) | 0.07 | 0.09 |

Table 2-5. Quarterly surface (0.3 m) and bottom (bottom minus 1 m) water chemistry for the MNS discharge, mixing zone, and background locations on Lake Norman during 2012 and 2013. Values less than detection were assumed to be equal to the detection limit for calculating a mean.

| LOCATION: | Mixing Zone 1.0 | | | | Mixing Zone 2.0 | | | | 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: | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 |
| Turbidity (NTU) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 1.8 | 1.2 | 4.0 | 1.6 | 1.8 | 1.1 | 2.1 | 2.4 | 1.8 | 1.3 | 1.8 | 1.5 | 3.6 | 3.1 | 2.3 | 1.0 | 3.7 | 3.3 | 3.8 | 0.9 | 5.9 | 3.5 |
| May | 1.1 | 1.2 | 1.9 | 0.9 | 1.2 | 1.4 | 2.4 | 1.1 | 1.2 | 1.2 | 1.2 | 1.3 | 1.5 | 1.5 | 1.5 | 1.0 | 2.8 | 1.1 | 2.0 | 1.4 | 3.3 | 1.5 |
| Aug | 2.4 | 1.5 | 1.1 | 1.3 | 1.9 | 1.5 | 1.2 | 0.9 | 2.7 | 1.3 | 2.3 | 1.4 | 1.0 | 1.1 | 1.9 | 1.3 | 3.4 | 1.3 | 2.8 | 2.1 | 4.1 | 1.6 |
| Nov | 2.0 | 2.4 | 1.2 | 2.1 | 1.9 | 1.7 | 1.4 | 2.3 | 1.8 | 1.6 | 1.7 | 1.9 | 1.7 | 2.2 | 1.8 | 2.0 | 4.7 | 3.3 | 1.4 | 1.7 | 4.5 | 2.1 |
| Annual Mean | 1.8 | 1.6 | 2.1 | 1.5 | 1.7 | 1.4 | 1.8 | 1.7 | 1.9 | 1.4 | 1.8 | 1.5 | 2.0 | 2.0 | 1.9 | 1.3 | 3.7 | 2.3 | 2.5 | 1.5 | 4.5 | 2.2 |
| Specific Conductance (umho/cm) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 68 | 69 | 66 | 67 | 68 | 69 | 67 | 67 | 70 | 70 | 69 | 69 | 67 | 68 | 68 | 68 | 67 | 65 | 66 | 68 | 66 | 64 |
| May | 63 | 68 | 68 | 67 | 63 | 68 | 62 | 67 | 65 | 69 | 64 | 68 | 64 | 68 | 61 | 68 | 59 | 67 | 58 | 68 | 59 | 67 |
| Aug | 51 | 68 | 75 | 77 | 51 | 68 | 71 | 75 | 51 | 68 | 50 | 68 | 67 | 68 | 53 | 68 | 64 | 75 | 54 | 68 | 77 | 76 |
| Nov | 55 | 68 | 95 | 91 | 55 | 69 | 95 | 188 | 55 | 69 | 55 | 69 | 58 | 68 | 55 | 68 | 94 | 68 | 57 | 70 | 59 | 70 |
| Annual Mean | 69 | 68 | 76 | 76 | 59 | 69 | 74 | 99 | 60 | 69 | 60 | 69 | 64 | 68 | 59 | 68 | 71 | 69 | 59 | 69 | 65 | 69 |
| pH (units) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 6.6 | 7.3 | 6.7 | 7.3 | 7.2 | 7.4 | 7.0 | 7.1 | 7.2 | 7.4 | 7.3 | 7.4 | 7.0 | 7.2 | 7.3 | 7.4 | 7.1 | 7.1 | 7.1 | 6.8 | 7.1 | 7.0 |
| May | 6.9 | 7.3 | 6.6 | 6.5 | 7.4 | 7.5 | 6.6 | 6.5 | 7.1 | 7.4 | 7.2 | 7.6 | 6.6 | 6.6 | 7.3 | 7.7 | 6.6 | 6.7 | 7.2 | 7.7 | 6.7 | 6.7 |
| Aug | 7.0 | 6.9 | 6.4 | 6.4 | 7.2 | 7.1 | 6.4 | 6.5 | 6.9 | 6.8 | 7.0 | 7.2 | 6.4 | 6.6 | 8.4 | 7.5 | 6.3 | 6.5 | 8.6 | 7.1 | 6.4 | 6.6 |
| Nov | 7.2 | 6.9 | 7.2 | 6.9 | 7.3 | 7.2 | 7.2 | 7.5 | 7.4 | 7.3 | 7.5 | 7.3 | 7.2 | 7.2 | 7.4 | 7.3 | 7.4 | 7.2 | 7.5 | 7.2 | 7.2 | 7.2 |
| Annual Mean | 6.9 | 7.1 | 6.7 | 6.8 | 7.3 | 7.3 | 6.8 | 6.9 | 7.1 | 7.2 | 7.2 | 7.4 | 6.8 | 6.9 | 7.6 | 7.5 | 6.8 | 6.9 | 7.6 | 7.2 | 6.9 | 6.9 |
| Alkalinity (mg $CaCO_3$/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 15 | 14 | 15 | 14 | 15 | 14 | 13 | 14 | 15 | 14 | 15 | 14 | 15 | 14 | 15 | 14 | 15 | 14 | 15 | 14 | 15 | 14 |
| May | 5 | 16 | 5 | 14 | 5 | 15 | 5 | 14 | 13 | 15 | 13 | 15 | 14 | 15 | 13 | 15 | 5 | 15 | 13 | 15 | 14 | 15 |
| Aug | 5 | 15 | 13 | 15 | 5 | 15 | 15 | 14 | 5 | 15 | 12 | 15 | 16 | 20 | 5 | 15 | 13 | 19 | 5 | 15 | 13 | 16 |
| Nov | 15 | 17 | 30 | 17 | 5 | 17 | 28 | 17 | 14 | 17 | 5 | 17 | 5 | 17 | 5 | 17 | 24 | 17 | 5 | 16 | 17 | 17 |
| Annual Mean | 10.0 | 15.5 | 15.8 | 15.0 | 7.5 | 15.3 | 15.3 | 14.8 | 11.8 | 15.3 | 11.3 | 15.3 | 12.5 | 16.5 | 9.5 | 15.3 | 14.3 | 16.3 | 9.5 | 15.0 | 14.8 | 15.5 |
| Chloride (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 6.9 | 8.2 | 6.5 | 7.8 | 6.9 | 8.1 | 6.9 | 7.5 | 6.9 | 7.7 | 6.9 | 7.7 | 6.8 | 7.7 | 6.9 | 7.5 | 6.5 | 6.5 | 6.4 | 7.6 | 6.4 | 6.4 |
| May | 6.1 | 7.1 | 5.9 | 6.9 | 6.1 | 7 | 5.7 | 6.9 | 6.2 | 7 | 6.1 | 7 | 6.1 | 7.0 | 5.2 | 7.1 | 5.1 | 6.8 | 4.9 | 6.9 | 4.9 | 6.6 |
| Aug | 3.8 | 6.8 | 5.3 | 7.0 | 3.8 | 6.8 | 5.2 | 7.0 | 3.7 | 6.6 | 3.7 | 6.7 | 4.3 | 6.8 | 4.3 | 6.8 | 5.2 | 7.0 | 4.3 | 7 | 5.2 | 6.9 |
| Nov | 4.0 | 6.8 | 4.9 | 6.8 | 4.0 | 6.8 | 4.9 | 6.8 | 4.0 | 6.8 | 4.1 | 6.8 | 4.0 | 6.8 | 4.1 | 6.8 | 4.5 | 6.8 | 4.2 | 6.9 | 3.9 | 6.9 |
| Annual Mean | 5.2 | 7.2 | 5.7 | 7.1 | 5.2 | 7.2 | 5.7 | 7.1 | 5.2 | 7.0 | 5.2 | 7.1 | 5.3 | 7.1 | 5.1 | 7.1 | 5.3 | 6.8 | 5.0 | 7.1 | 5.1 | 6.7 |
| Sulfate (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 4.0 | 4.6 | 4.0 | 4.5 | 4.0 | 4.5 | 3.9 | 4.4 | 4.0 | 4.4 | 4.0 | 4.3 | 4.0 | 4.3 | 3.8 | 4.2 | 3.7 | 4.0 | 3.6 | 4.3 | 3.7 | 4.0 |
| May | 4.1 | 4.2 | 4.1 | 4.1 | 4.2 | 4.2 | 4.1 | 4.1 | 4.1 | 4.2 | 4.1 | 4.2 | 4.1 | 4.1 | 4.0 | 4.2 | 4.0 | 4.1 | 4.2 | 4.2 | 4.0 | 4.0 |
| Aug | 3.2 | 4.1 | 3.7 | 4.2 | 3.2 | 4.1 | 3.7 | 4.3 | 3.2 | 4 | 3.2 | 4.1 | 3.5 | 4.1 | 3.3 | 4.1 | 3.7 | 4.2 | 3.4 | 4.2 | 3.7 | 4.2 |
| Nov | 3.2 | 3.8 | 2.2 | 3.8 | 3.2 | 3.8 | 1.9 | 3.9 | 3.2 | 3.8 | 3.3 | 3.8 | 3.2 | 3.8 | 3.3 | 3.8 | 2.4 | 3.9 | 3.2 | 3.9 | 3.0 | 3.9 |
| Annual Mean | 3.6 | 4.2 | 3.5 | 4.2 | 3.7 | 4.2 | 3.4 | 4.2 | 3.6 | 4.1 | 3.7 | 4.1 | 3.7 | 4.1 | 3.6 | 4.1 | 3.5 | 4.1 | 3.6 | 4.2 | 3.6 | 4.0 |
| Calcium (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 4.2 | 4.1 | 4.3 | 4.2 | 4.2 | 4.1 | 4.2 | 4.2 | 4.3 | 4.1 | 4.3 | 4.1 | 4.3 | 4.1 | 4.3 | 4.1 | 4.3 | 4.2 | 4.2 | 4.1 | 4.3 | 4.1 |
| May | 4.0 | 4.0 | 4.1 | 4.2 | 4.0 | 4.1 | 4.1 | 4.3 | 4.0 | 4.1 | 4.0 | 4.0 | 4.1 | 4.3 | 4.1 | 4.0 | 4.1 | 4.3 | 4.0 | 4.2 | 4.0 | 4.3 |
| Aug | 3.3 | 4.1 | 4.3 | 4.5 | 3.3 | 4.1 | 4.3 | 4.4 | 3.3 | 4.1 | 3.3 | 4.1 | 4.0 | 4.5 | 3.4 | 4.1 | 4.3 | 4.5 | 3.6 | 4.1 | 4.3 | 4.4 |
| Nov | 3.7 | 4.2 | 4.6 | 4.2 | 3.7 | 4.1 | 4.7 | 4.3 | 3.7 | 4.1 | 3.7 | 4.1 | 3.8 | 4.1 | 3.8 | 4.1 | 4.4 | 4.2 | 4.0 | 4.3 | 4.0 | 4.3 |
| Annual Mean | 3.8 | 4.1 | 4.3 | 4.3 | 3.8 | 4.1 | 4.3 | 4.3 | 3.8 | 4.1 | 3.8 | 4.1 | 4.0 | 4.3 | 3.9 | 4.1 | 4.3 | 4.3 | 4.0 | 4.2 | 4.1 | 4.3 |
| Magnesium (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 2.0 | 2.0 | 2.0 | 1.9 | 2.0 | 2.0 | 2.0 | 1.9 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 2.0 | 1.9 | 1.8 | 1.8 | 1.9 | 1.9 | 1.7 |
| May | 1.8 | 2.0 | 1.8 | 1.9 | 1.9 | 2.0 | 1.8 | 2.0 | 1.8 | 2.0 | 1.8 | 2.0 | 1.8 | 2.0 | 1.7 | 2.0 | 1.7 | 1.9 | 1.6 | 2.0 | 1.6 | 1.9 |
| Aug | 1.5 | 1.9 | 1.8 | 2.0 | 1.5 | 1.9 | 1.8 | 1.9 | 1.4 | 1.9 | 1.4 | 1.9 | 1.7 | 2.0 | 1.5 | 1.9 | 1.8 | 2.0 | 1.5 | 1.9 | 1.8 | 1.9 |
| Nov | 1.6 | 1.9 | 1.9 | 1.9 | 1.6 | 1.9 | 1.9 | 2.0 | 1.6 | 1.9 | 1.6 | 1.9 | 1.6 | 1.9 | 1.6 | 1.9 | 1.8 | 1.9 | 1.7 | 1.9 | 1.6 | 1.9 |
| Annual Mean | 1.7 | 1.9 | 1.9 | 1.9 | 1.8 | 1.9 | 1.9 | 1.9 | 1.7 | 1.9 | 1.7 | 1.9 | 1.8 | 2.0 | 1.7 | 1.9 | 1.8 | 1.9 | 1.7 | 1.9 | 1.7 | 1.9 |

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

Table 2-5. (Continued).

| LOCATION: | Mixing Zone 1.0 | | | | Mixing Zone 2.0 | | | | 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: | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 | 2013 | 2012 |
| Zinc (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 2.0 | 2.0 | 2.2 | 2.0 | 2.5 | 2.0 | 2.1 | 2.0 | 1.7 | 2.0 | 1.7 | 2.0 | 2.1 | 2.0 | 1.5 | 2.0 | 2.6 | 2.0 | 2.2 | 2.0 | 2.0 | 2.0 |
| May | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.1 | 1.0 |
| Aug | 1.0 | 1.0 | 1.5 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Nov | 1.1 | 1.0 | 2.0 | 1.3 | 1.0 | 1.0 | 2.5 | 1.0 | 1.0 | 1.1 | 2.0 | 1.0 | 1.3 | 1.0 | 1.0 | 1.0 | 1.9 | 1.0 | 1.1 | 1.0 | 1.9 | 1.4 |
| Annual Mean | 1.3 | 1.3 | 1.7 | 1.3 | 1.4 | 1.3 | 1.7 | 1.3 | 1.2 | 1.3 | 1.4 | 1.3 | 1.4 | 1.3 | 1.1 | 1.3 | 1.6 | 1.3 | 1.3 | 1.3 | 1.5 | 1.4 |
| Nitrite-Nitrate (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 120 | 160 | 162 | 190 | 118 | 160 | 130 | 200 | 124 | 160 | 121 | 160 | 132 | 170 | 112 | 160 | 172 | 230 | 201 | 170 | 201 | 240 |
| May | 180 | 140 | 268 | 260 | 180 | 140 | 281 | 250 | 185 | 150 | 182 | 140 | 247 | 250 | 213 | 140 | 317 | 260 | 226 | 120 | 277 | 280 |
| Aug | 78 | 14 | 326 | 240 | 73 | 25 | 313 | 260 | 109 | 47 | 113 | 34 | 229 | 120 | 10 | 13 | 300 | 200 | 10 | 10 | 312 | 220 |
| Nov | 52 | 45 | 10 | 45 | 53 | 45 | 10 | 44 | 52 | 46 | 54 | 45 | 36 | 46 | 64 | 49 | 31 | 40 | 125 | 91 | 145 | 92 |
| Annual Mean | 108 | 90 | 192 | 184 | 106 | 93 | 184 | 189 | 118 | 101 | 118 | 95 | 161 | 147 | 100 | 91 | 205 | 183 | 141 | 98 | 234 | 208 |
| Ammonia (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 75 | 63 | 147 | 78 | 121 | 63 | 94 | 74 | 80 | 65 | 84 | 62 | 80 | 69 | 89 | 62 | 88 | 75 | 263 | 65 | 86 | 73 |
| May | 48 | 87 | 37 | 130 | 49 | 130 | 39 | 130 | 51 | 130 | 46 | 130 | 41 | 130 | 56 | 130 | 40 | 130 | 28 | 130 | 55 | 130 |
| Aug | 38 | 60 | 38 | 68 | 39 | 63 | 44 | 58 | 45 | 66 | 41 | 59 | 52 | 100 | 70 | 53 | 52 | 86 | 55 | 62 | 58 | 80 |
| Nov | 100 | 95 | 344 | 78 | 94 | 83 | 403 | 75 | 103 | 82 | 94 | 81 | 126 | 84 | 93 | 82 | 320 | 84 | 91 | 75 | 131 | 74 |
| Annual Mean | 65 | 76 | 142 | 89 | 76 | 85 | 145 | 84 | 70 | 86 | 66 | 83 | 75 | 96 | 77 | 82 | 125 | 94 | 34 | 83 | 83 | 89 |
| Total Phosphorous (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 8 | 5 | 13 | 8 | 7 | 5 | 8 | 9 | 8 | 5 | 7 | 6 | 10 | 8 | 7 | 5 | 13 | 12 | 15 | 5 | 15 | 16 |
| May | 10 | 7 | 8 | 7 | 11 | 6 | 10 | 6 | 9 | 5 | 8 | 7 | 9 | 8 | 13 | 7 | 11 | 7 | 13 | 5 | 14 | 8 |
| Aug | 10 | 11 | 7 | 8 | 10 | 9 | 6 | 6 | 12 | 9 | 11 | 9 | 8 | 9 | 11 | 8 | 9 | 8 | 15 | 8 | 9 | 7 |
| Nov | 7 | 11 | 10 | 10 | 7 | 7 | 13 | 5 | 7 | 5 | 8 | 5 | 9 | 5 | 9 | 5 | 17 | 6 | 11 | 6 | 18 | 7 |
| Annual Mean | 9 | 9 | 9 | 8 | 9 | 7 | 9 | 6 | 9 | 6 | 9 | 7 | 9 | 7 | 10 | 6 | 13 | 8 | 14 | 6 | 14 | 10 |
| Orthophosphate (ug/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 7 | 5 | 5 |
| May | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 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 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Annual Mean | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Silicon (mg/L) | | | | | | | | | | | | | | | | | | | | | | |
| Feb | 3.9 | 4.5 | 4.1 | 4.4 | 4.0 | 4.6 | 3.9 | 4.4 | 4.0 | 4.5 | 4.0 | 4.6 | 4.0 | 4.5 | 3.9 | 4.5 | 4.1 | 4.3 | 4.1 | 4.4 | 4.1 | 4.2 |
| May | 3.7 | 3.9 | 4.2 | 4.5 | 3.7 | 3.9 | 4.2 | 4.6 | 3.8 | 3.9 | 3.7 | 3.9 | 4.2 | 4.7 | 3.7 | 3.9 | 4.3 | 4.5 | 3.8 | 3.6 | 4.1 | 4.5 |
| Aug | 3.4 | 3.6 | 4.5 | 4.8 | 3.4 | 3.6 | 4.5 | 4.6 | 3.5 | 3.6 | 3.5 | 3.7 | 4.3 | 4.5 | 3.0 | 3.6 | 4.5 | 4.7 | 3.0 | 3.5 | 4.4 | 4.6 |
| Nov | 4.0 | 4.3 | 4.8 | 4.2 | 4.8 | 4.2 | 4.9 | 4.2 | 3.9 | 4.2 | 4.0 | 4.2 | 4.0 | 4.2 | 4.1 | 4.1 | 4.9 | 4.2 | 4.5 | 4.3 | 5.2 | 4.3 |
| Annual Mean | 3.8 | 4.1 | 4.4 | 4.5 | 4.0 | 4.1 | 4.4 | 4.5 | 3.8 | 4.1 | 3.8 | 4.1 | 4.1 | 4.5 | 3.7 | 4.0 | 4.5 | 4.4 | 3.9 | 4.0 | 4.5 | 4.4 |

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

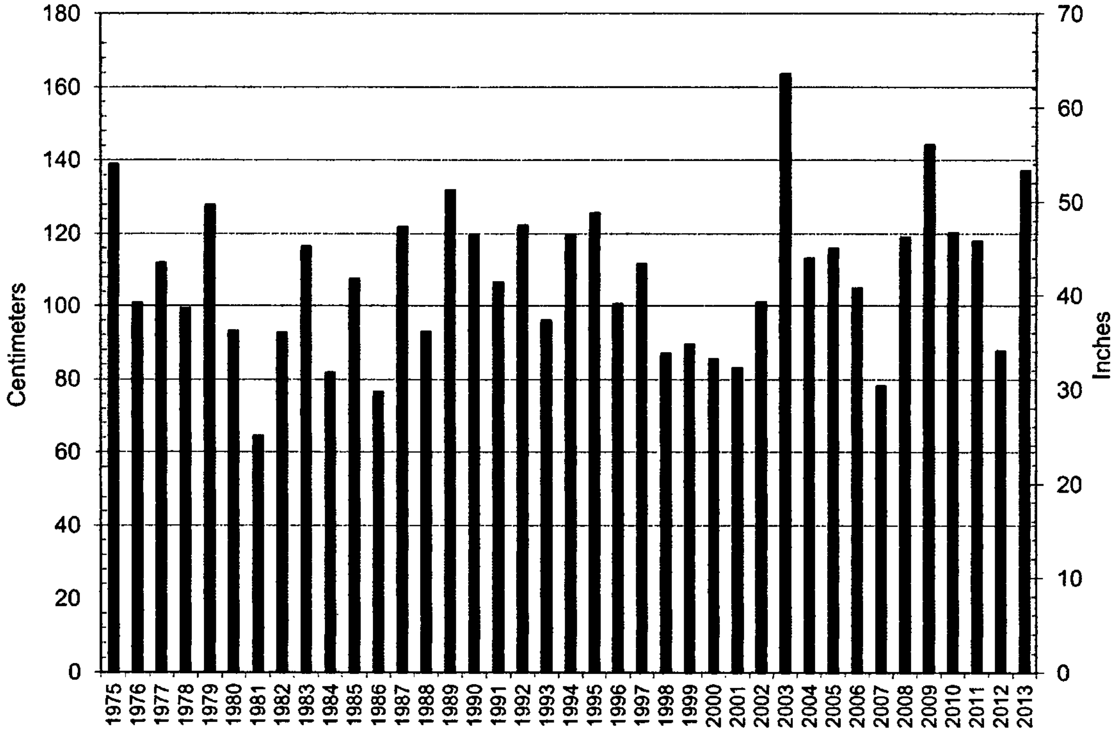


Figure 2-2a. Annual precipitation totals in the vicinity of MNS.

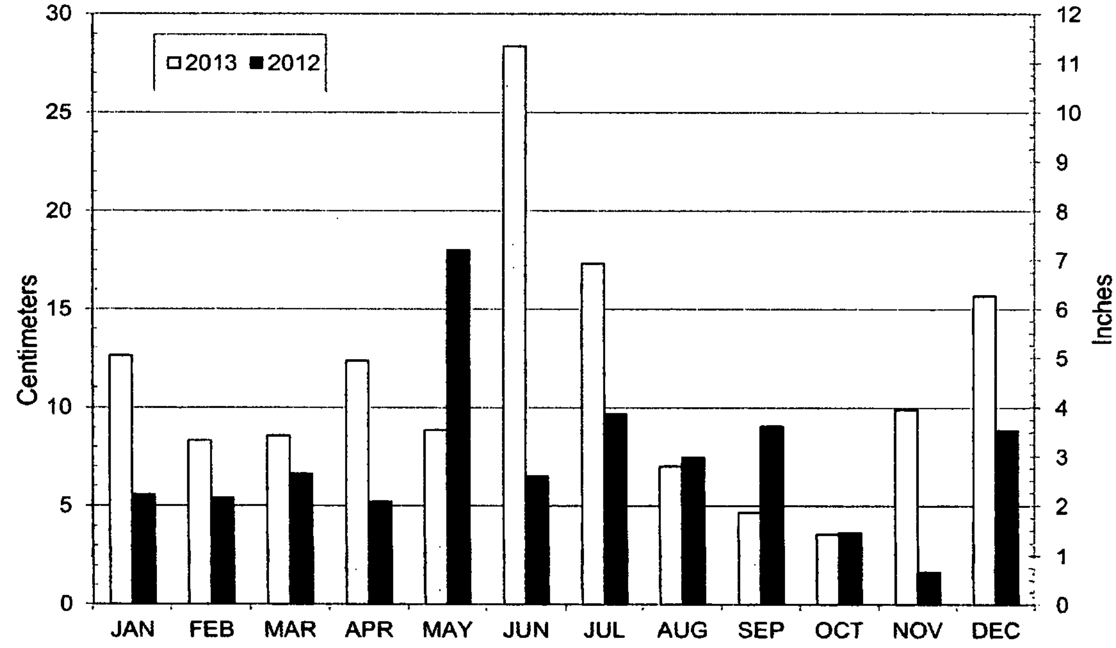


Figure 2-2b. Monthly precipitation totals in the vicinity of MNS in 2012 and 2013.

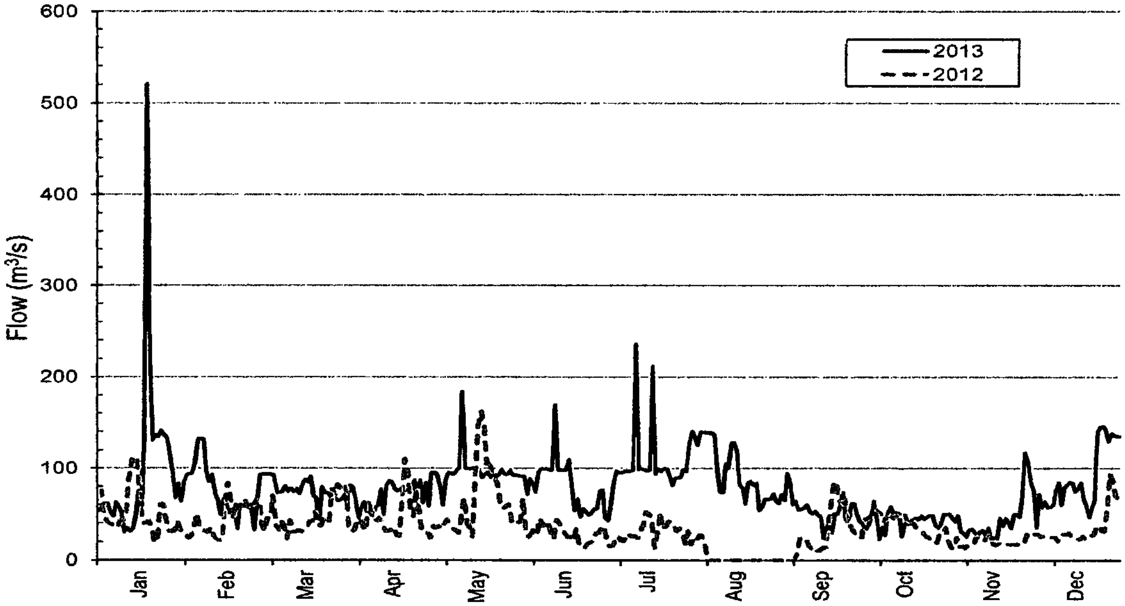


Figure 2-2d. Mean daily inflows, expressed in cubic meters per second ($m^3/s$) into Lake Norman from Lookout Shoals Hydroelectric Station for 2012 and 2013. Data were compiled from hourly average release and spill information.

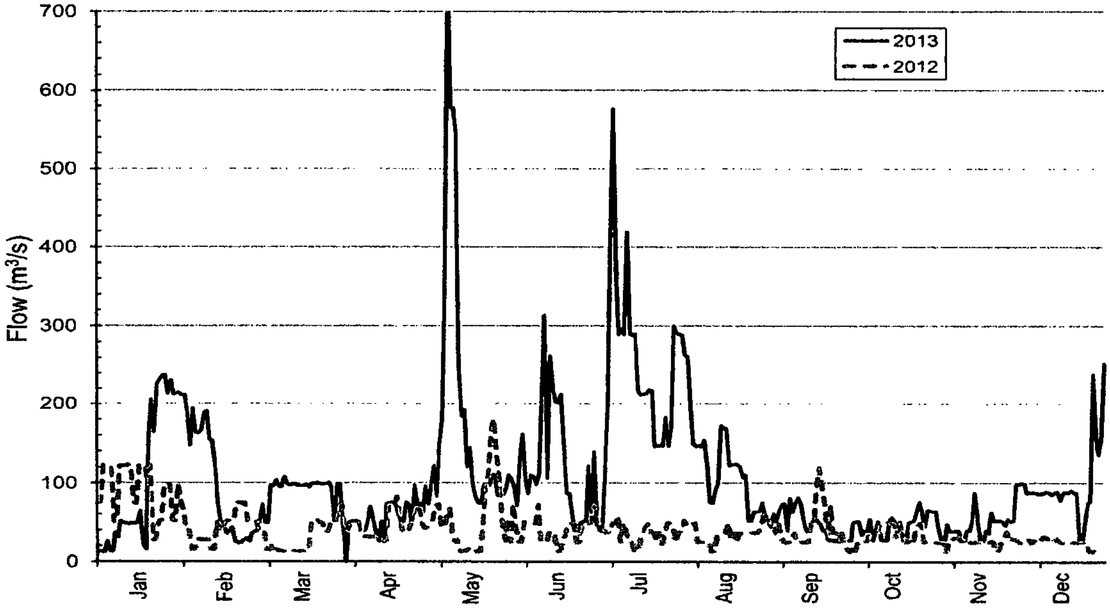


Figure 2-2e. Mean daily outflows from Lake Norman, expressed in cubic meters per second (m3/s), via Cowans Ford Hydroelectric Station for 2012 and 2013. Data were compiled from hourly average release and spill information.

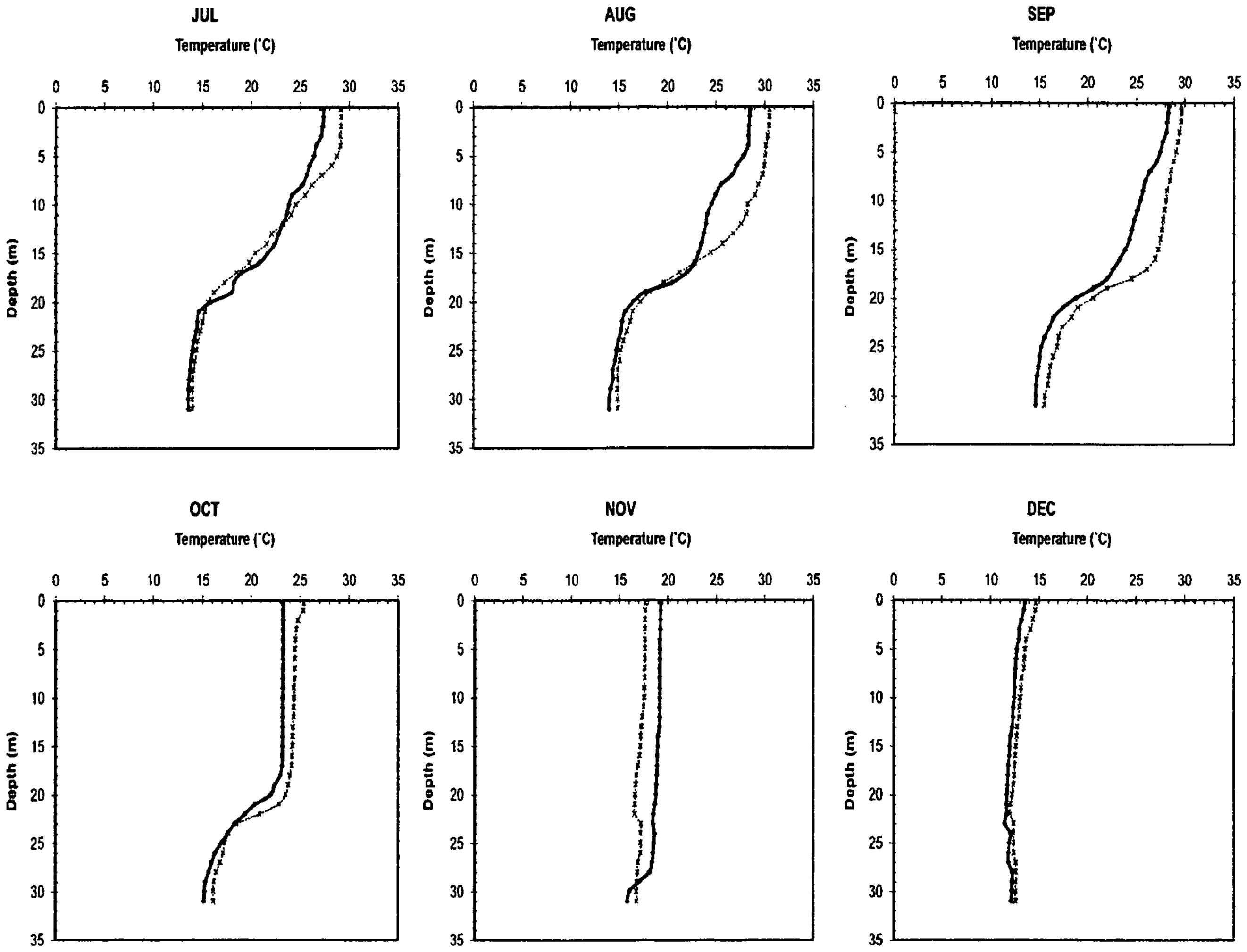


Figure 2-3. (Continued).

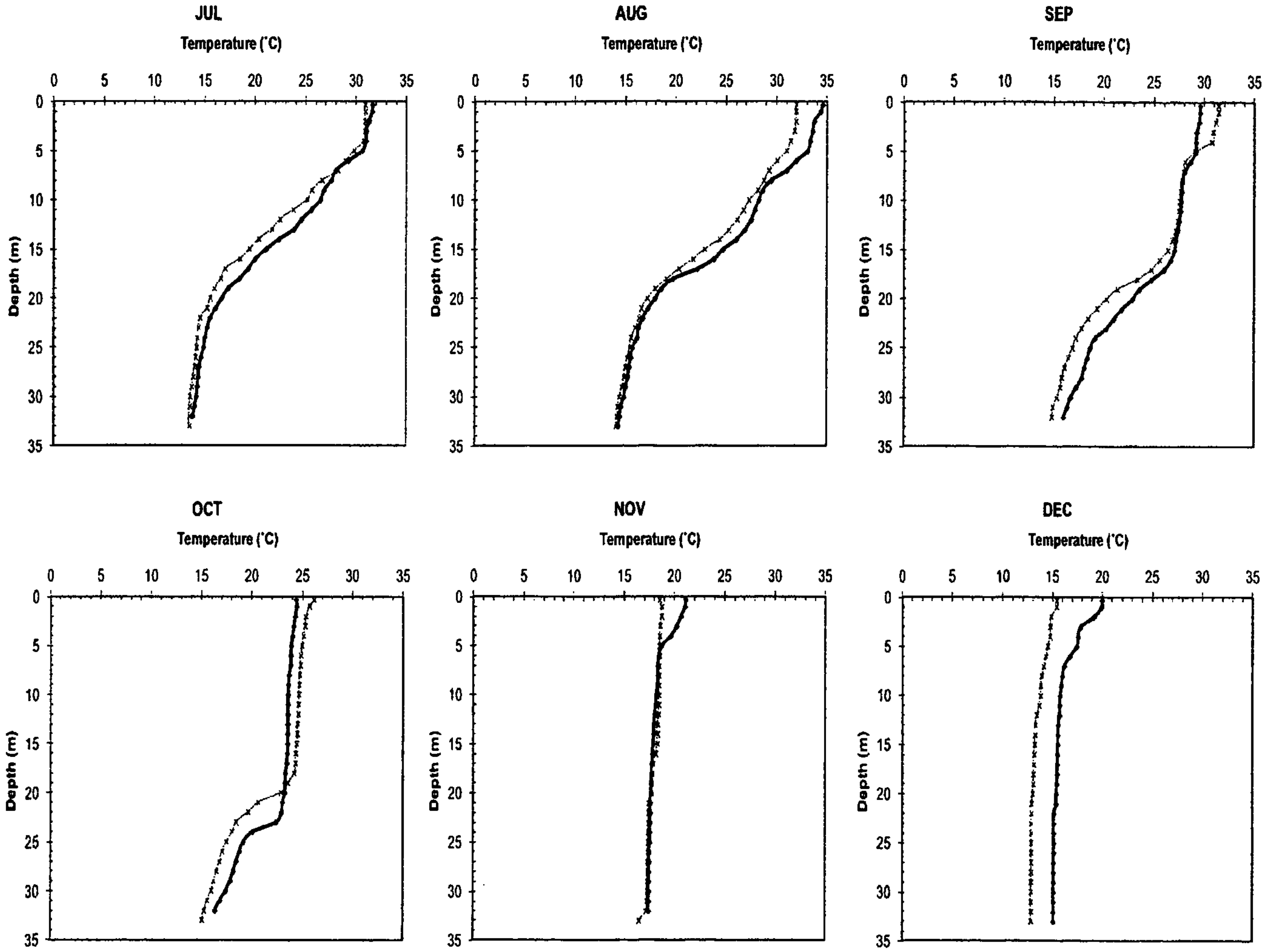


Figure 2-4 (Continued).

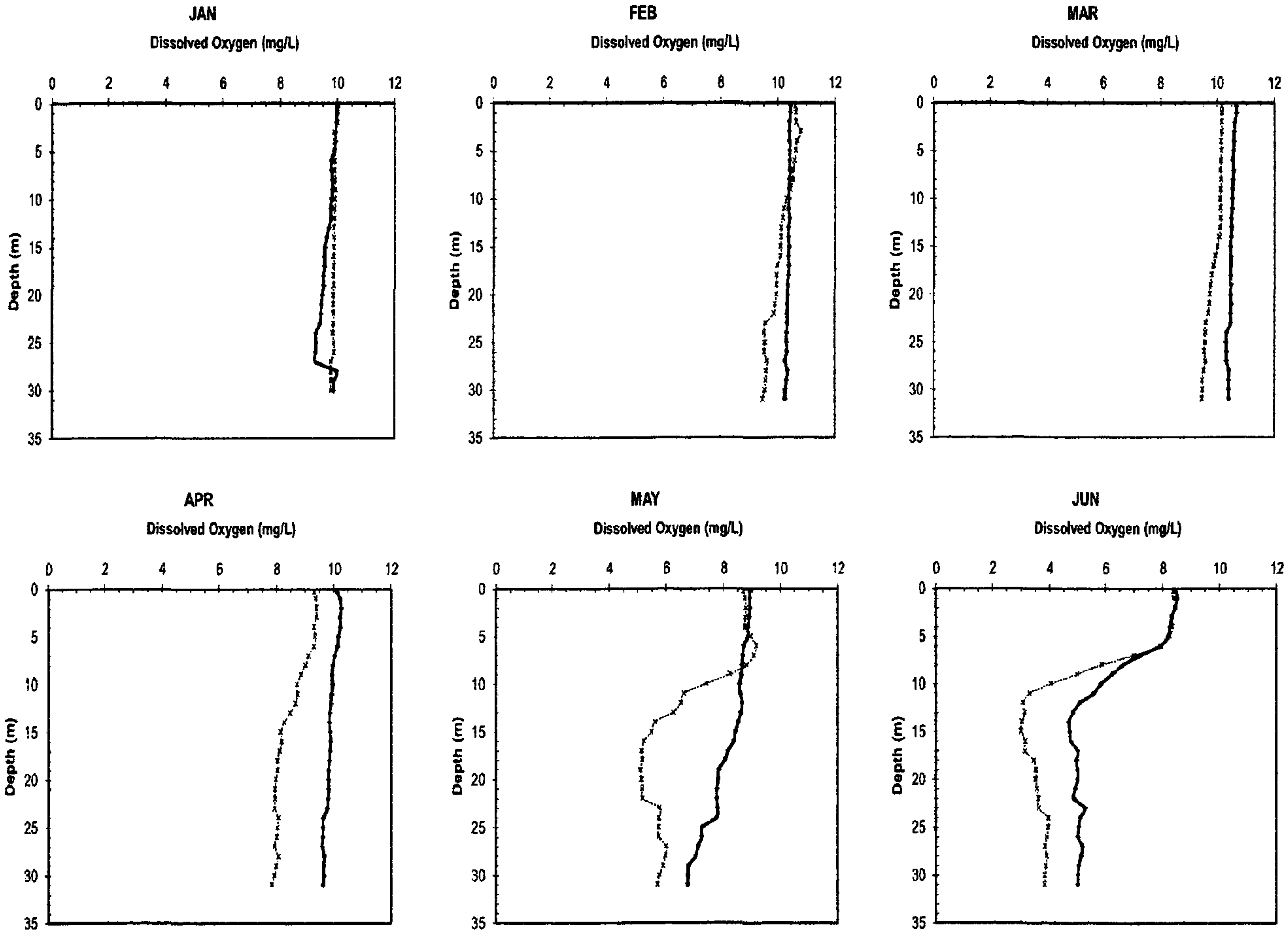


Figure 2-6. Monthly mean dissolved oxygen profiles for the MNS background zone in 2012 (××) and 2013 (♦♦).

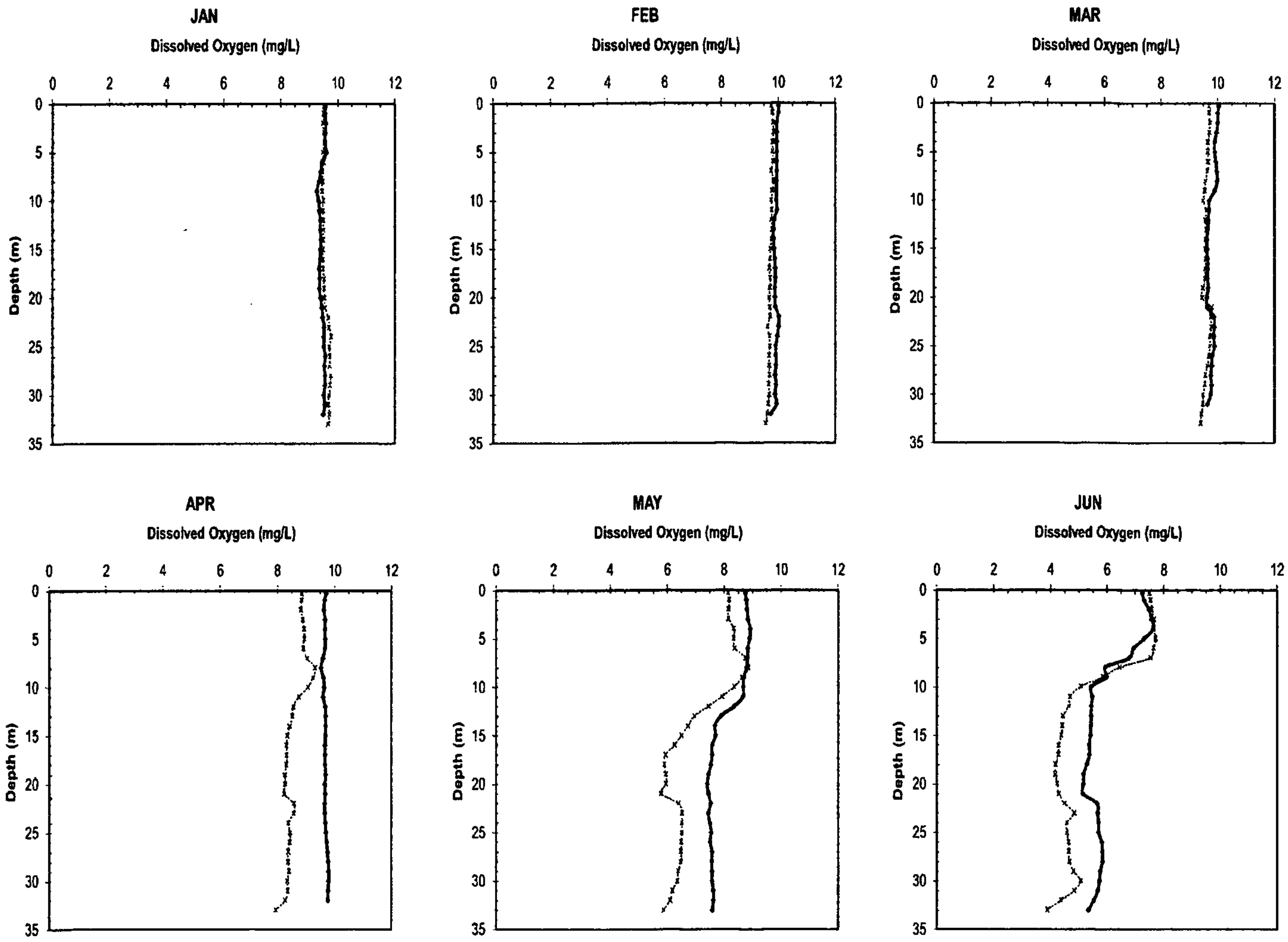


Figure 2-7. Monthly mean dissolved oxygen profiles for the MNS mixing zone in 2012 (××) and 2013 (♦ ♦).

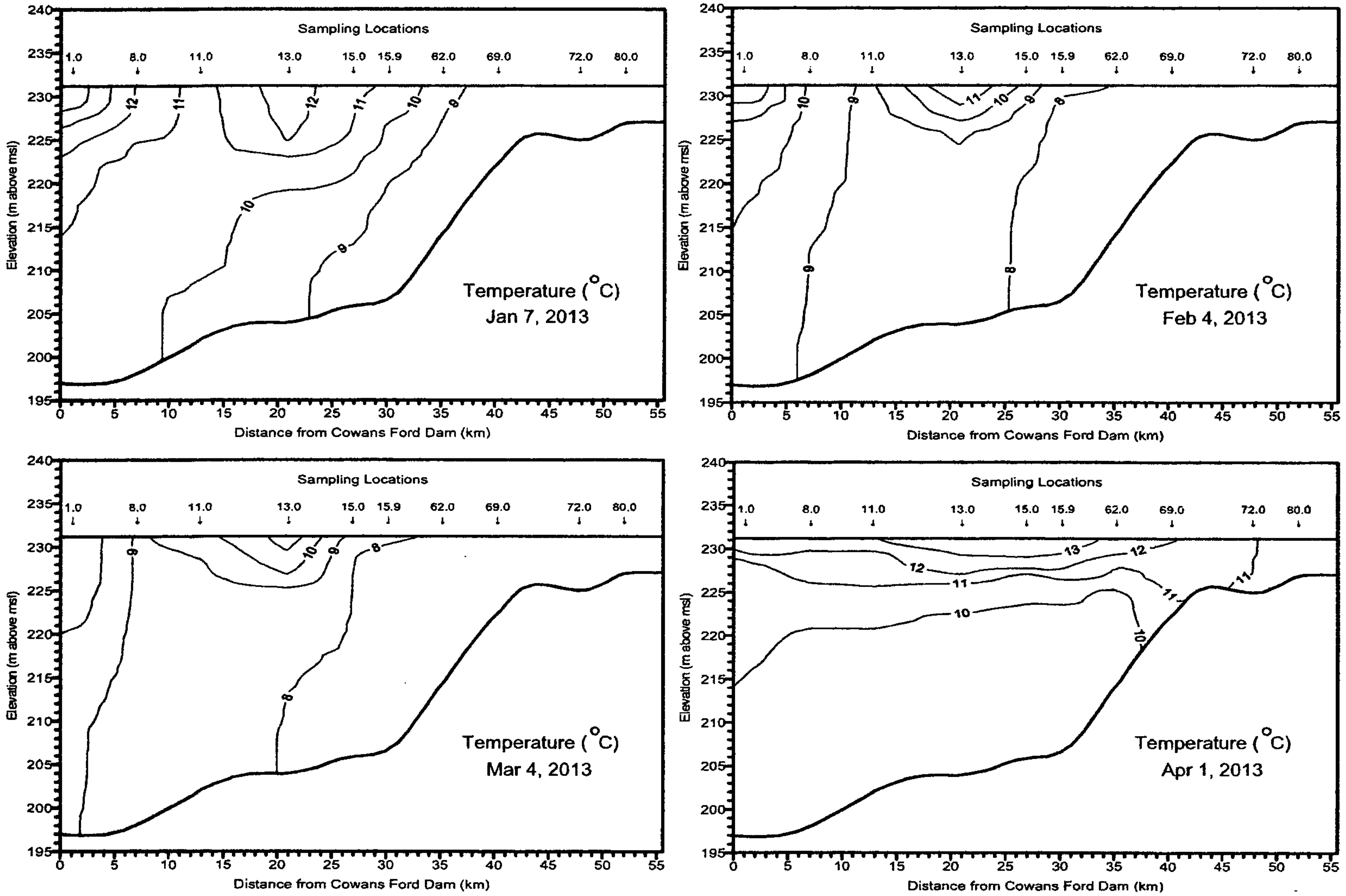


Figure 2-8. Monthly reservoir-wide temperature isotherms for Lake Norman in 2013.

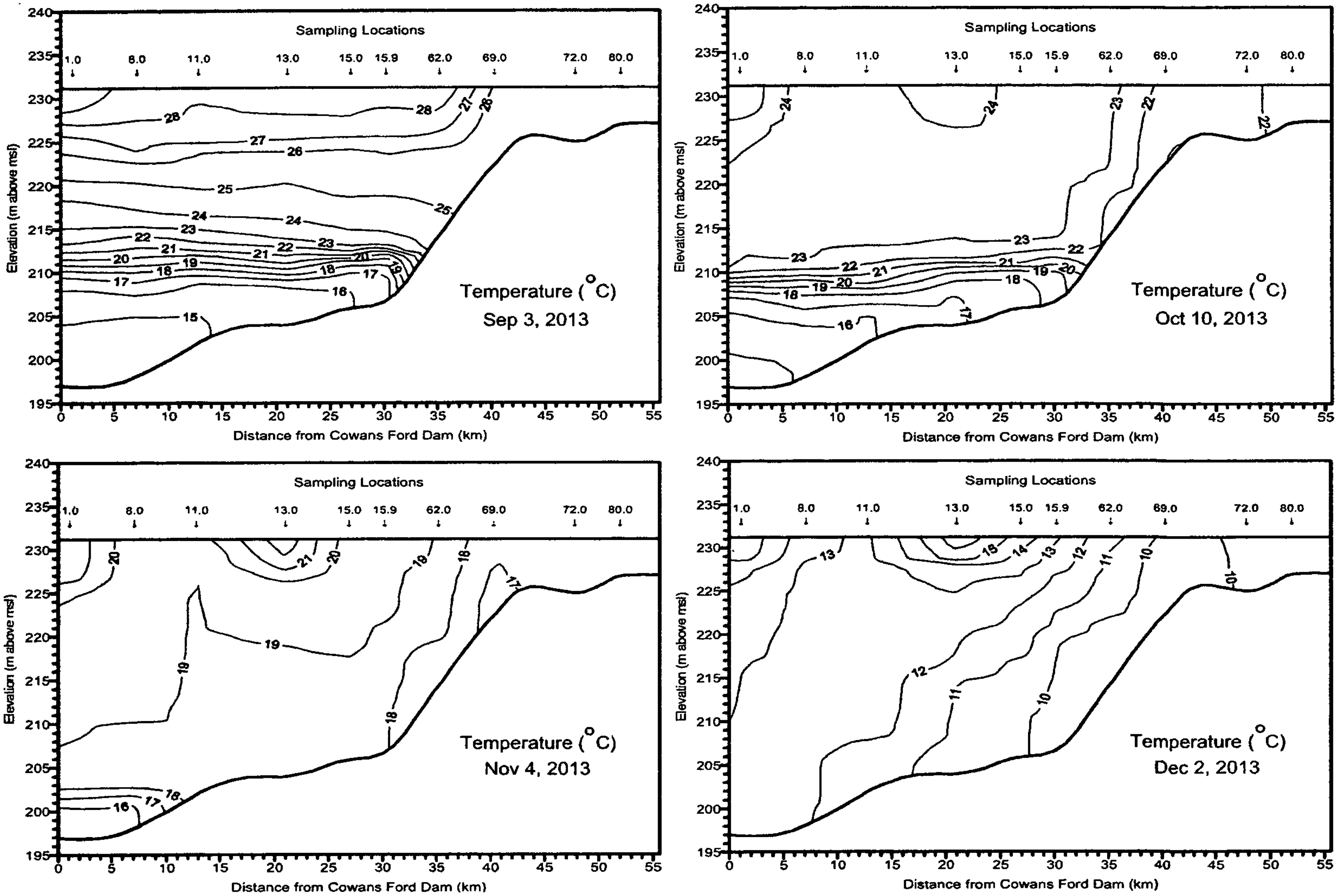


Figure 2-8. (Continued).

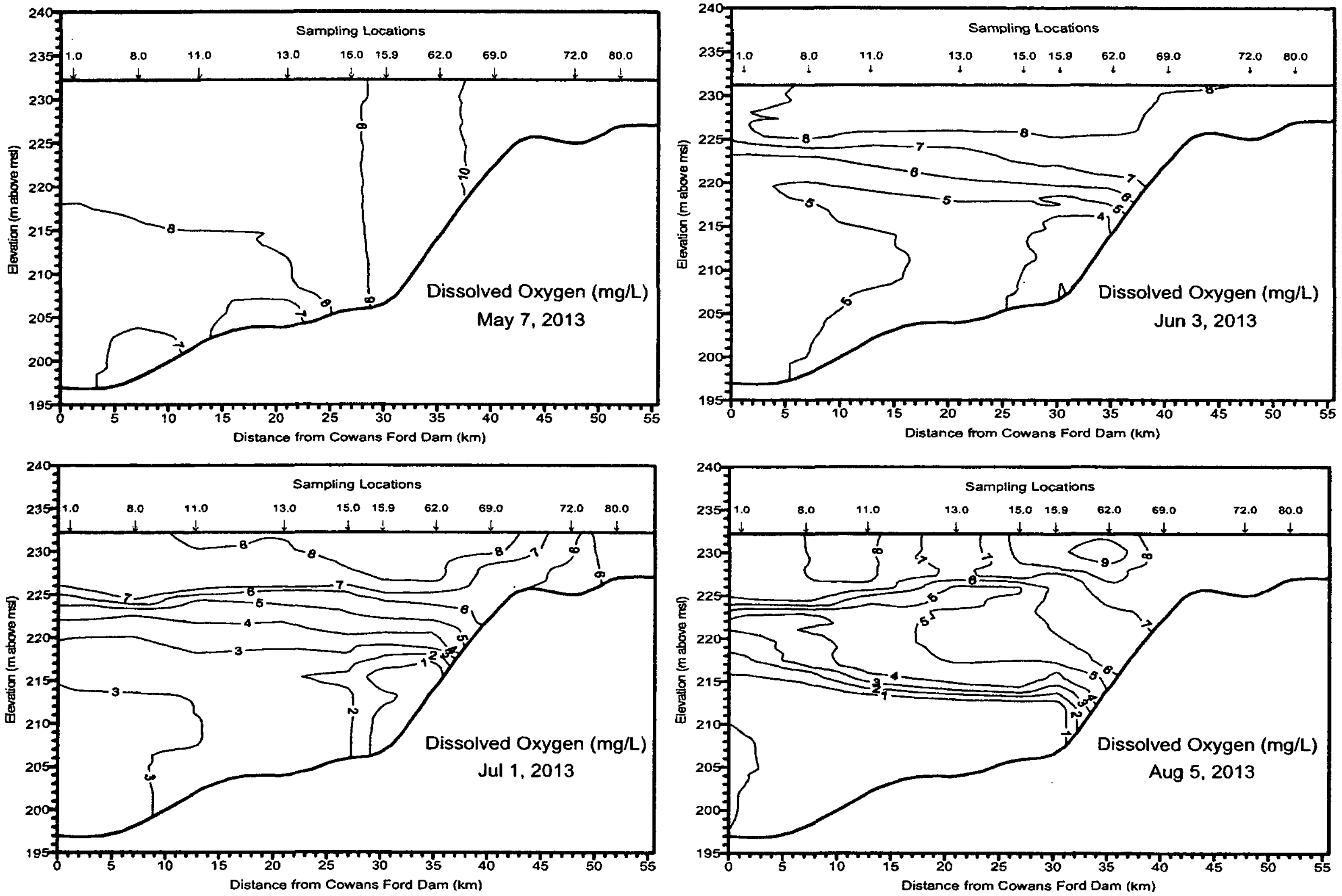


Figure 2-9. (Continued).

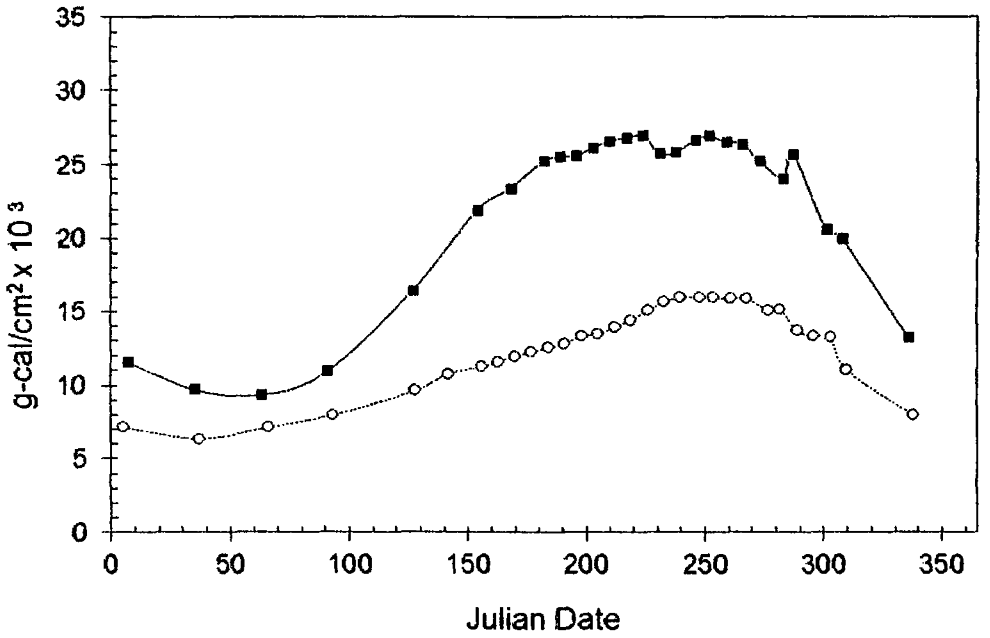


Figure 2-10a. Heat content of the entire water column (■) and the hypolimnion (○) in Lake Norman in 2013.

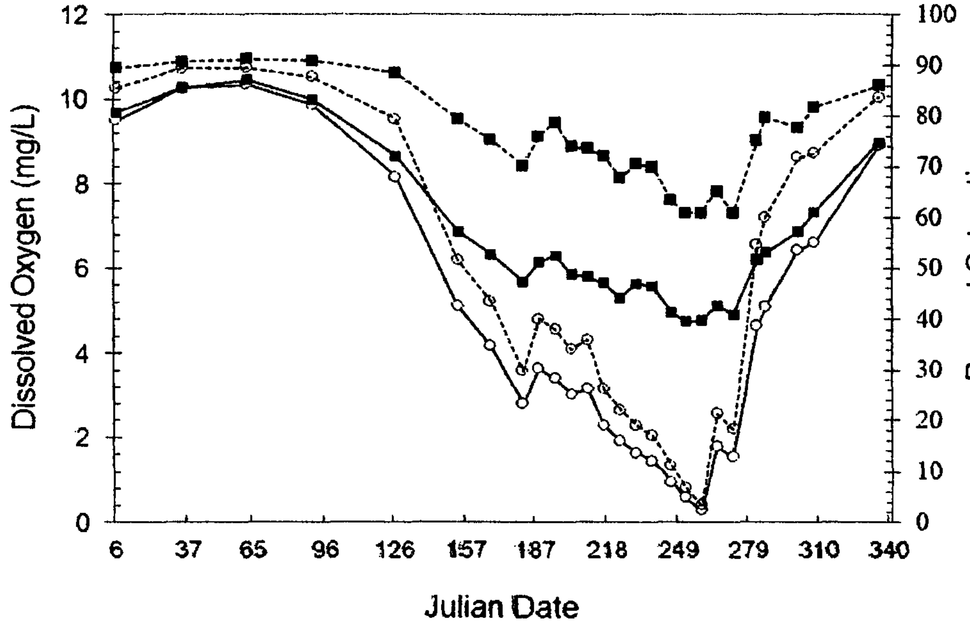


Figure 2-10b. Dissolved oxygen content (–) and percent saturation (---) of the entire water column (■) and the hypolimnion (○) of Lake Norman in 2013.

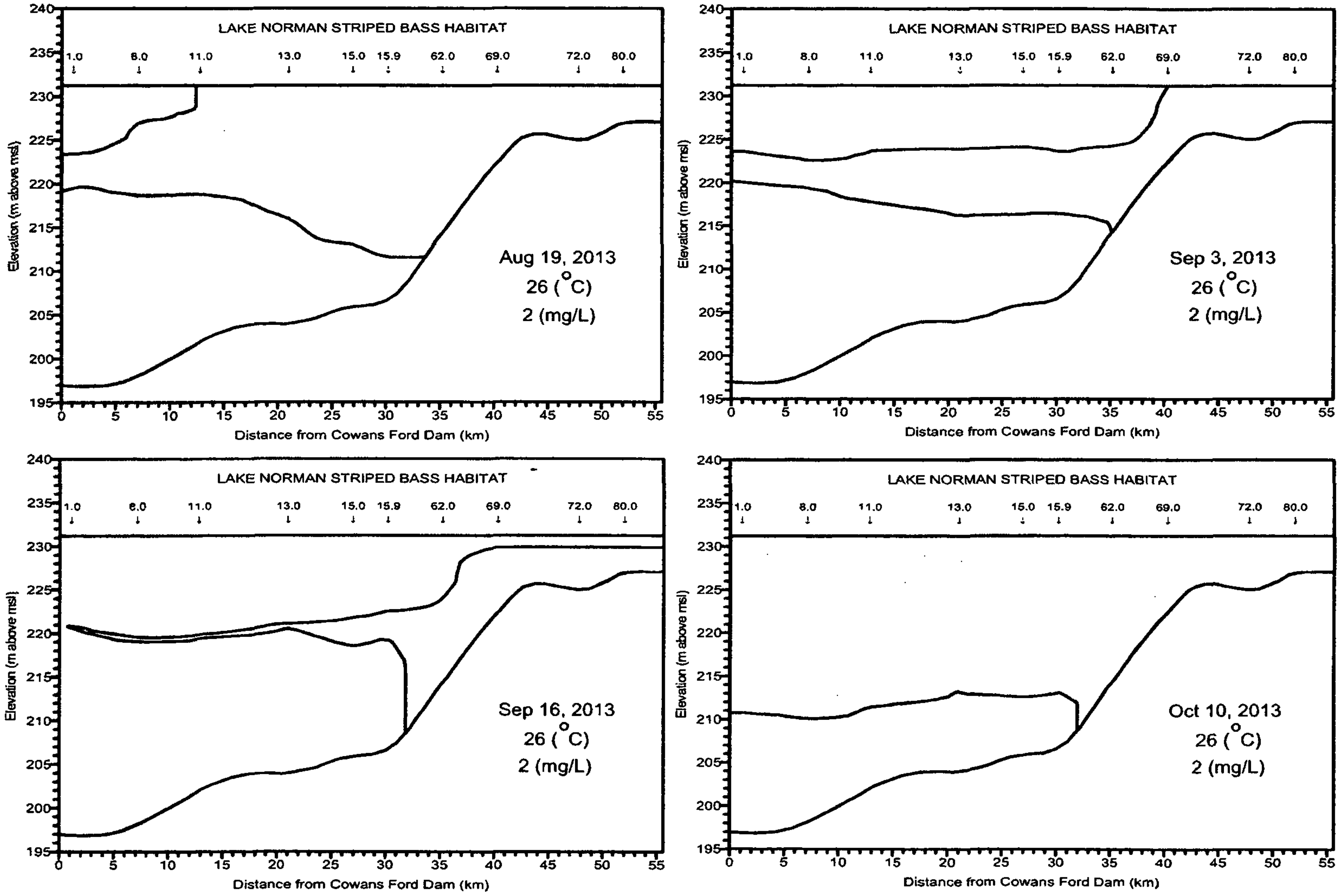


Figure 2-11. (Continued).

# CHAPTER 3

# PHYTOPLANKTON

## INTRODUCTION

Phytoplankton standing crop parameters were monitored in 2013 in accordance with the National Pollutant Discharge Elimination System (NPDES) permit for McGuire Nuclear Station (MNS). The objectives of the phytoplankton study of the Lake Norman Maintenance Monitoring Program are to:

1. describe quarterly/seasonal patterns of phytoplankton standing crop and species composition throughout Lake Norman; and
2. compare phytoplankton data collected during the 2013 study with data collected in prior study years (1987 – 2012).

In studies conducted on Lake Norman from 1973 through 1985, considerable spatial and temporal variability in phytoplankton standing crops and taxonomic composition were reported (Duke Power Company 1976, 1982, and 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 (Duke Energy 2013).

## METHODS AND MATERIALS

Quarterly sampling was conducted at Locations 2.0 and 5.0 in the mixing zone, and Locations 8.0, 9.5, 11.0, 13.0, 15.9, and 69.0 in Lake Norman (Figure 2-1). Duplicate Van Dorn samples from 0.3, 4.0, and 8.0 m (i.e., the estimated euphotic zone) were composited at all locations except Location 69.0, where Van Dorn samples were taken at 0.3, 3.0, and 6.0 m due to the shallower depth. Sampling has typically occurred in February (winter), May (spring), August (summer), and November (fall) of most years. As in previous years and based on the original study design (Duke Power Company 1988), phytoplankton density, biovolume, and taxonomic composition were determined for samples collected at Locations

During 2013, chlorophyll concentrations showed considerable spatial variability. The maximum concentration in February was observed at Location 11.0, while the May maximum was recorded from Location 15.9. Maximum concentrations among sampling locations in August and November were observed at Locations 9.5 and 69.0, respectively (Table 3-1; Figure 3-2). Minimum concentrations occurred at Location 69.0 during all but November. The trend of increasing chlorophyll concentrations from downlake to uplake, which had been observed during many previous years, was clearly apparent only during November and apparent to some extent during May, but was not apparent during February and August (Table 3-1 and Figure 3-2).

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 by upstream dams. During periods of high flow, algal production and standing crop are depressed due in great part to washout. Conversely, production and standing crop increases during periods of low flow which results in high retention time. However, over long periods of low flow, production and standing crop gradually decline. These conditions result in the comparatively high variability in chlorophyll concentrations observed between Locations 15.9 and 69.0 throughout many previous years, as opposed to Locations 2.0 and 5.0 which have usually shown similar concentrations during sampling periods.

Quarterly chlorophyll concentrations during the period of record (August 1987 – November 2013) have varied considerably, resulting in moderate to wide historical ranges. During February periods of 1988 through 2013, chlorophyll concentrations ranged from 0.75 to 28.84 µg/L (Duke Energy 2013). For historical purposes, February concentrations up to 3.0 µg/L were considered in the low range, concentrations from greater than 3.0 to 6.0 µg/L were placed in the intermediate range, and concentrations greater than 6.0 µg/L were in the high range. During February 2013, chlorophyll concentrations at Locations 13.0 and 69.0 were in the low range for this time of year, while concentrations at Locations 2.0 and 15.9 were in the mid-range. Concentrations from Locations 5.0, 8.0, 9.5, and 11.0 were in the high range (Figure 3-3).

During May periods, chlorophyll concentrations have ranged from 0.97 to 27.77 µg/L (Duke Energy 2013). May chlorophyll concentrations up to 3.0 µg/L were placed in the low range, while concentrations from greater than 3.0 to 7.0 µg/L were considered in the intermediate range. Concentrations above 7.0 µg/L were characterized as high. During May, mean chlorophyll *a* concentrations at all but Locations 2.0 and 69.0 were in the mid historical

Phytoplankton densities and biovolumes demonstrated a spatial trend similar to that of chlorophyll; that is, during May and November increasing values from downlake locations to uplake locations with standing crops increasing through midlake, and then declining uplake during February and August (Table 3-2 and Figure 3-2).

### Seston

Seston dry weights represent a combination of algal matter and other organic and inorganic material. Dry weights during 2013 were most often higher than those recorded during 2012 (Duke Energy 2012 and Table 3-3). A general pattern of increasing values from downlake to uplake was observed for the most part during all periods (Figure 3-2). This spatial trend was only similar to that of chlorophyll concentrations and standing crops during May and November.

Seston ash-free dry weights represent organic material and may reflect spatial trends of chlorophyll and phytoplankton standing crop values. This relationship was somewhat noticeable to varying extents during all seasons. During February and May, ash-free dry weights increased from downlake to uplake, while in November there was little difference among locations. In August, weights increased through the midlake, and then showed a gradual decline through the uplake (Tables 3-1 through 3-3).

### Secchi Depths

Secchi depth is a visual 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 2.0 through 9.5 downlake. Depths ranged from 0.4 m at Location 69.0 in February and May and Location 15.9 in May, to 3.7 m at Location 9.5 in May (Table 3-1). The lakewide mean Secchi depth during 2013 was lower than that of 2012, but was within historical ranges of depths recorded since measurements were first reported in 1992 (Duke Energy 2013).

### 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 2013. Ten classes comprising 103 genera deeper light penetration, extended periods of low water due to drawdown, and shifts in nutrient inputs and concentrations (Duke Power 2000, 2001, and 2002). Whatever the cause, the phenomenon was lakewide and not localized near MNS or Marshall Steam Station; therefore, it was most likely due to a combination of natural environmental factors, and not station operations. Since 2002, taxonomic composition during the summer shifted back to green algae predominance (Duke Energy 2012). The consequent shift to diatoms during the summer of 2013 may have been due to short-term changes in environmental factors due to higher than normal levels of rainfall in the summer and subsequent reservoir flow-through rates (Chapter 2).

During most previous November periods, diatoms were the most dominant forms (Table 3-4; Figures 3-7 through 3-11). On occasion, cryptophytes have dominanted fall communities (Duke Energy 2013).

Blue-green algae, which are often implicated in nuisance blooms, were not abundant in 2013 samples. Their overall contribution to phytoplankton densities has seldom exceeded 4% of totals (Duke Energy 2013). Prior to 1991, blue-green algae were often dominant at uplake locations during the summer (Duke Power Company 1988, 1989, 1990, 1991, and 1992).

## SUMMARY

Lake Norman continues to be oligo-mesotrophic based on long-term, annual mean chlorophyll concentrations. Individual chlorophyll concentrations during 2013 were within historical ranges. Lakewide mean chlorophyll decreased from February to the annual minimum in May, and then increased to the annual maximum in August. The overall lakewide concentration declined in November. Considerable spatial variability was observed in 2013. In most past years, maximum chlorophyll concentrations were observed uplake at Locations 15.9 and 69.0, while minimum chlorophyll concentrations were most often recorded from downlake at Locations 2.0 and 5.0. During 2013, this pattern was observed in May and November; however, in February concentrations declined from uplake to downlake and in August, the maximum was observed at midlake and the minimum at the furthest uplake location. This type variability may have been related to high rainfall and discharge during 2013. The highest chlorophyll value recorded in 2013 (9.53 µg/L at Location 9.5 in August) was well below the NC State water quality standard of 40 µg/L.

Table 3-1. Mean chlorophyll *a* concentrations (µg/L) in composite samples and Secchi depths (m) observed in Lake Norman in 2013.

| Sample Month = | Feb | May | Aug | Nov |
|---|---|---|---|---|
| Location | Chlorophyll | | | |
| 2.0 | 5.93 | 3.84 | 6.36 | 3.55 |
| 5.0 | 6.13 | 2.14 | 6.81 | 2.22 |
| 8.0 | 6.07 | 3.74 | 8.84 | 3.74 |
| 9.5 | 7.64 | 3.23 | 9.53 | 4.73 |
| 11.0 | 6.17 | 5.01 | 6.05 | 6.88 |
| 13.0 | 2.86 | 5.05 | 7.12 | 6.23 |
| 15.9 | 3.59 | 5.63 | 4.83 | 6.25 |
| 69.0 | 1.20 | 1.68 | 1.86 | 7.77 |

| Sample Month = | Feb | May | Aug | Nov |
|---|---|---|---|---|
| Location | Secchi Depth | | | |
| 2.0 | 2.7 | 3.4 | 1.8 | 2.3 |
| 5.0 | 2.6 | 3.2 | 1.7 | 2.0 |
| 8.0 | 2.7 | 2.7 | 1.9 | 2.3 |
| 9.5 | 2.8 | 3.7 | 1.7 | 2.6 |
| 11.0 | 1.9 | 2.7 | 1.6 | 2.3 |
| 13.0 | 1.3 | 0.7 | 0.8 | 1.4 |
| 15.9 | 1.3 | 0.4 | 1.4 | 2.1 |
| 69.0 | 0.4 | 0.4 | 1.2 | 1.5 |
| Annual mean from all Locations = | | | | 1.92 |

Table 3-4. Dominant classes, their most abundant species, and their percent composition (in parentheses) at Lake Norman locations during each sampling period of 2013.

| Location | Feb | May |
|---|---|---|
| 2.0 | Bacillariophyceae (61.4)<br>*Tabellaria fenestrata* (48.2) | Bacillariophyceae (77.2)<br>*Fragilaria crotonensis* (33.2) |
| 5.0 | Bacillariophyceae (74.5)<br>*T. fenestrata* (65.9) | Bacillariophyceae (74.8)<br>*F. crotonensis* (29.0) |
| 9.5 | Bacillariophyceae (81.0)<br>*T. fenestrata* (69.5) | Bacillariophyceae (73.7)<br>*F. crotonensis* (39.5) |
| 11.0 | Bacillariophyceae (63.2)<br>*T. fenestrata* (44.3) | Bacillariophyceae (82.7)<br>*F. crotonensis* (59.2) |
| 15.9 | Bacillariophyceae (63.0)<br>*Melosira ambigua* (27.7) | Bacillariophyceae (69.1)<br>*F. crotonensis* (32.7) |
|  | Aug | Nov |
| 2.0 | Bacillariophyceae (60.3)<br>*Anomoeoneis vitrea* (29.5) | Bacillariophyceae (68.8)<br>*Tabellaria fenestrata* (47.1) |
| 5.0 | Bacillariophyceae (57.6)<br>*A. vitrea* (31.0) | Bacillariophyceae (72.4)<br>*T. fenestrata* (33.4) |
| 9.5 | Bacillariophyceae (59.0)<br>*A. vitrea* (33.8) | Bacillariophyceae (66.1)<br>*T. fenestrata* (25.4) |
| 11.0 | Bacillariophyceae (60.5)<br>*A. vitrea* (29.9) | Bacillariophyceae (70.9)<br>*Melosira ambigua* (33.9) |
| 15.9 | Bacillariophyceae (53.1)<br>*A. vitrea* (32.6) | Bacillariophyceae (59.5)<br>*T. fenetrata* (24.6) |

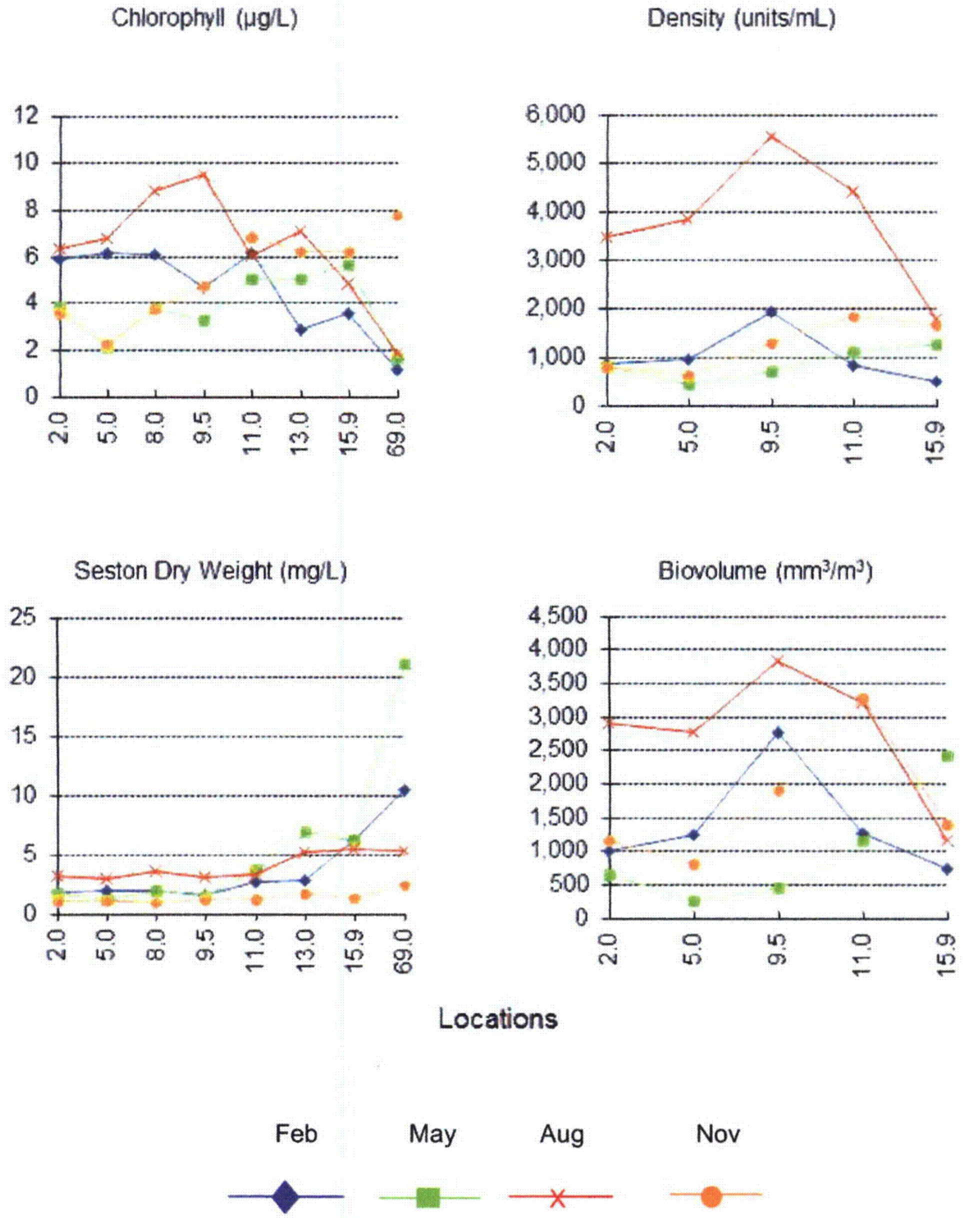


Figure 3-2. Phytoplankton chlorophyll *a*, densities, biovolumes, and seston dry weights at locations in Lake Norman in February, May, August, and November 2013.

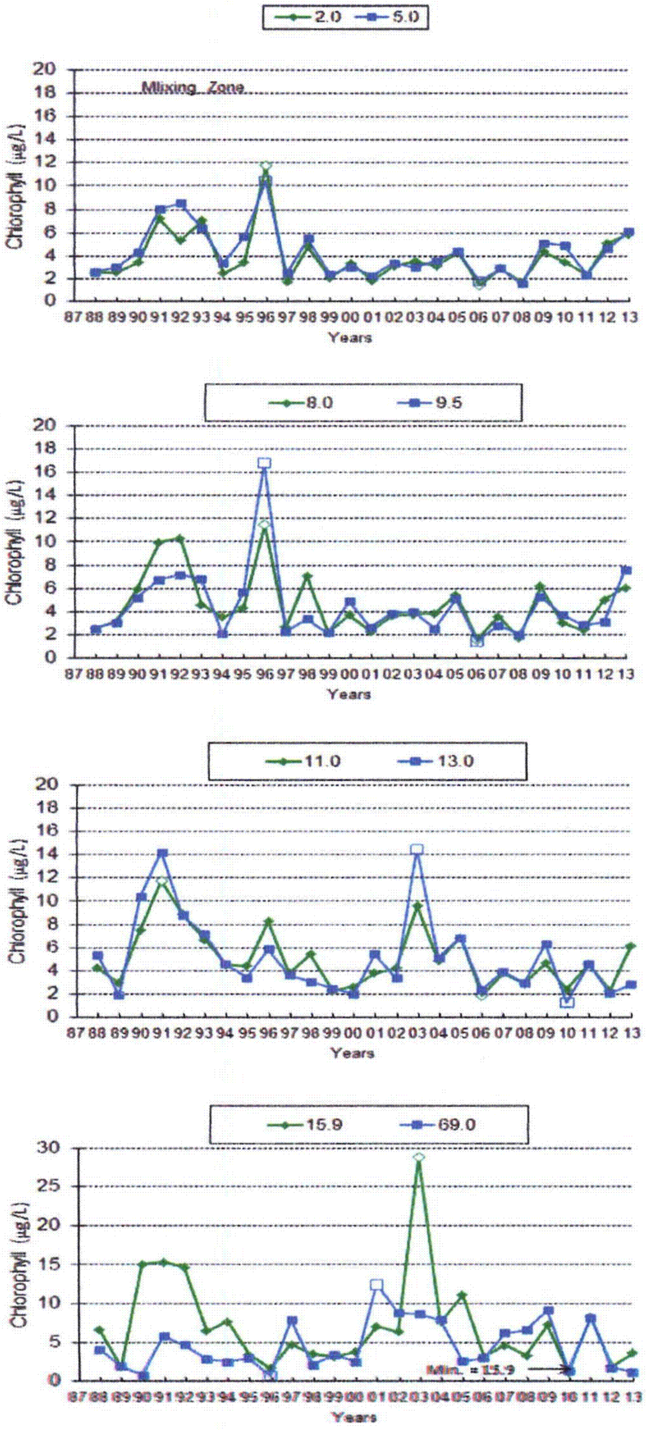


Figure 3-4. Phytoplankton mean chlorophyll concentrations by location for samples collected in Lake Norman from May 1988 through 2013 (Note: clear data points represent long-term maxima).

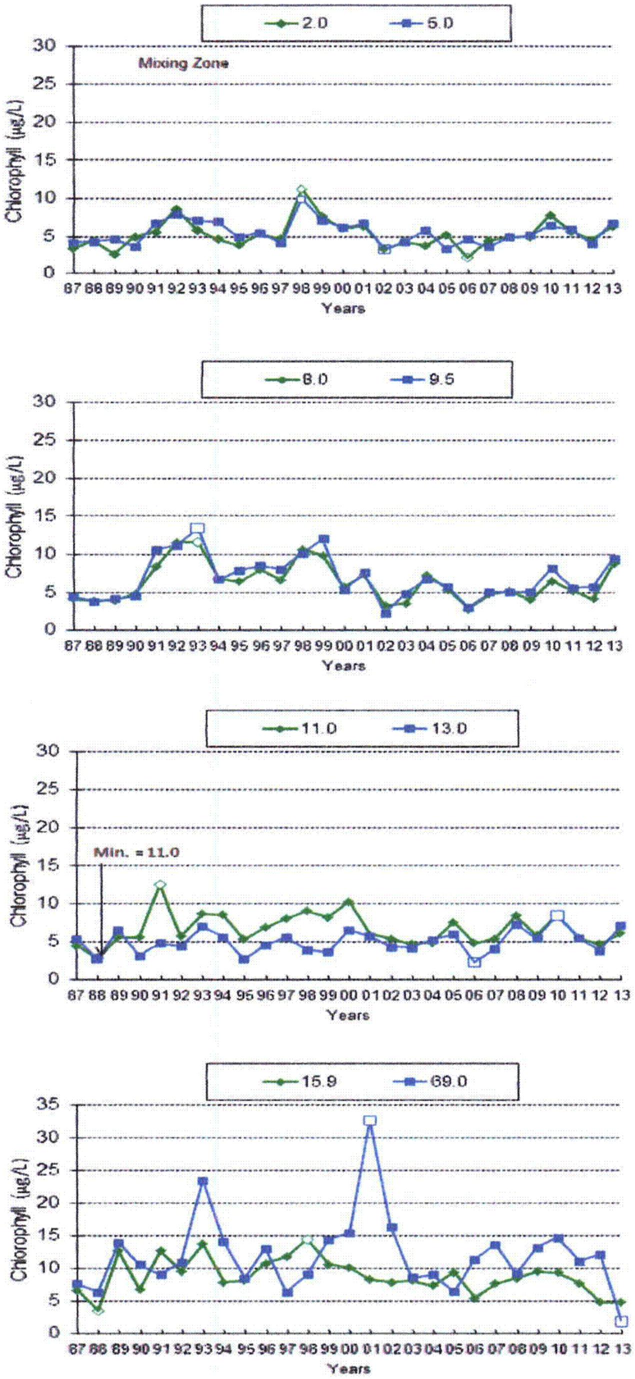


Figure 3-6. Phytoplankton mean chlorophyll concentrations by location for samples collected in Lake Norman during November 1987 through 2013 (Note that clear data points represent long-term maxima).

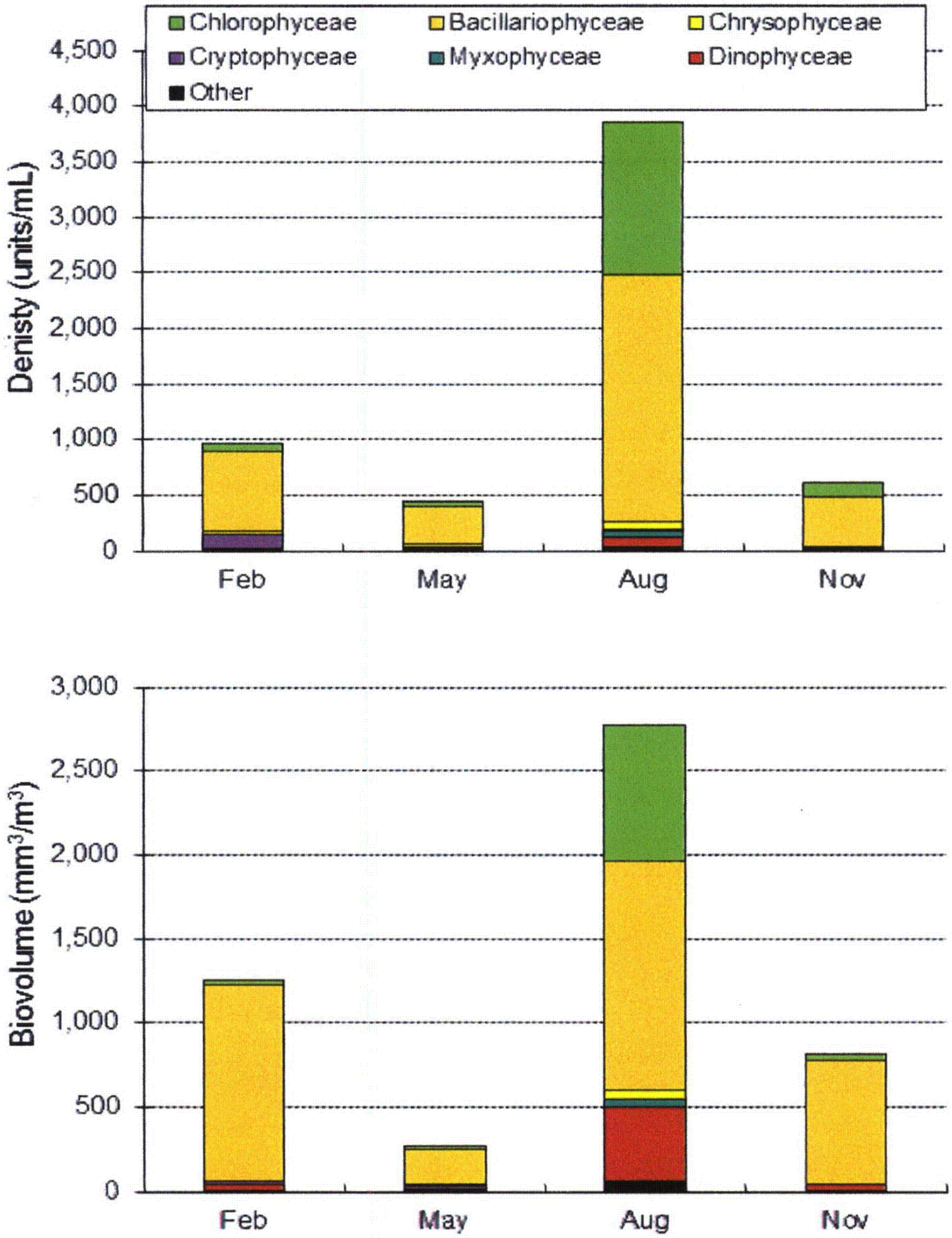


Figure 3-8. Class composition of phytoplankton standing crop parameters (mean density and biovolume) from euphotic zone samples collected at Location 5.0 in Lake Norman during 2013.

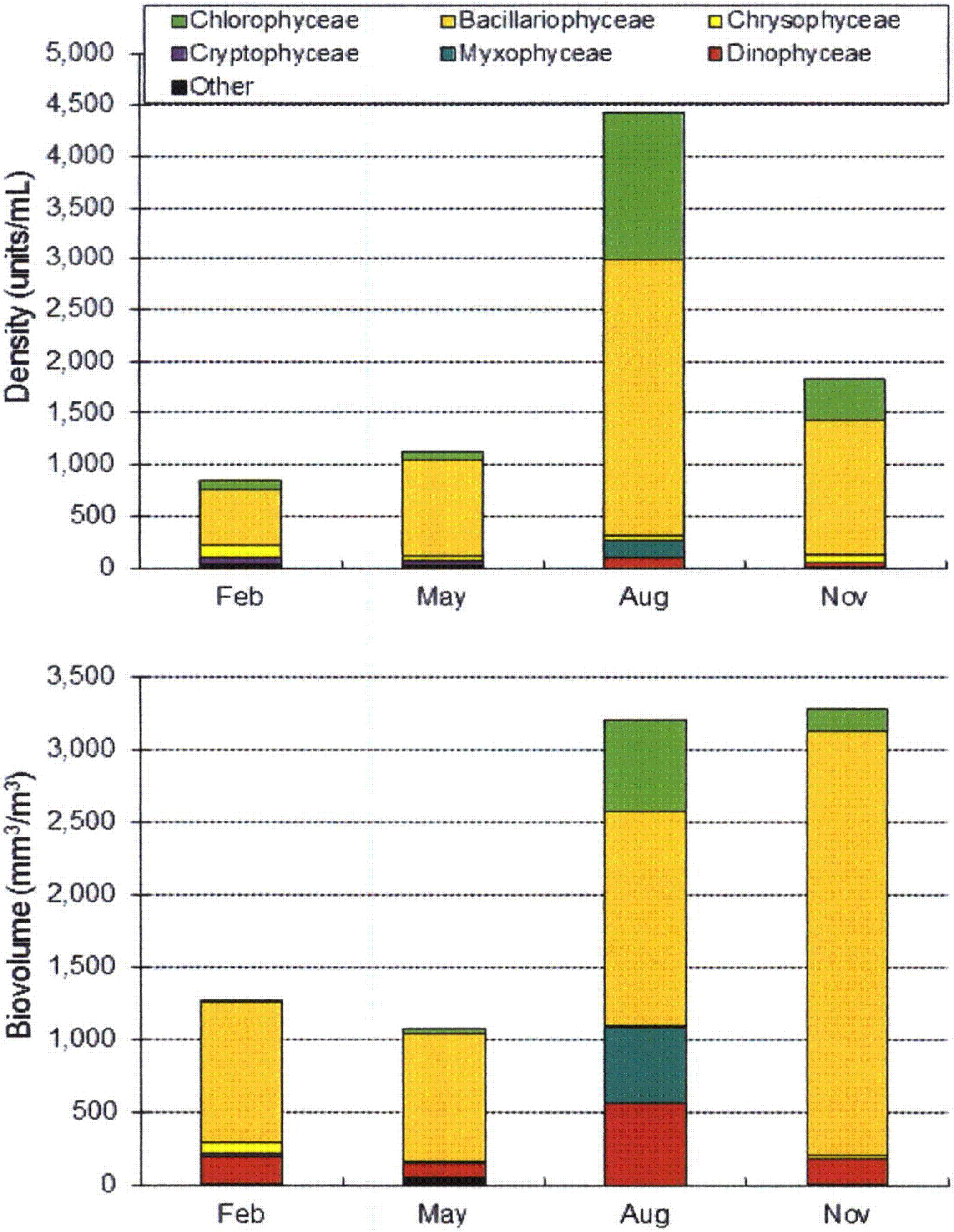


Figure 3-10. Class composition of phytoplankton standing crop parameters (mean density and biovolume) from euphotic zone samples collected at Location 11.0 in Lake Norman during 2013.

# CHAPTER 4

# ZOOPLANKTON

## INTRODUCTION

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

1. describe and characterize quarterly/seasonal patterns of zooplankton standing crops at selected locations on Lake Norman; and
2. compare and evaluate, where possible, zooplankton data collected during 2013 with historical data collected during the period 1987 – 2012.

Studies conducted between 1973 and 1985 using primarily monthly zooplankton data from Lake Norman, showed that zooplankton populations demonstrated a bimodal seasonal distribution with highest values generally occurring in the spring and a less pronounced fall peak (Duke Power Company 1976, 1982, and 1985). Considerable spatial and year-to-year variability has been observed in zooplankton abundance in Lake Norman (Duke Power Company 1976 and 1985; Hamme 1982; Menhinick and Jensen 1974). Since quarterly sampling began in August 1987, distinct bimodal seasonal distributions have been less apparent due to the 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) during each season: winter (January through March), spring (April through June), summer (July through September), and fall (October through December) 2013. 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).

and temporal trends, most of the following discussion will focus primarily on zooplankton communities in this area of the water column.

Epilimnetic zooplankton densities during all seasons of 2013 were mostly within historical ranges, however, considerably lower than normal densities were recorded in February (Figures 4-4 through 4-7). The record low values in 2013 were from Locations 2.0, 5.0, 9.5, and 11.0 in February. Record lows were also observed at Location 15.9 in August and Locations 2.0 and 5.0 in November. The highest winter densities recorded from Locations 2.0 and 11.0 occurred in 1996, while the winter maximum at Location 9.5 was recorded in 1995 (Figure 4-4). The winter maximum from Location 5.0 occurred in 2004, while the long-term winter maximum from Location 15.9 occurred in 2011. Long-term maximum densities for spring occurred at Locations 2.0 and 5.0 in 2005, while the highest spring values from Locations 11.0 and 15.9 occurred in 2002. The highest spring peak at Location 9.5 was observed in 2005 (Figure 4-5). Long-term summer maxima occurred in 1988 at Locations 2.0, 5.0, and 11.0, while summer maxima at Locations 9.5 and 15.9 occurred in 2007 and 2003, respectively (Figure 4-6). The long-term maxima for the fall occurred at Locations 2.0 and 5.0 in 2009 and Locations 9.5 and 11.0 in 2006, while the fall maximum at Location 15.9 occurred in 1999 (Figure 4-7).

Year-to-year fluctuations of epilimnetic densities among background locations, particularly Locations 11.0 and 15.9 have generally been far more apparent than in the mixing zone (Figures 4-4 through 4-7). These uplake locations are far more susceptible to hydrological fluctuations associated with the more riverine zone of the reservoir that can have direct influences on phytoplankton communities (Chapter 3). These impacted phytoplankton communities subsequently provide a food source for zooplankton, particularly microcrustaceans. Conditions at Locations 2.0 and 5.0 in the mixing zone are less variable due to the dampening influences of the Cowans Ford Dam. In 2013, an additional issue was very high rainfall, particularly during the spring and summer months (Chapter 2). High rainfall and subsequent hydroelectric releases may have been a cause of lower than average zooplankton densities, particularly uplake in the riverine zone.

## Community Composition

Since the Lake Norman Maintenance Monitoring Program began in August 1987, 143 zooplankton taxa have been recorded (Table 4-2). During 2013, 66 taxa were identified, as compared to 56 recorded in 2012 (Duke Energy 2013). Six taxa, previously unrecorded important during the spring. In most past years *Bosmina* was also the dominant zooplankter during most seasons, however, *Bosminopsis* was most often dominant during the summer (Duke Energy 2013).

Long-term seasonal trends of cladoceran densities were variable and described in detail in previous maintenance monitoring reports (Duke Energy 2013). During 2013, cladocerans were equally distributed at both the mixing zone and background locations. Maximum densities at mixing zone and at background locations occurred in the winter and spring, respectively (Figure 4-11).

### *Rotifera*

*Polyarthra* was the most abundant rotifer, dominating most samples in spring, summer, and fall. During the winter, *Asplanchna*, *Keratella*, and *Syncheata* were variously dominant in both epilimnetic and whole-column samples (Table 4-3). All of these taxa were important constituents of rotifer populations, as well as zooplankton communities, in previous studies of Lake Norman (Duke Energy 2013 and 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 occasional peaks in the summer and fall (Figure 4-12). During 2013, peak rotifer densities at mixing zone locations occurred during the fall, while densities at background locations peaked in the spring.

## SUMMARY

During 2013, seasonal mean densities were below the long-term mean and the mean density in the winter was the lowest winter mean yet recorded. The lower than normal zooplankton densities cannot be readily explained and may have been due to unseasonable conditions during winter, spring, and summer. Historically, maxima most often occurred in winter and spring, while minima most often occurred in the fall. As in past years, epilimnetic densities were higher than whole-column densities. Mean zooplankton densities were often higher among background locations than among mixing zone locations during 2013, but to a lesser degree than in previous years. Spatial trends of zooplankton populations were generally similar to those of phytoplankton, with increasing densities from downlake to uplake during

Table 4-1. Total zooplankton densities (No. X 1000/$m^3$), densities of major zooplankton taxonomic groups, and percent composition (in parentheses) of major taxa in the epilimnion and whole-column net tow samples collected from Lake Norman in winter (February), spring (May), summer (August), and fall (November) 2013.

| | | | Locations | | | | |
|---|---|---|---|---|---|---|---|
| **Season and Sample Date** | **Sample Type** | **Taxa** | **2.0** | **5.0** | **9.5** | **11.0** | **15.9** |
| | Epilimnion | Copepoda | 3.87 | 3.80 | 5.73 | 10.13 | 11.34 |
| Winter | | | (30.0) | (29.3) | (40.1) | (21.7) | (43.5) |
| 2/5/13 | | Cladocera | 3.81 | 5.36 | 5.74 | 8.40 | 4.94 |
| | | | (29.6) | (41.4) | (40.2) | (18.0) | (19.0) |
| | | Rotifera | 5.13 | 3.80 | 2.79 | 28.10 | 9.77 |
| | | | (39.8) | (29.3) | (19.5) | (60.3) | (37.5) |
| | | Others[b] | 0.07 | 0 | 0.02 | 0 | 0 |
| | | | (0.5) | (0) | (0.2) | (0) | (0) |
| | | Total | 12.87 | 12.96 | 14.28 | 46.63 | 26.05 |
| | | | | | | | |
| | Whole-column | | **2.0** | **5.0** | **9.5** | **11.0** | **15.9** |
| | | Depth | 30 m | 19 m | 17 m | 25 m | 21 m |
| | | Copepoda | 4.43 | 3.68 | 4.59 | 13.11 | 13.12 |
| | | | (30.5) | (32.1) | (39.0) | (35.0) | (51.7) |
| | | Cladocera | 4.05 | 5.58 | 4.34 | 8.81 | 3.53 |
| | | | (27.9) | (48.8) | (36.9) | (23.5) | (13.9) |
| | | Rotifera | 6.02 | 2.19 | 2.84 | 15.54 | 8.70 |
| | | | (41.4) | (19.1) | (24.1) | (41.4) | (34.3) |
| | | Others | 0.08 | 0 | 0 | 0.03 | 0.02 |
| | | | (0.2) | (0) | (0) | (0.1) | (0.1) |
| | | Total | 14.55 | 11.45 | 11.77 | 37.49 | 25.37 |

| | | | Locations | | | | |
|---|---|---|---|---|---|---|---|
| **Season and Sample Date** | **Sample Type** | **Taxa** | **2.0** | **5.0** | **9.5** | **11.0** | **15.9** |
| | Epilimnion | Copepoda | 35.43 | 37.80 | 55.69 | 58.34 | 21.96 |
| Spring | | | (63.3) | (56.9) | (46.5) | (47.9) | (14.0) |
| 5/10/13 | | Cladocera | 2.64 | 1.94 | 15.12 | 9.56 | 27.25 |
| | | | (4.7) | (2.9) | (12.6) | (7.8) | (17.5) |
| | | Rotifera | 17.91 | 26.72 | 48.93 | 53.99 | 106.49 |
| | | | (32.0) | (40.2) | (40.9) | (44.3) | (68.2) |
| | | Others | 0.02 | 0 | 0 | 0 | 0.40 |
| | | | (<0.1) | (0) | (0) | (0) | (0.3) |
| | | Total | 56.00 | 66.46 | 119.74 | 121.89 | 156.10 |
| | | | | | | | |
| | Whole-column | | **2.0** | **5.0** | **9.5** | **11.0** | **15.9** |
| | | Depth | 30 m | 18 m | 17 m | 25 m | 20 m |
| | | Copepoda | 11.83 | 33.86 | 26.72 | 26.76 | 24.70 |
| | | | (68.0) | (54.1) | (47.2) | (57.0) | (25.8) |
| | | Cladocera | 1.67 | 2.07 | 10.81 | 6.54 | 15.42 |
| | | | (9.6) | (3.3) | (19.2) | (13.9) | (16.1) |
| | | Rotifera | 38.8 | 26.63 | 19.02 | 13.59 | 55.18 |
| | | | (22.3) | (42.6) | (33.6) | (28.9) | (57.7) |
| | | Others | 0.02 | 0 | 0 | 0.11 | 0.37 |
| | | | (0.1) | (0) | (0) | (0.2) | (0.4) |
| | | Total | 17.40 | 62.56 | 56.55 | 47.00 | 95.67 |

---

[b] Others = *Chaoborus* spp., Chironomidae, Trichoptera, Ostricoda, and Annelida

Table 4-2. Zooplankton taxa identified from samples collected quarterly on Lake Norman from 1987 to 2013.

| Taxon | 87-98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CRUSTACEA | | | | | | | | | | | | | | | | |
| Copepoda | | | | | | | | | | | | | | | | |
| Cyclopidae | | | | | | | | | | | | | | | | |
| *Cyclops Thomas* Forbes[c] | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *C. vernalis* Fischer | X | | | | | | | | | | | | | | | X |
| *C.* spp. O. F. Muller | X | | | X | X | X | | | | | | X | X | | | |
| *Eucyclops agilis* (Koch) | X | | | | | | | | | | | | | | | |
| *E. prionophorus* Kiefer | | | | | | | | | | X | | | | | | |
| *Mesocyclops edax* (S. A. Forbes) | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *M.* spp. Sars | X | | | X | X | X | | | | | X | | | | X | |
| *Paracyclops fimbriarus* v. *poppei* | | | | | | X | | | | | | | | | | |
| *Tropocyclops prasinus* (Fischer) | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *T.* spp. (Fischer) | X | | | X | X | | X | | X | X | X | X | X | | | |
| Diaptomidae | | | | | | | | | | | | | | | | |
| *Diaptomus birgei* Marsh | | | X | | | | | | | | | | | | X | |
| *D. mississippiensis* Marsh | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *D. pallidus* Herick | X | X | | | | X | | X | | | | | | | | X |
| *D. reighardi* Marsh[d] | | X | | | | | | | | | | | | | | X |
| *D.* spp. Marsh | X | X | X | | X | X | | | | | X | X | | X | | |
| Temoridae | | | | | | | | | | | | | | | | |
| *Epishura fluviatilis* Herrick | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| Ergasilidae | | | | | | | | | | | | | | | | |
| *Ergasilus* spp. Smith | X | | | | | | | | X | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Cladocera | | | | | | | | | | | | | | | | |
| Bosminidae | | | | | | | | | | | | | | | | |
| Unidentified Bosminidae | | | | | | | | | | | | | | | | X |
| *Bosmina longirostris* (O. F. M.) | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |
| *B.* spp. Baird | X | | X | X | X | | | | | | | | | | | X |
| *Bosminopsis dietersi* Richard | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| *Eubosmina longispina* Lydig | | | | | | | | | | | | | | | | X |
| *E. tubicen* Brehm | | | | | | | | | | | | | | | | X |
| *E.* spp. (Baird) | X | | | | | | | | | | | | | | | X |
| Chydoridae | | | | | | | | | | | | | | | | |
| Unidentifued Chydoridae | | | | | | | | | | | | | | | | X |
| *Alona* spp.Baird | X | | | | | | | | | X | | X | | | X | X |
| *Alonella* spp. (Birge) | | X | | | | | | | | | | | | X | | |
| *Chydorus* spp. Leach | X | X | | X | X | | X | X | | | X | | | | | |
| *Disparalona acutirostris* (Birge) | | | | | | | X | | | | | | | | | |
| *Leydigia acanthoceroides* (Fis.) | | | | | | | X | | | | | | | | | |
| *L.* spp. Freyberg | X | | | | | X | X | | | X | X | | | X | X | |

---

[c] Initial name by Forbes (1882), known as *Diacyclops thomasi.* May be confused with *Acanthocyclops thomasi*
[d] Synomymous with *Skistodiaptomus reighardii*

Table 4-2. (Continued). Page 3 of 5

| Taxon | 87-98 | 99 | 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rotifera | | | | | | | | | | | | | | | | |
| Asplanchnidae | | | | | | | | | | | | | | | | |
| *Asplanchna brightwelli* Gosse | X | | X | | | | | | | | | | | | | X |
| *A. priodonta* Gosse | X | X | X | | | | X | | | | | X | | | | X |
| *A.* spp. Gosse | X | X | X | X | X | X | X | X | X | | X | X | X | X | X | X |
| Brachionidae | | | | | | | | | | | | | | | | |
| *Anuraeopsis fissa* (Gosse) | | | | | | | X | | | X | | | | | | |
| *A.* spp. Lauterborne | X | X | | | | | X | | X | X | | | | | | |
| *Kellicottia bostoniensis* (Rou.) | X | X | X | 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 | X | X | X | X | X | X | X |
| *K.* spp. Rousselet | X | | | X | X | X | X | X | | | | X | | | X | |
| *Keratella americana* Carlin | | | | | | | | | | X | | | | | | |
| *K. cochlearis* Raderorgan | | X | X | | | | X | | | X | X | X | X | X | X | X |
| *K. quadrata* Mannchen | | | | | | | | | | | | | X | X | X | |
| *K. taurocephala* Myers | X | X | | | | | X | X | | X | X | | | X | X | X |
| *K.* spp. Bory de St. Vincent | X | X | X | X | X | | X | X | X | X | X | X | X | X | X | X |
| *Notholca spp. Gosse* | X | | | | | | | | | | | | | | | X |
| *Platyias patulus* Harring | | | | | X | | | | | | | | | | | |
| *P.* spp. | | | | | | | | | | | | | | | | X |
| Collothecidae | | | | | | | | | | | | | | | | |
| *Collotheca balatonica* Harring | X | X | X | | X | X | X | X | X | X | X | X | X | X | X | |
| *C. mutabilis* (Hudson) | X | X | X | | | X | X | X | X | X | X | X | X | X | X | |
| *C.* spp. Harring | X | | X | X | X | X | | | | | X | X | X | X | X | X |
| Conochilidae | | | | | | | | | | | | | | | | |
| *Conochilus unicornis* (Rouss.) | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| *C.* spp. Hlava | X | | | X | X | | | | | | | X | | | X | X |
| *Conochiloides dossuarius* Hud. | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | |
| *C.* spp. Hlava | X | | | X | | X | | | | | | | | | X | X |
| Filinidae | | | | | | | | | | | | | | | | |
| *Filinia* spp. Bory de St. Vincent | X | | | | | | X | | | | | | X | | | |
| Froscularidae | | | | | | | | | | | | | | | | |
| *Ptygura libra* Meyers | X | | X | | X | X | X | X | X | X | X | X | X | X | X | |
| *P.* spp. Ehrenberg | X | | | | X | X | | | | | | X | | | | |
| Gastropodidae | | | | | | | | | | | | | | | | |
| *Ascomorpha ecaudis* Perty | | | | | | | | | | | | | | | X | |
| *A.* spp. Perty | | | | | | | | | | | | | | | X | |
| *Brachionus angularis* Gosse | | | | | | | | | | | | | X | | X | |
| *B. calyciflorus* Pallas | | | | | | | | X | | | | | | | | |
| *B. 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 |
| *Gastropus stylifer* Imhof | X | X | X | X | | | X | | X | X | | | X | X | | |
| *G.* spp. Imhof | X | | | X | | | | | | | | | | | | |
| Hexarthradae | | | | | | | | | | | | | | | | |
| *Hexarthra mira* Hudson | X | X | X | X | | X | | | | X | X | X | X | X | | |

Table 4-2. (Continued). Page 5 of 5

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Insecta** | | | | | | | | | | | | | | | | |
| *Chaoborus* spp. Lichtenstein | X | X | | X | X | | X | X | X | X | X | X | X | X | X | X |
| Chironomidae (unidentified) | | | | | | | | | | | | | | | | X |
| Trichoptera (unidentified) | | | | | | | | | | | | | | | | X |
| | | | | | | | | | | | | | | | | |
| **Annelida (unidentified)** | | | | | | | | | | | | | | | | X |

Table 4-3. (Continued).

| **Locations** | Winter | Spring | Summer | Fall |
|---|---|---|---|---|
| | | **Rotifera:** | **Epilimnion** | |
| 2.0 | *Asplanchna* (50.0) | *Keratella* (42.8) | *Polyarthra* (55.5) | *Polyarthra* (50.2) |
| 5.0 | *Keratella* (47.7) | *Polyarthra* (92.5) | *Polyarthra* (42.3) | *Polyarthra* (66.8) |
| 9.5 | *Asplanchna* (38.8) | *Polyarthra* (86.5) | *Asplanchna* (70.1) | *Polyarthra* (37.6) |
| 11.0 | *Synchaeta* (69.1) | *Polyarthra* (49.0) | *Polyarthra* (41.3) | *Polyarthra* (51.3) |
| 15.9 | *Polyarthra* (37.7) | *Kellicotia* (39.3) | *Keratella* (70.8) | *Polyarthra* (46.2) |
| | | **Rotifera:** | **Whole-column** | |
| 2.0 | *Keratella* (38.9) | *Polyarthra* (52.6) | *Polyarthra* (46.2) | *Kellicotia* (80.2) |
| 5.0 | *Keratella* (60.5) | *Polyarthra* (93.7) | *Polyarthra* (47.7) | *Polyarthra* (67.7) |
| 9.5 | *Asplanchna* (41.8) | *Polyarthra* (84.8) | *Asplanchna* (46.3) | *Polyarthra* (45.8) |
| 11.0 | *Synchaeta* (46.5) | *Polyarthra* (41.2) | *Polyarthra* (42.8) | *Polyarthra* (51.5) |
| 15.9 | *Polyarthra* (37.9) | *Kellicotia* (38.4) | *Keratella* (56.8) | *Polyarthra* (43.5) |

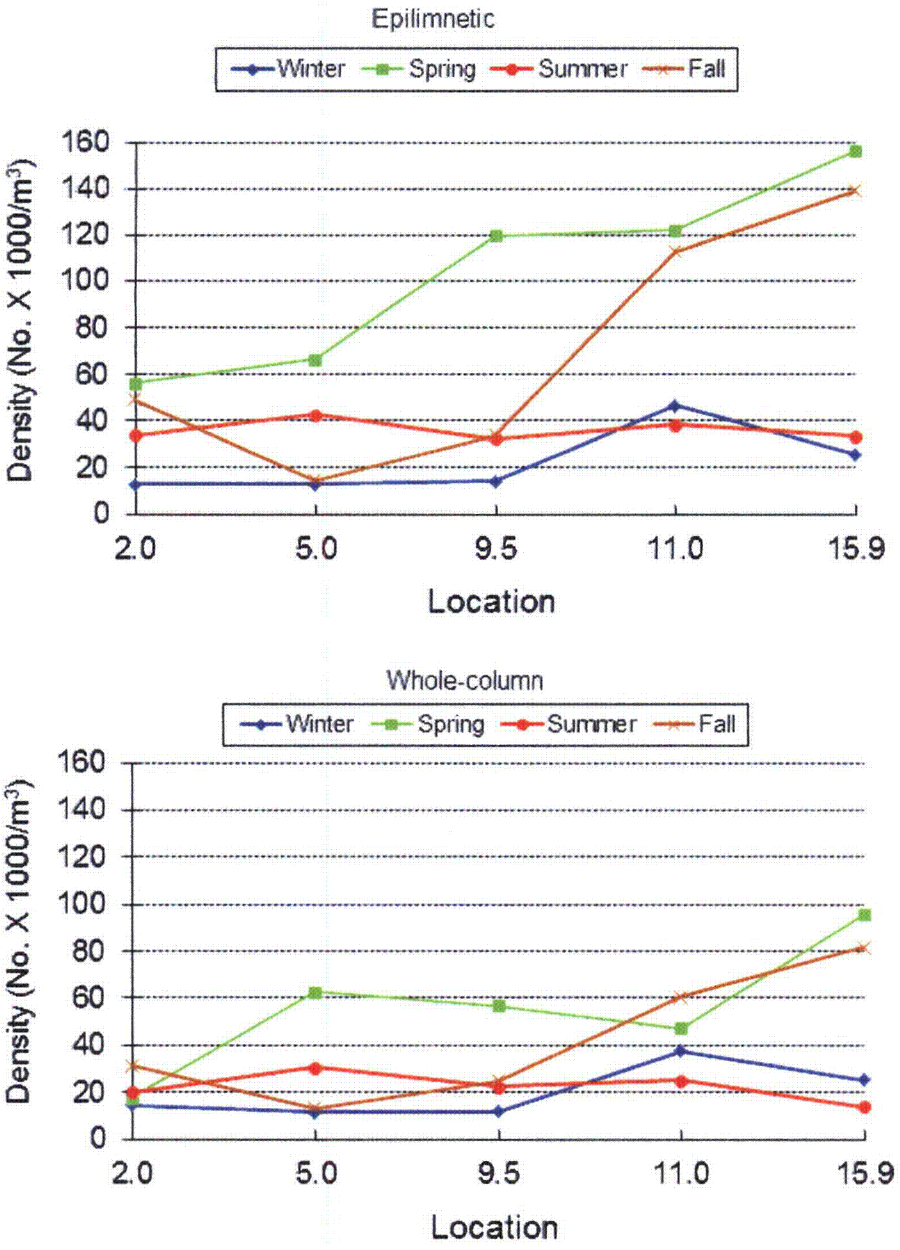
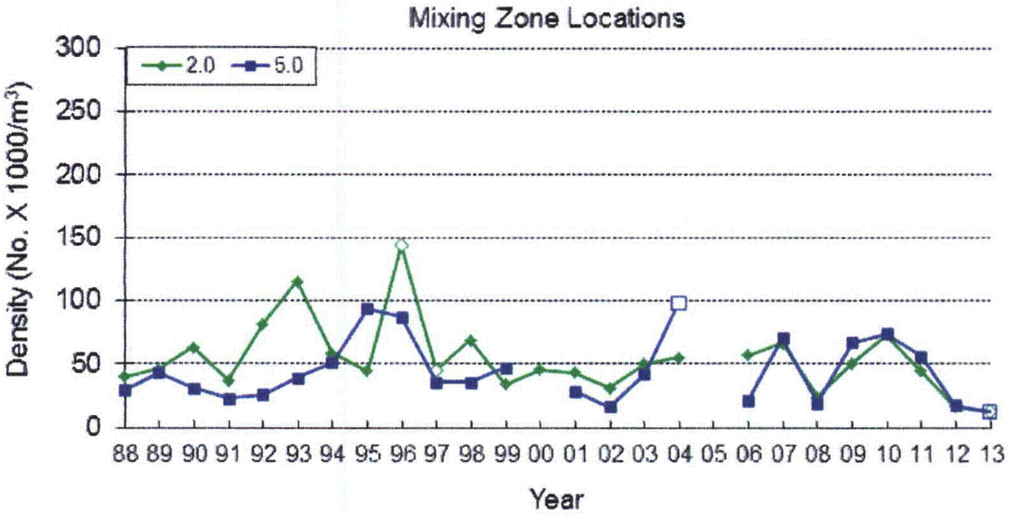


Figure 4-2. Total zooplankton density by location for samples collected in Lake Norman in 2013.

Winter


Mixing Zone Locations

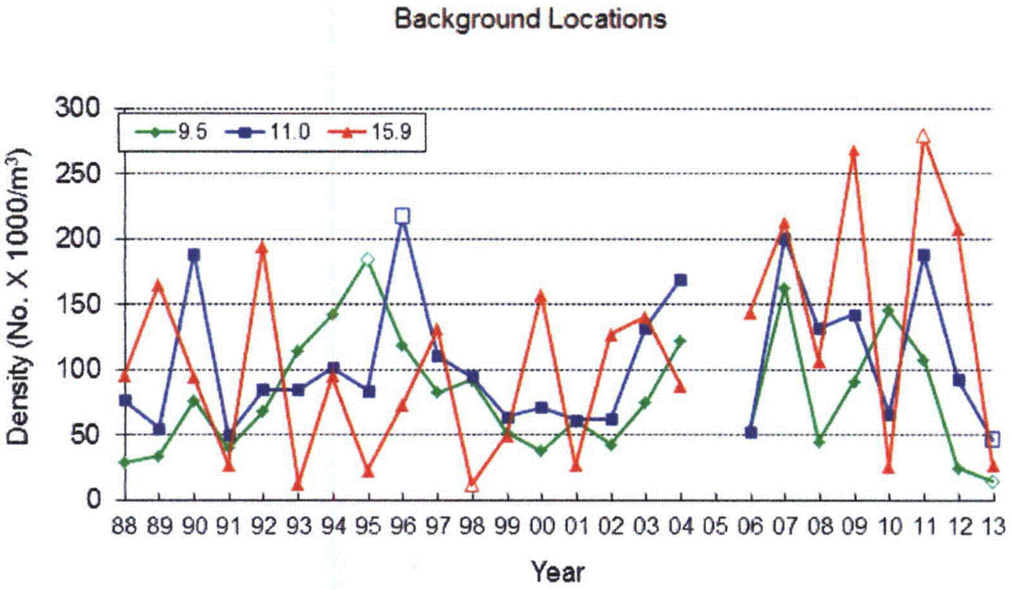
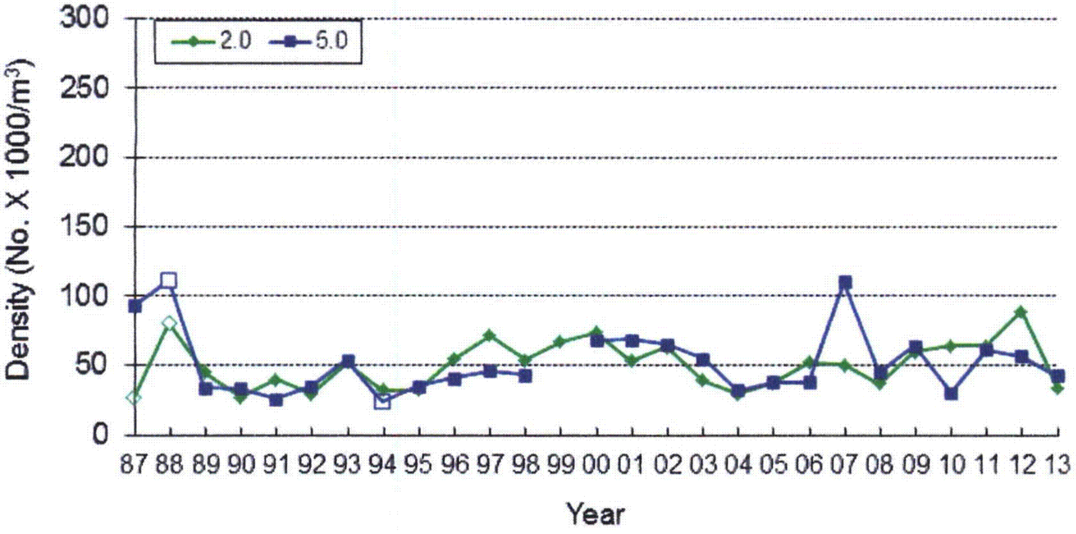

Background Locations

Figure 4-4. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the winter periods of 1988 – 2013 (clear data points represent long-term maxima and minima).


Summer

Mixing Zone Locations

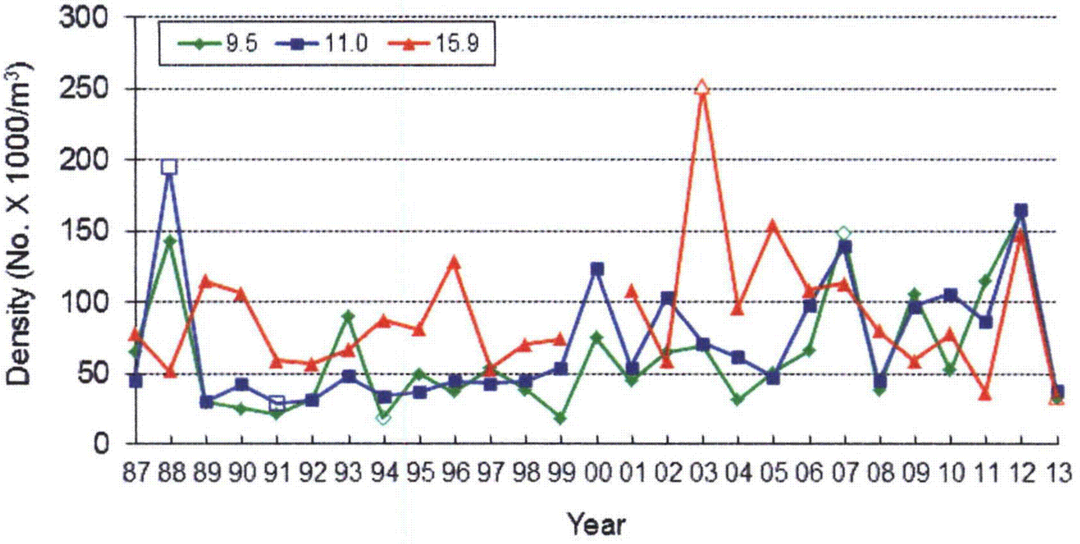

Background Locations

Figure 4-6. Total zooplankton densities by location and year for epilimnetic samples collected in Lake Norman in the summer periods of 1987 – 2013 (clear data points represent long-term maxima and minima).

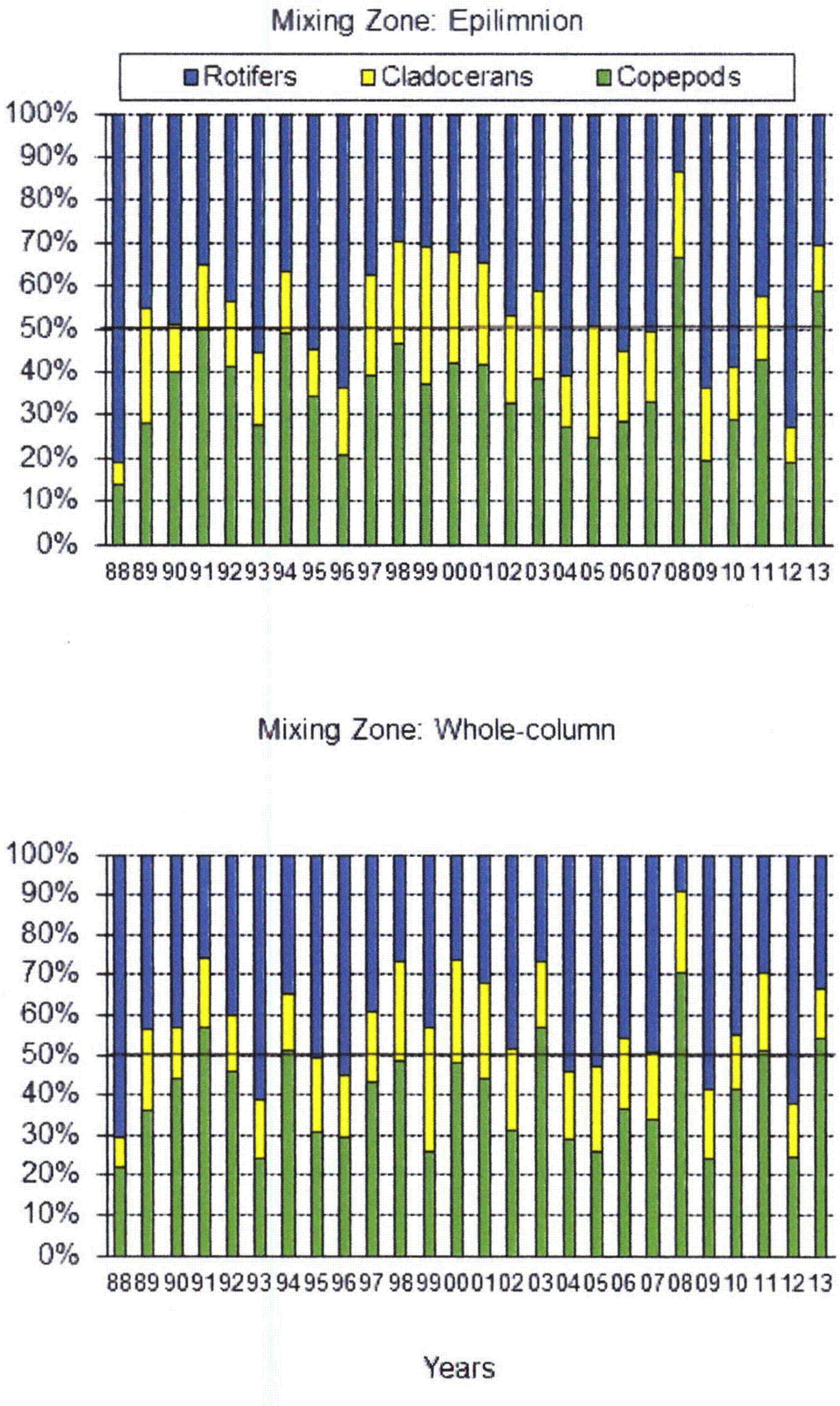


Figure 4-8. Annual percent composition of major zooplankton taxonomic groups from mixing zone locations (Locations 2.0 and 5.0 combined) during 1988 – 2013. (Note: does not include Location 5.0 in the fall of 2002 or winter samples from 2005).

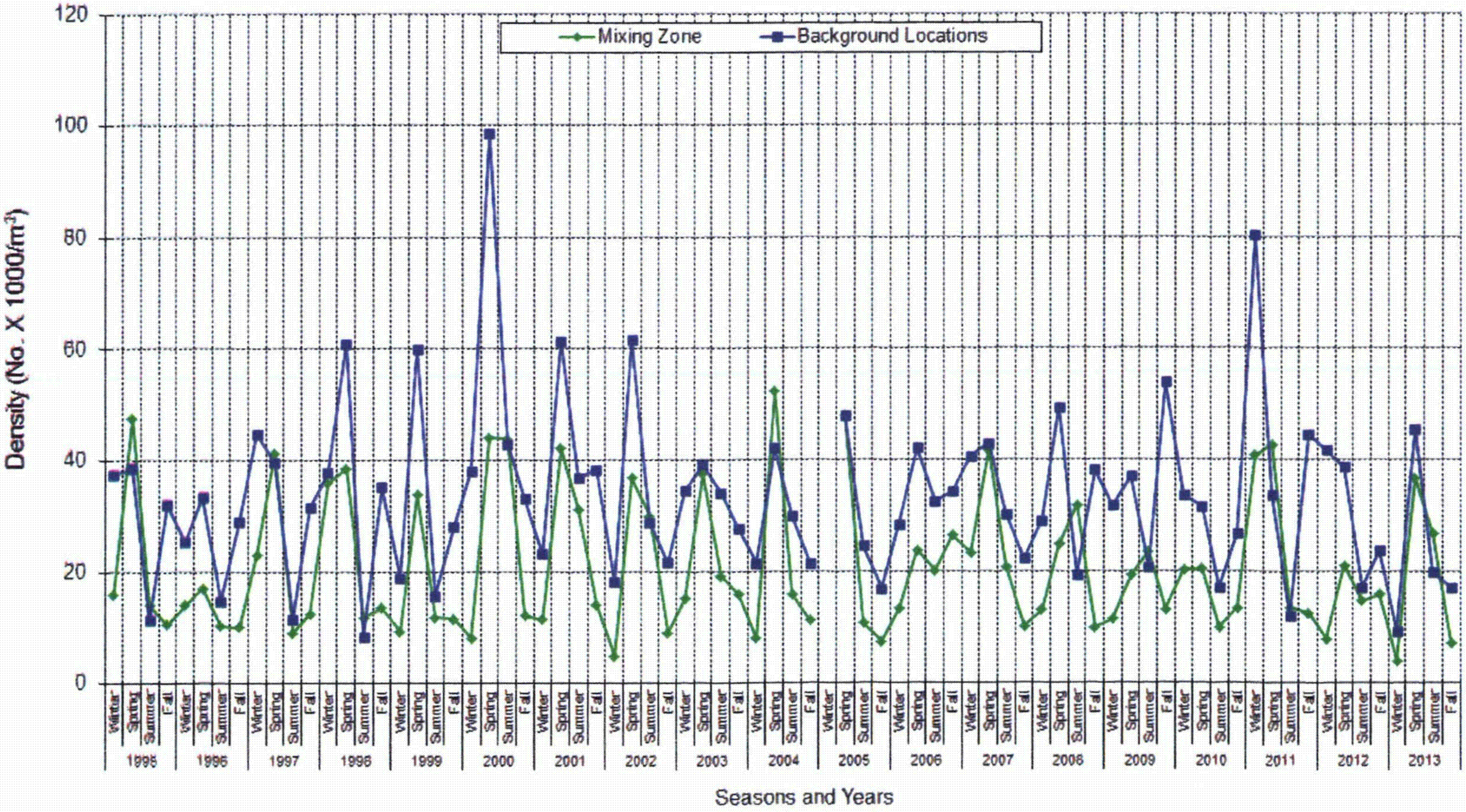


Figure 4-10. Copepod densities during each season of each year among epilimnetic samples collected in Lake Norman from 1995 through 2013 (mixing zone = mean of Locations 2.0 and 5.0; background = mean of Locations 9.5, 11.0, and 15.9).

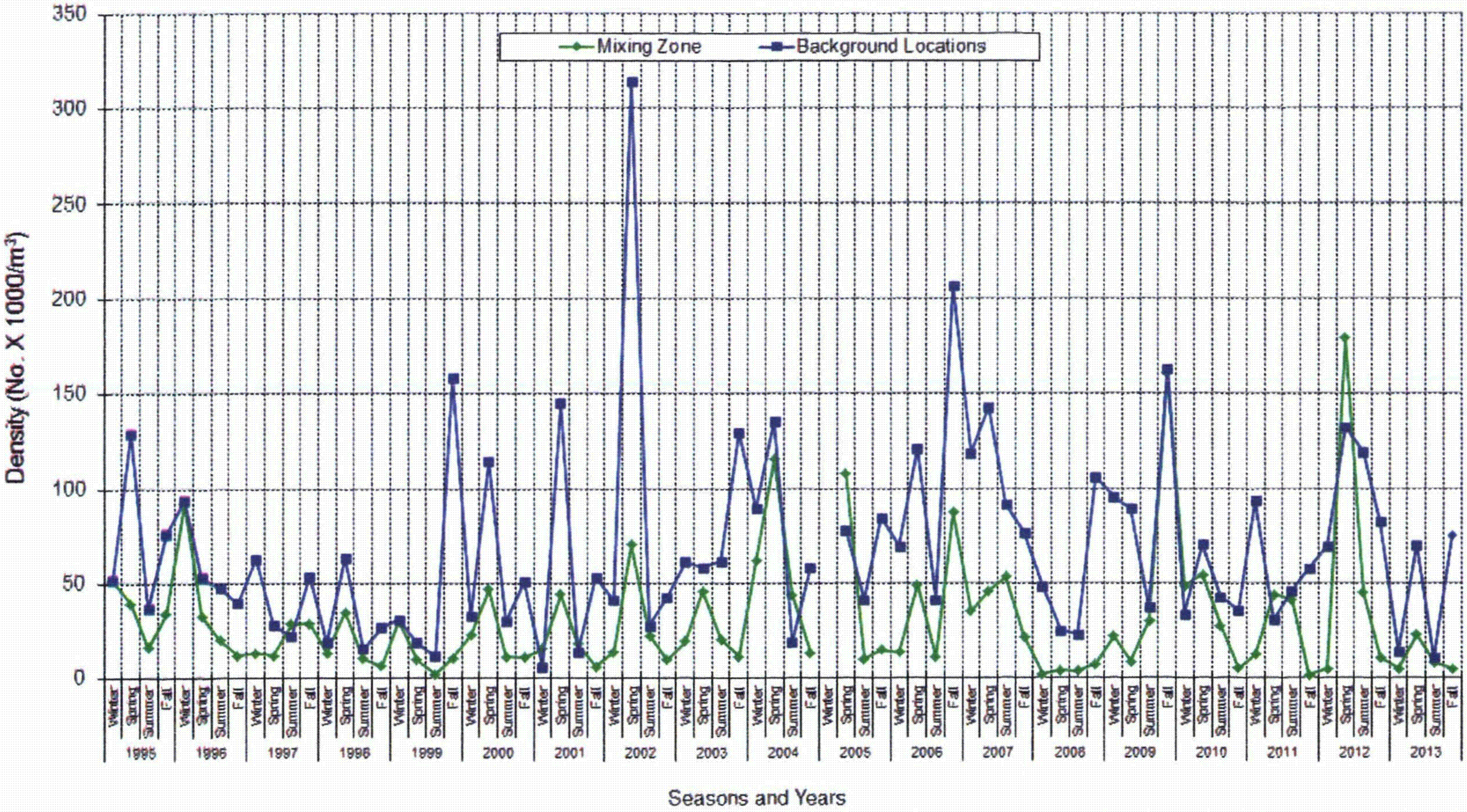


Figure 4-12. Rotifer densities during each season of each year among epilimnetic samples collected in Lake Norman from 1995 through 2013 (mixing zone = mean of Locations 2.0 and 5.0; background = mean of Locations 9.5, 11.0, and 15.9).

length (TL, mm) and weight (g) were obtained for each individual collected. Surface water temperature (°C) was measured with a calibrated thermistor at each transect.

Annual catch per unit effort (CPUE per 3,000 m) was determined by area for number of individuals, biomass, and number of species collected. Otoliths were removed from all largemouth bass ≥ 150 mm and a subsample of spotted bass (4 from each 25-mm TL size class 150-350 mm per area and all ≥ 350 mm) and sectioned for age determination (Quist et al. 2012). Black bass < 150 mm were assumed to be age 1 because young-of-year bass are not historically collected during spring surveys. Growth rates were compared between species and among areas. Condition (Wr) based on relative weight was calculated for spotted bass and largemouth bass ≥ 150 mm TL, using the formula $Wr = (W/Ws) \times 100$, where W = weight of the individual fish and Ws = length-specific mean weight for a fish as predicted by a weight-length equation for each species (Neumann et al. 2012). Resulting metrics were compared among areas using ANOVA ($P < 0.05$).

### Summer Striped Bass Mortality Surveys

Mortality surveys were conducted at least weekly during July and August to specifically search for dead or dying striped bass in Zones 1 to 4. All observed dead and dying striped bass were collected and a subsample of individual TLs was measured prior to disposal.

### Striped Bass and Hybrid Striped Bass Netting Survey

Striped bass and hybrid striped bass were collected in early December for age, growth, and condition determinations. Fish were collected from local anglers and in monofilament gill nets. The nets measured 76.2 m long x 6.1 m deep and contained two 38.1-m panels of either 38- and 51-mm square mesh or 63- and 76-mm square mesh. Nets were set overnight in areas where striped bass were previously located. Individual TL and weight were obtained and otoliths removed and sectioned for age determination (Quist et al. 2012). Growth and condition ($W_r$) were determined as described previously for black bass.

### Fall Hydroacoustic and Purse Seine Surveys

Density and distribution of pelagic forage fish in Lake Norman were determined using mobile hydroacoustic (Rudstam et al. 2012) and purse seine (Hayes et al. 2012) techniques. The lake was divided into zones (Figure 5-1) due to its large size and habitat spatial (see Chapters 3 and 4). There is no apparent temporal trend in the biomass of fish collected within each area since 1993.

Spotted bass, thought to have originated from angler introductions, were first collected in Lake Norman in the MNS area during a 2000 fish health assessment survey. The number of individuals and biomass of spotted bass collected have increased since 2001 (Figure 5-3a and b). Spotted bass were most abundant and had the highest biomass in the MSS area in 2013, similar to recent years.

Spotted bass (> 150 mm) mean $W_r$ values were similar in the MSS (80.6) and REF areas (82.7) with both statistically higher than the MNS area (75.3). The REF mean $W_r$ value was slightly above the range of observed historical values (70.5 to 82.3) (Duke Power 2004a, 2005, unpublished data; Duke Energy 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2014).

The number of individuals (33) and biomass (23.5 kg) of largemouth bass collected from all areas in 2013 marked historical lows continuing a downward temporal trend (Figure 5-4a and b). As in most years, the number of individuals (27) and biomass (18.9 kg) of largemouth bass were highest in the MSS area in 2013. Typically, the number of individuals and biomass were intermediate in the REF area and lowest in the MNS area following a longitudinal gradient reported from similar reservoirs in Georgia (Maceina and Bayne 2001) and Kentucky (Buynak et al. 1989). However, the low number of largemouth bass collected from Lake Norman in 2013 and recent years diminishes the significance of this comparison.

The overall largemouth bass (> 150 mm) mean $W_r$ value was 85.5, within the range of observed historical values (76.0 to 89.9; Duke Power 2004a, 2005, and unpublished data; Duke Energy 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2014). The low number of largemouth bass collected prevented a meaningful comparison among areas.

Spotted bass growth for all areas was fastest through Age 3 and slowed with increasing age as in previous years (Table 5-2). Largemouth bass numbers in 2013 were inadequate for growth rate comparisons with spotted bass or with previous years of largemouth bass data. Largemouth bass population parameters from surveyed areas have declined sharply in recent years likely due to congeneric competition from the introduced spotted bass (Sammons and Bettoli 1999; Long and Fisher 2000; Pope et al. 2005). However, other introduced species (e.g., alewife [*Alosa pseudoharengus*] and white perch [*Morone americana*]) may have contributed to these declines (Kohler and Ney 1980; Madenjian et al. 2000).

Preferred cool water habitat was available throughout Lake Norman in summer 2013 due to the atypical spring and early summer meteorological conditions. Therefore, adult alewife and, in turn, striped bass were not attracted to the lower Lake Norman hypolimnion.

### Winter Striped Bass Netting Survey

Striped bass (47) collected in December 2013 ranged in TL from 344 to 676 mm and were dominated by age 1 and age 2 fish (Figure 5-6). Striped bass growth was fastest through age 3 and slowed with increasing age, although the low number of older striped bass collected diminishes the significance of this comparison. Mean $W_r$ was highest for age 1 fish (92.9) and remained between 83.4 and 90.4 for Age 2-6 fish. Mean $W_r$ was 90.7 (0.8 SE) for all striped bass in 2013, above the range of observed historical values (78.5 to 86.1). Growth in 2013 was consistent with historical values measured since consistent annual gillnetting began in 2003, given the preponderance of young fish (Duke Power 2004a and 2005; Duke Energy 2006, 2007, 2008, 2009, 2010, 2011, 2012, and 2014).

The NCWRC ceased annual stocking of striped bass after 2012 and, instead, began stocking hybrid striped bass in summer 2013. Twenty hybrid striped bass were collected during the netting survey and an additional two were collected from anglers. The mean $W_r$ was 88.9, comprised mostly of young-of-year (stocked) fish. However, six of the collected fish were age 1 or 2, likely stocked by local anglers.

### Fall Hydroacoustics and Purse Seine Surveys

Mean forage fish density estimates in the surveyed zones of Lake Norman ranged from 5,633 (Zone 2) to 16,575 (Zone 5) fish/ha in September 2013 (Figure 5-7). Zone 6 fish densities were indeterminate using hydroacoustics due to the shallow nature of the riverine habitat. The annual forage fish population survey of Lake Norman has demonstrated considerable variability within and among zones since 1997.

Threadfin shad dominated the epilimnetic Lake Norman forage fish community purse seine survey in mid-September 2013 (93.5%), similar to surveys since 1993 (Table 5-3). The modal length class of threadfin shad collected in 2013 was 46-50 mm indicating most fish to be young-of-year (Figure 5-8). Alewife comprised at most 25.0% (2002) of the historical pelagic forage fish surveys. The percent composition of alewife has remained relatively low from 2005 to 2013 (range = 1.5 to 6.5%) with a noticeable exception in 2009 (11.6%).

Table 5-1. Number of individuals (No.) and biomass (Kg) of fish collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, spring 2013.

| | | MSS | | REF | | MNS | | **Total** | |
|---|---|---|---|---|---|---|---|---|---|
| Scientific name | Common name | No. | Kg | No. | Kg | No. | Kg | **No.** | **Kg** |
| **Lepisosteidae** | | | | | | | | | |
| *Lepisosteus osseus* | Longnose gar | | | | | 1 | 0.19 | 1 | 0.19 |
| **Clupeidae** | | | | | | | | | |
| *Alosa pseudoharengus* | Alewife | 1 | 0.01 | | | | | 1 | 0.01 |
| *Dorosoma cepedianum* | Gizzard shad | 13 | 5.65 | 15 | 8.14 | 1 | 0.51 | 29 | 14.31 |
| *Dorosoma petenense* | Threadfin shad | 85 | 0.61 | 135 | 0.91 | | | 220 | 1.51 |
| **Cyprinidae** | | | | | | | | | |
| *Cyprinella chloristia* | Greenfin shiner | | | 1 | 0.00 | 3 | 0.01 | 4 | 0.01 |
| *Cyprinella nivea* | Whitefin shiner | 3 | 0.01 | 9 | 0.06 | | | 12 | 0.06 |
| *Cyprinus carpio* | Common carp | 39 | 105.03 | 4 | 9.01 | 1 | 1.99 | 44 | 116.03 |
| *Notropis hudsonius* | Spottail shiner | 3 | 0.03 | 22 | 0.17 | | | 25 | 0.20 |
| **Ictaluridae** | | | | | | | | | |
| *Ictalurus furcatus* | Blue catfish | 2 | 3.20 | | | | | 2 | 3.20 |
| *Ictalurus punctatus* | Channel catfish | 8 | 4.25 | 2 | 0.83 | 1 | 0.55 | 11 | 5.63 |
| *Pylodictis olivaris* | Flathead catfish | 4 | 1.04 | 5 | 1.40 | 3 | 1.02 | 12 | 3.45 |
| **Moronidae** | | | | | | | | | |
| *Morone americana* | White perch | 43 | 2.51 | | | | | 43 | 2.51 |
| **Centrarchidae** | | | | | | | | | |
| *Lepomis auritus* | Redbreast sunfish | 79 | 2.89 | 213 | 4.26 | 168 | 3.65 | 460 | 10.79 |
| *Lepomis cyanellus* | Green sunfish | 61 | 1.68 | 246 | 4.54 | 43 | 0.78 | 350 | 7.00 |
| *Lepomis gulosus* | Warmouth | 3 | 0.05 | 7 | 0.06 | 8 | 0.06 | 18 | 0.18 |
| *Lepomis* hybrid | Hybrid sunfish | 35 | 1.25 | 48 | 1.60 | 17 | 0.54 | 100 | 3.39 |
| *Lepomis macrochirus* | Bluegill | 918 | 15.77 | 788 | 15.80 | 352 | 5.92 | 2,058 | 37.49 |
| *Lepomis microlophus* | Redear sunfish | 41 | 7.01 | 15 | 1.96 | 12 | 0.69 | 68 | 9.66 |
| *Micropterus punctulatus* | Spotted bass | 153 | 39.15 | 94 | 26.01 | 114 | 13.74 | 361 | 78.91 |
| *Micropterus salmoides* | Largemouth bass | 27 | 18.86 | 5 | 3.25 | 1 | 1.44 | 33 | 23.54 |
| *Micropterus* hybrid | Hybrid black bass | 4 | 2.08 | 1 | 0.58 | 1 | 0.46 | 6 | 3.12 |
| *Pomoxis nigromaculatus* | Black crappie | 6 | 1.62 | 1 | 0.50 | | | 7 | 2.12 |
| **Percidae** | | | | | | | | | |
| *Etheostoma olmstedi* | Tessellated darter | 1 | 0.00 | | | | | 1 | 0.00 |
| **Total** | | 1,529 | 212.70 | 1,611 | 79.08 | 726 | 31.54 | 3,866 | 323.33 |
| **Total no. species** | | 19 | | 16 | | 13 | | | 21 |
| **Mean water temperature (° C)** | | 20.8 | | 18.4 | | 18.5 | | | 19.2 |

Table 5-2. Mean TL (mm) at age (years) for spotted bass and largemouth bass collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, spring 2013.

| | | Age (years) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Area | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Spotted bass | MSS | 172 | 261 | 340 | 355 | 393 | 418 | | | | | |
| | REF | 166 | 262 | 345 | 374 | 406 | 351 | 418 | | | | |
| | MNS | 200 | 292 | 345 | 384 | 393 | 360 | | | | | |
| | **Mean TL (mm)** | **192** | **271** | **343** | **366** | **400** | **376** | **418** | | | | |
| Largemouth bass | MSS | 193 | 261 | 346 | 345 | 397 | 402 | 427 | | | 500 | 496 |
| | REF | | 337 | 314 | | 420 | | | | | | |
| | MNS | | | | | | | | | 474 | | |
| | **Mean TL (mm)** | **193** | **299** | **340** | **345** | **401** | **402** | **427** | | **474** | **500** | **496** |

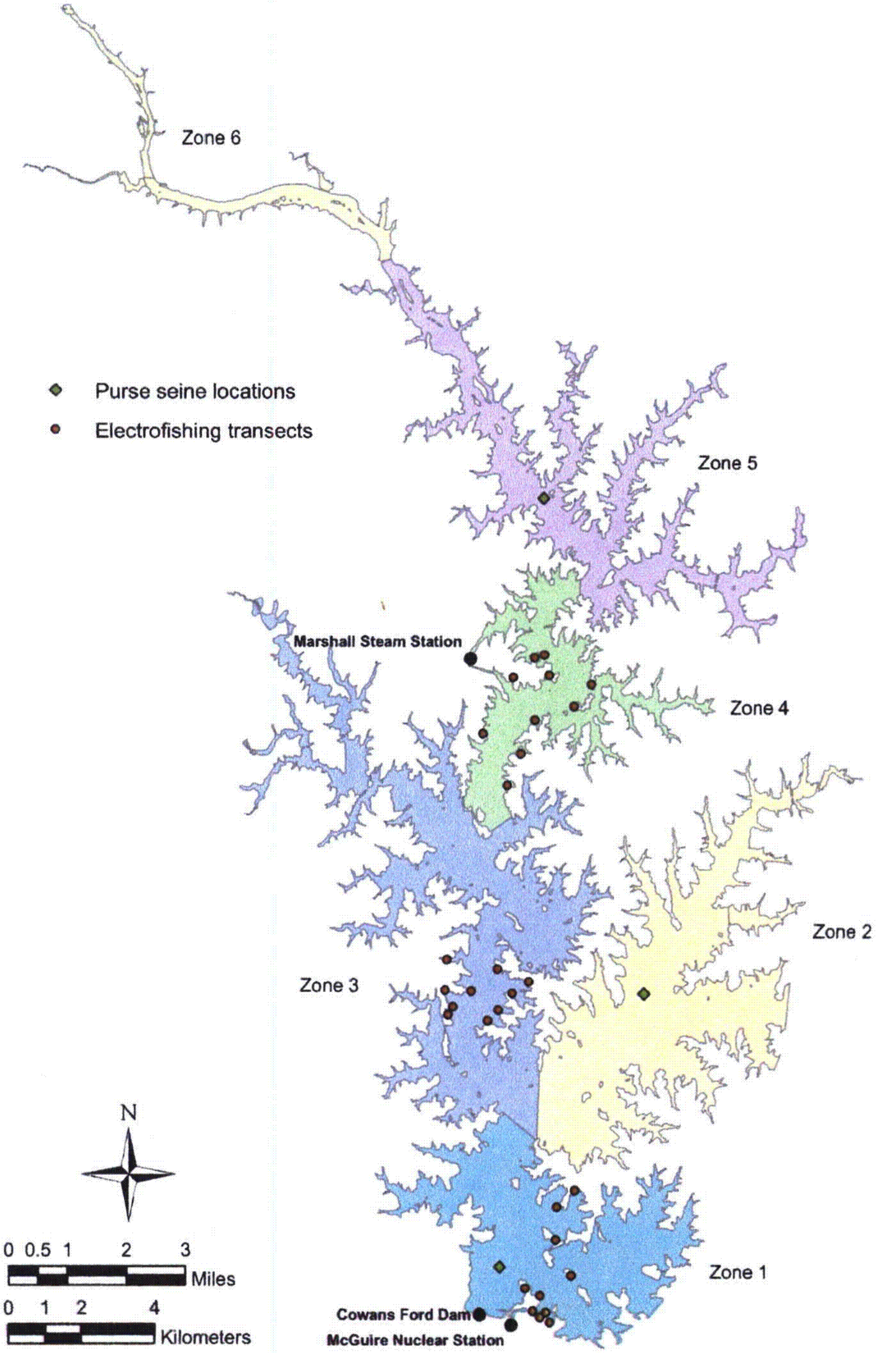


Figure 5-1. Sampling locations and zones associated with fishery assessments in Lake Norman.

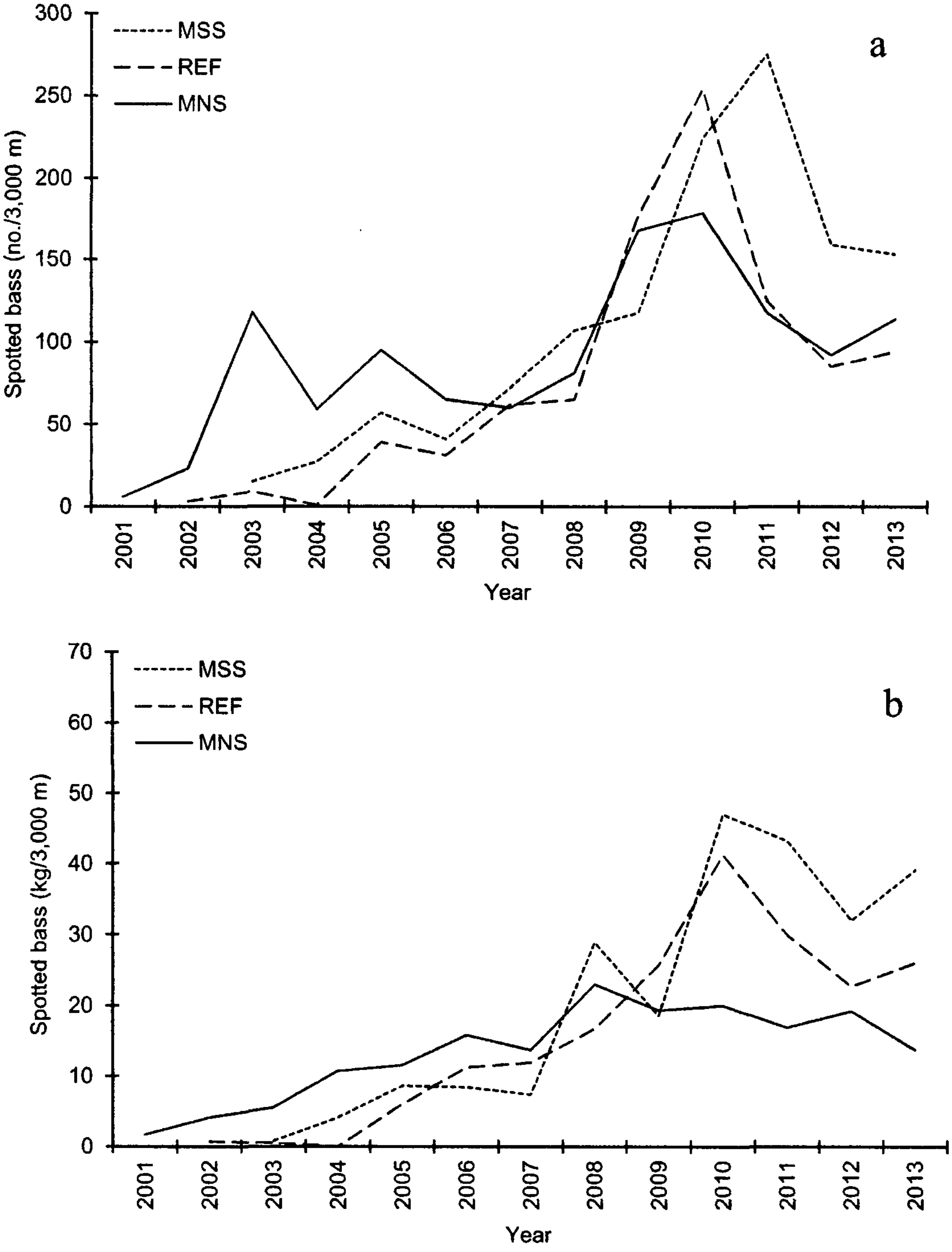


Figure 5-3. Total number of individuals (a) and biomass (b) of spotted bass collected from electrofishing ten 300-m transects each, at three areas (MSS, REF, MNS) in Lake Norman, spring 2001 – 2013.

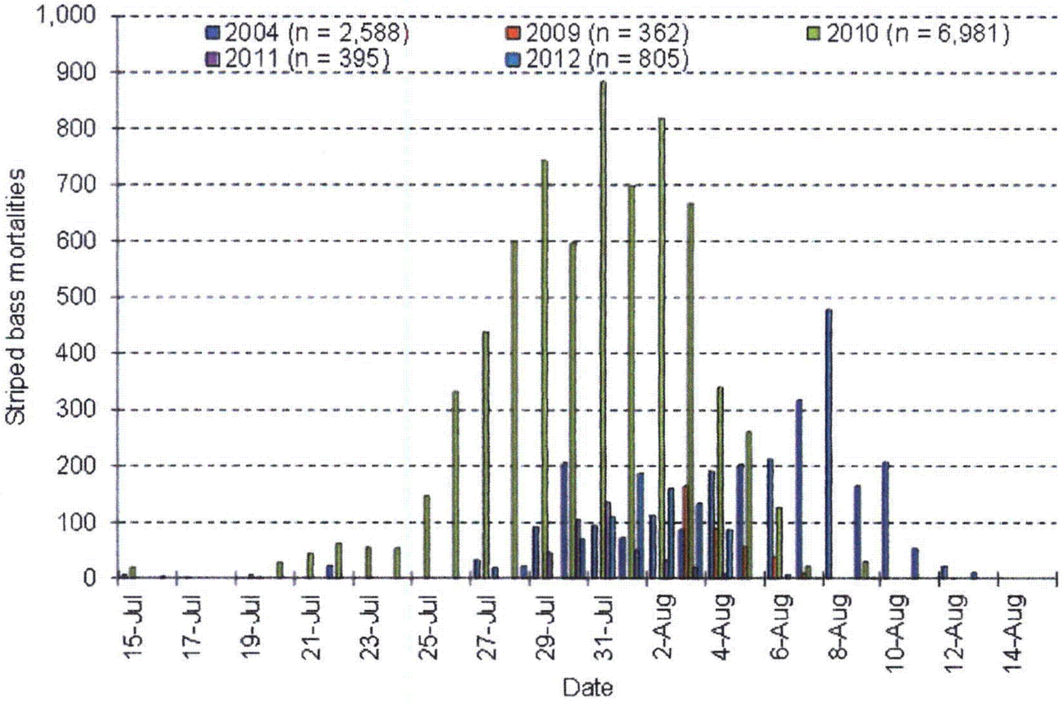


Figure 5-5. Number of striped bass mortalities in lower Lake Norman by date in summer 2004, 2009 – 2012.

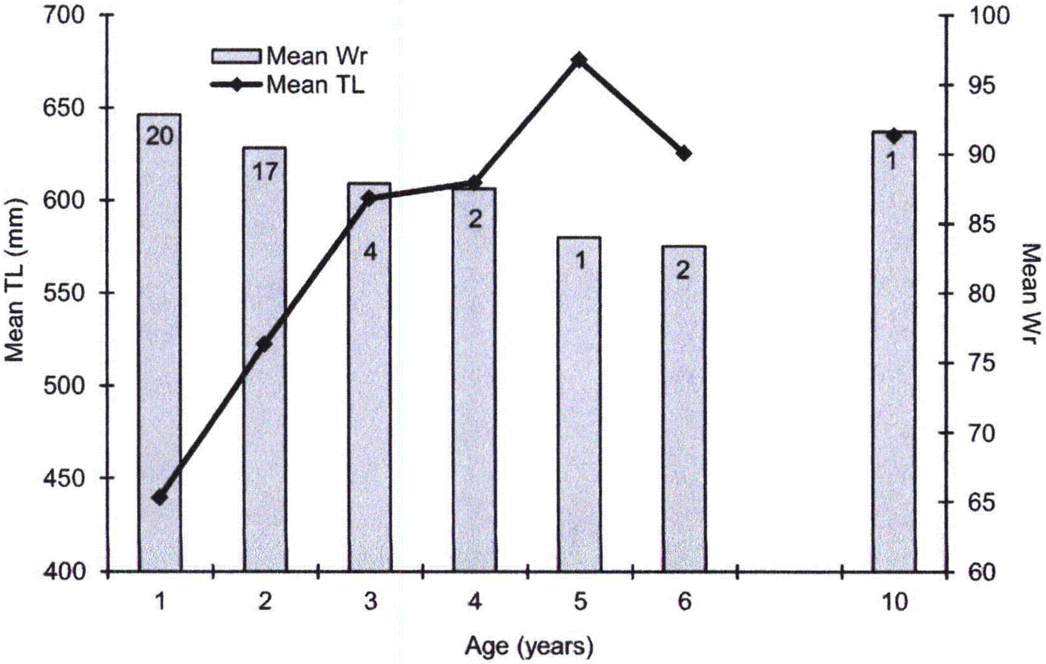


Figure 5-6. Mean TL and condition (Wr) by age of striped bass collected in Lake Norman, winter 2013. Numbers of fish by age are inside bars.

# LITERATURE CITED

American Public Health Association (APHA). 1995. Standard methods for the examination of water and wastewater. 19th Edition. APHA. Washington, DC.

Analytical Software. 2008. Statistix 9. Analytical Software. Tallahassee, FL.

Brandt, SB. 1996. Acoustic assessment of fish abundance and distribution. Pages 385-432 *in* BR Murphy and DW Willis, editors. Fisheries techniques. American Fisheries Society. Bethesda, MD.

Buynak, GL, LE Kornman, A Surmont, and B Mitchell. 1989. Longitudinal differences in electrofishing catch rates and angler catches of black bass in Cave Run Lake, KY. North American Journal of Fisheries Management. 9:226-230.

Cole, TM and HH Hannan. 1985. Dissolved oxygen dynamics. *in* Reservoir limnology: ecological perspectives. KW Thornton, BL Kimmel and FE Payne, editors. John Wiley & Sons, Inc. New York, NY.

Coutant, CC. 1985. Striped bass, temperature, and dissolved oxygen: A speculative hypothesis for environmental risk. Transactions of the American Fisheries Society. 114:31-61.

Devries, DR and RV Frie. 1996. Determination of age and growth. Pages 483-512 *in* BR Murphy and DW Willis, editors. Fisheries techniques. American Fisheries Society. Bethesda, MD.

Duke Energy. 2006. Lake Norman maintenance monitoring program: 2005 summary. Duke Energy Corporation, Charlotte, NC.

Duke Energy. 2007. Lake Norman maintenance monitoring program: 2006 summary. Duke Energy Corporation, Charlotte, NC.

Duke Energy. 2008. Lake Norman maintenance monitoring program: 2007 summary. Duke Energy Corporation, Charlotte, NC.

Duke Energy. 2009. Lake Norman maintenance monitoring program: 2008 summary. Duke Energy Corporation, Charlotte, NC.

Duke Energy. 2010. Lake Norman maintenance monitoring program: 2009 summary. Duke Energy Corporation, Charlotte, NC.

Duke Energy. 2011. Lake Norman maintenance monitoring program: 2010 summary. Duke Energy Corporation, 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.

Ford, DE. 1987. Mixing processes in DeGray Reservoir. *in* Proceedings of the DeGray Lake symposium. RH Kennedy and J Nix, editors. USACE Technical Report E87-4.

Hamme, RE. 1982. Zooplankton. Pages 323-353 *in* JE Hogan and WD Adair, editors. Lake Norman Summary, Technical Report DUKEPWR/82-02. Duke Power Company. Charlotte, NC.

Hannan, HH, IR Fuchs, and DC 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, DB, CP Ferrier, and WW Taylor. 2012. Active fish capture methods. Pages 267-304 *in* AV Zale, DL Parrish and TM Sutton, editors. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethesda, MD.

Higgins, JM and BR Kim. 1981. Phosphorus retention models for Tennessee Valley Authority reservoirs. Water Resources Research. 17:571-576.

Neumann, RM, CS Guy, and DW Willis. 2012. Length, weight, and associated indices. Pages 637-676 *in* AV Zale, DL Parrish and TM Sutton, editors. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethesda, MD.

North Carolina Department of Environment, Health, and Natural Resources. 1991. 1990 Algal bloom report. Division of Environmental Management, Water Quality Section.

North Carolina Department of Environment and Natural Resources (NCDENR). 2004. Red book. Surface waters and wetland standards. NC Administrative Code. 15a NCAC 02B.0100, .0200 and .0300. August 1, 2004.

NCDENR. 2012. North Carolina Division of Water Quality (DWQ) annual report of fish kill events 2012. NCDENR-DWQ. Raleigh, NC.

Petts, GE. 1984. Impounded rivers: Perspectives for ecological management. John Wiley & Sons, Inc. New York, NY.

Pope, KL, SR Denny, CL Harthorn, CJ Chizinski, and KK Cunningham. 2005. Food habits of co-occurring populations of largemouth bass and spotted bass in two New Mexico reservoirs. Journal of Freshwater Ecology. 20:37-46.

Quist MC, MA Pegg, and DR DeVries. 2012. Age and Growth. Pages 677-731 *in* AV Zale, DL Parrish and TM Sutton, editors. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethesda, MD.

Rodriguez, MS. 1982. Phytoplankton. Pages 154-260 *in* Lake Norman summary. JE Hogan and WD Adair, editors. Technical Report DUKEPWR/82-02. Duke Power Company. Charlotte, NC.

Rudstam, LG, JM Jech, SL Parker-Stetter, JK Horne, PJ Sullivan, and DM Mason. 2012. Fisheries acoustics. Pages 597-636 *in* AV Zale, DL Parrish and TM Sutton, editors. Fisheries Techniques, 3rd edition. American Fisheries Society, Bethesda, MD.

Sammons, SM, and PW Bettoli. 1999. Spatial and temporal variation in electrofishing catch rates of three species of black bass (*Micropterus* spp.) from Normandy Reservoir, Tennessee. North American Journal of Fisheries Management. 19:454-461.

Siler, JR. 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, JR, WJ Foris, and MC McInerny. 1986. Spatial heterogeneity in fish parameters within a reservoir. Pages 122-136 *in* Fisheries management: Strategies for the 80's. GE Hall and MJ Van Den Avyle, editors. Reservoir Committee, Southern Division American Fisheries Society. Bethesda, MD.

# APPENDIX TABLES

Appendix Table A-1. Phytoplankton taxa identified in quarterly samples collected in Lake Norman for the periods 1987 – 1991, 1992 – 1996, 1997 – 2001, 2002 – 2006, 2007 – 2011, and each year from 2012 and 2013.

| | Years | | | | | | |
|---|---|---|---|---|---|---|---|
| **Taxon** | **87-91** | **92-96** | **97-01** | **02-06** | **07-11** | **12** | **13** |
| Class: Chlorophyceae | | | | | | | |
| *Acanthosphaera zachariasi* Lemmerman | X | X | | | | | |
| *Actidesmium hookeri* Reinsch | | X | | | | | |
| *Actinastrum hantzchii* Lagerheim | X | X | | X | X | | |
| *Ankistrodesmus braunii* (Naegeli) Brunn | | X | X | X | X | X | X |
| *A. convolutus* Corda | | | X | | X | | |
| *A. falcatus* (Corda) Ralfs | X | X | X | X | X | X | X |
| *A. fusiformis* Corda sensu Korsch. | X | X | | | | | |
| *A. nannoselene* Skuja | | | X | | | | |
| *A. spiralis* (Turner) Lemm. | X | X | X | | | | |
| *A.* spp. Corda | X | X | | | | | |
| *Arthrodesmus convergens* Ehrenberg | | X | | X | X | X | X |
| *A. incus* (Breb.) Hassall | X | X | X | X | X | X | X |
| *A. incus* v *extensus* Anderson | | | | | X | | X |
| *A. incus* v *ralfsii* W. West | | | | | X | X | |
| *A. octocornis* Ehrenberg | | | | X | X | X | X |
| *A. ralfsii* W. West | | | | X | X | | X |
| *A. subulatus* Kuetzing | | X | X | X | X | X | |
| *A. validus* v. *increassalatus* Scott & Gron. | | | | X | | | X |
| *A.* spp. Ehrenberg | | X | | | | | |
| *Asterococcus limneticus* G. M. Smith | X | X | X | X | X | X | X |
| *A. superbus* (Cienk.) Scherffel | | | | X | X | X | X |
| *Botryococcus braunii* Kuetzing | X | X | | | | | |
| *Carteria fritzschii* Takeda | X | | X | X | X | X | X |
| *C. globosa* Korsch | | | | X | X | X | X |
| *C.* spp. Diesing | X | X | X | X | | X | X |
| *Characium ambiguum* Hermann | | | | X | | | |
| *C. limneticum* Lemmerman | | | | X | | | |
| *C.* spp. Braun | X | | | | | | |
| *Chlamydomonas* spp. Ehrenberg | X | X | X | X | X | X | X |
| *Chlorella ellipsoida* Gerneck | | | | | | X | |
| *C. vulgaris* Beyerink | | | X | X | X | X | X |
| *C.* spp. Beyerlink | | | | | | X | X |
| *Chlorogonium euchlorum* Ehrenberg | X | X | X | X | X | X | X |
| *C. spirale* Scherffel & Pascher | | X | | X | X | X | |
| *Closteriopsis longissima* W. & G.S. West | X | X | X | X | X | X | X |
| *C. longissima* v. *tropica* West & West | | | | | X | X | |
| *Closterium abruptum* v *brevis* West. & West | | | | | X | X | |
| *C. acutum* Brebisson | | | | X | X | | |
| *C. cornu* Ehrenberg | | | X | X | | | |
| *C. gracile* Brebisson | | X | | | X | | |
| *C. incurvum* Brebisson | X | X | X | | X | X | X |
| *C. parvulum* Nageli | | | | X | | | |
| *C. pusillum* Hantzsch | | | | | X | | |

Appendix Table 3-1. (Continued).

| Taxon | Years<br>87-91 | 92-96 | 97-01 | 02-06 | 07-11 | 12 | 13 |
|---|---|---|---|---|---|---|---|
| *Dimorphococcus* spp. Braun | X | | | | | | |
| *Elakatothrix gelatinosa* Wille | X | X | X | X | X | X | X |
| *Errerella bornheimiensis* Conrad | | | | X | X | X | X |
| *Euastrum ansatum* v. *dideltiforme* Ducel. | | | | X | | | |
| *E. binal* (Turp.) Ehrenberg | | | | X | X | | |
| *E. denticulatum* (Kirch.) Gay | | X | X | X | X | X | X |
| *E. elegans* Kuetzing | | | | X | X | | |
| *E. turneri* West | | | | | X | | |
| *E.* spp. Ehrenberg | X | X | | | X | | |
| *Eudorina elegans* Ehrenberg | X | X | | X | X | | X |
| *E. unicocca* G. M. Smith | | | | | | | X |
| *Franceia droescheri* (Lemm.) G. M. Sm. | X | X | X | X | X | X | X |
| *F. ovalis* (France) Lemm. | X | X | X | X | X | X | X |
| *F. tuberculata* G. M. Smith | | | | X | | | |
| *Gloeocystis ampla* (Kuetz.) Lagerheim | | | | | | | X |
| *G. botryoides* (Kuetz.) Nageli | X | X | X | X | X | | |
| *G. gigas* Kuetzing | X | X | X | X | X | X | X |
| *G. major* Gerneck *ex.* Lemmermann | | | X | X | X | | |
| *G. planktonica* (West & West) Lemm. | X | X | X | X | X | X | X |
| *G. vesciculosa* Naegeli | | | X | X | X | X | X |
| *G.* spp. Nageli | X | X | | | | | |
| *Golenkinia paucispina* West & West | X | | | X | X | X | X |
| *G. radiata* Chodat | X | X | X | X | X | X | X |
| *Gonium pectorale* Mueller | | | X | X | 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 |
| *K. elongata* G.M. Smith | | | X | X | X | X | X |
| *K. lunaris* (Kirch.) Mobius | X | X | | X | X | | X |
| *K. lunaris* v. *dianae* Bohlin | X | X | X | X | X | X | X |
| *K. lunaris* v. *irregularis* G.M. Smith | | | X | X | X | | |
| *K. obesa* W. West | X | X | | X | X | X | X |
| *K. subsolitaria* G. S. West | X | X | X | X | X | X | X |
| *K.* spp. Schmidle | X | X | X | X | X | | X |
| *Lagerheimia ciliata* (Lagerheim) Chodat | X | | | X | X | X | X |
| *L. citriformis* (Snow) G. M. Smith | | | X | X | X | | X |
| *L. longiseta* (Lemmermann) Printz | X | | | X | X | | |
| *L. longiseta* v. *major* G. M. Smith | | | | | X | | |
| *L. quadriseta* (Lemm.) G. M. Smith | | X | | | X | | X |
| *L. subsala* Lemmerman | X | X | X | X | X | X | X |
| *Lobomonas rostrata* Hazen | | | | | X | | |
| *Mesostigma viride* Lauterborne | X | X | X | X | X | X | X |
| *Micractinium pusillum* Fresen. | X | X | X | X | X | X | X |
| *Monoraphidium contortum* Thuret | X | X | | | | | |
| *M. pusillum* Printz | X | X | | | | | |
| *Mougeitia elegantula* Whittrock | X | X | X | X | X | X | X |
| *M.* spp. Agardh | X | X | | | X | | |
| *Nephrocytium agardhianum* Nageli | X | | | X | X | X | X |
| *N. ecdysiscepanum* W. West | | | | X | | | |
| *N. limneticum* (G.M. Smith) G.M. Smith | X | | X | X | X | X | X |

Appendix Table 3-1. (Continued). Page 5 of 13

| Taxon | Years<br>87-91 | 92-96 | 97-01 | 02-06 | 07-11 | 12 | 13 |
|---|---|---|---|---|---|---|---|
| *S. quadricauda* v. *longispina* (Chodat) G. M. Smith | | | | | | X | |
| *S. serratus* (Corda) Bohlin | | | | X | X | | |
| *S. smithii* Teiling | | X | | X | X | | |
| *S.* spp. Meyen | X | X | | | | | |
| *Schizochlamys compacta* Prescott | | X | X | X | X | X | X |
| *S. gelatinosa* A. Braun | | | X | X | X | X | X |
| *Schoederia setigera* (Schroed.) Lemm. | X | | | X | X | X | |
| *Selenastrum bibraianum* Reinsch | | | | X | X | X | X |
| *S. gracile* Reinsch | X | X | | X | X | | |
| *S. minutum* (Nageli) Collins | X | X | X | X | X | X | X |
| *S. westii* G. M. Smith | | X | X | X | X | X | X |
| *Sorastrum americanum* (Bohlin) Schm. | | | X | X | X | X | |
| *S. spinulosum* Nageli | | | | | X | | |
| *Sphaerocystis schoeteri* Chodat | X | X | X | X | X | X | X |
| *Sphaerozosma granulatum* Roy & Bl | X | | | | | | |
| *Stauastrum americanum* (W&W) G. Sm. | X | X | X | X | X | X | X |
| *S. apiculatum* Brebisson | X | | X | X | X | X | X |
| *S. arachne* v. *curvatum* W. & G.S. West | | | | | X | X | X |
| *S. arctison* v *glabrum* W. & G.S. West | | | | | X | | |
| *S. aspinosum* v. *annulatum* W.& G.S.Wst. | | | | | X | | |
| *S. brachiatum* Ralfs | | | X | X | X | X | X |
| *S. breviaculeatum* G. M. Smith | | | | | X | | |
| *S. brevispinum* Brebisson | X | | X | | | | |
| *S. chaetocerus* (Schoed.) G. M. Smith | | X | | | | X | |
| *S. capitulum* Brebisson | | | | X | | | |
| *S. cingulum* v *floridense* Scott & Gron. | | | | | X | | |
| *S. clevii* (Wittr.) Roy & Bill | | | | | X | | |
| *S. curvatum* W. West | | X | X | X | X | X | X |
| *S. curvatum* v. *elongatum* G.M. Smith | | | | | X | | |
| *S. cuspidatum* Brebisson | X | | X | X | X | X | X |
| *S. dejectum* Brebisson | X | X | X | X | X | | X |
| *S. dickeii* v. *maximum* West & West | X | | | X | | | |
| *S. dickeii* v. *rhomboidium* W.& G.S. West | | | | X | X | | |
| *S. gladiosum* Turner | | X | | | X | | |
| *S. leptocladum* Nordstedt | | | | X | | X | |
| *S. leptocladum* v. *coronutum* Wille | | | | | | X | |
| *S. leptocladum* v. *sinuatum* Wolle | X | | | | | | |
| *S. manfeldtii* v. *fluminense* Schumacher | X | X | X | X | X | X | X |
| *S. megacanthum* Lundell | X | X | | X | X | X | X |
| *S. ophiura* v. *cambricum* (Lund) W. & W. | | | X | X | X | | |
| *S. orbiculare* Ralfs | X | X | | X | X | | |
| *S. paradoxum* Meyen | X | X | X | X | X | X | |
| *S. paradoxum* v. *cingulum* W. & W. | X | | | X | X | X | X |
| *S. paradoxum* v. *parvum* W. West | X | | X | X | X | X | X |
| *S. pentacerum* (Wolle) G. M. Smith | | | | X | X | X | X |
| *S. protectum* v *planktonicum* G.M. Smith | | | | | X | | |
| *S. setigerum* Cleve | | | | | X | X | |
| *S. subcruciatum* Cook & Wille | X | X | X | X | X | X | X |
| *S. tetracerum* Ralfs | X | X | X | X | X | X | X |

Appendix Table 3-1. (Continued).

| Taxon | Years | | | | | | |
|---|---|---|---|---|---|---|---|
| | 87-91 | 92-96 | 97-01 | 02-06 | 07-11 | 12 | 13 |
| *A. pediculus* v. *minor* Grunow | | | | | X | | |
| *Anomoeoneis vitrea* (Grunow) Ross | X | X | X | X | X | X | X |
| *A.* spp. Pfitzer | | X | | | | | |
| *Asterionella formosa* Hassall | X | X | X | X | X | X | X |
| *Attheya zachariasi* J. Brun | X | X | X | X | X | X | X |
| *Cocconeis placentula* Ehrenberg | X | | X | X | X | | X |
| *C.* spp. Ehrenberg | | X | | X | | | |
| *Cyclotella comta* (Ehrenberg) Kutzing | X | X | X | | X | X | X |
| *C. glomerata* Bachmann | | X | X | X | X | X | X |
| *C. meneghiniana* Kuetzing | X | X | X | X | X | X | X |
| *C. pseudostelligera* Hustedt | X | | | | | | |
| *C. stelligera* Cleve & Grunow | X | X | X | X | X | X | X |
| *C.* spp. Kuetzing | X | | | | | | |
| *Cymbella affinis* Kutzing | | | X | X | | | |
| *C. gracilis* (Rabenhorst) Cleve | | | | X | | X | |
| *C. minuta* (Bliesch & Rabn.) Reim. | X | X | X | X | X | X | X |
| *C. naviculiformis* Auersw. *ex* Heib. | | | | | X | | |
| *C. tumida* (Brebisson) van Huerck | | X | | | X | X | X |
| *C. turgida* (Gregory) Cleve | X | | | | X | | |
| *C.* spp. Agardh | X | | | | | | |
| *Denticula elegans* Kuetzing | | | | X | X | X | X |
| *D. elegans* v. *crassa* (Naegeli) Hustedt | | | | | X | | |
| *D. thermalis* Kuetzing | | | X | X | X | | |
| *Diploneis ellyptica* (Kuetzing) Cleve | | | | X | X | | X |
| *D. marginestriata* Hustedt | | | | | X | | |
| *D. ovalis* (Hilse) Cleve | | | | X | | | |
| *D. puella* (Schum.) Cleve | | | | X | X | | |
| *D.* spp. Ehrenberg | X | | | | | | |
| *Eunotia flexuosa* v. *eurycephala* Grun. | | | X | | | | |
| *E. zasuminensis* (Cab.) Koerner | X | X | X | X | X | X | X |
| *Fragillaria. construens* (Ehrenberg) Grun. | | | | X | X | | |
| *F. crotonensis* Kitton | X | X | X | X | X | X | X |
| *F. virescens* Ralfs | | | | | X | | |
| *Frustulia rhomboides* (Ehrenberg) de Toni | X | | | X | | | |
| *F. rhomboides* v. *saxonica* (Rabh.) de Toni | | | | X | | | |
| *Gomphonema angustatum* (Kuetzing) Rabhorst | | | | X | | | |
| *G. gracile* (Her.) Van Huerk | | | | | X | | X |
| *G. parvulum* Kuetzing | | | | X | X | X | X |
| *G.* spp. Agardh | X | X | X | | | | X |
| *Gyrosigma scalproides* (Rabh.) Cleve | | | | | | | X |
| *Melosira ambigua* (Grunow) O. Muller | X | X | X | X | X | X | X |
| *M. distans* (Ehrenberg) Kutzing | X | X | | X | X | X | X |
| *M. granulata* (Ehrenberg) Ralfs | X | X | X | X | X | X | |
| *M. granulata* v. *angustissima* O. Muller | X | X | | X | X | X | X |
| *M. italica* (Ehrenberg) Kuetzing | X | | | | | X | X |
| *M. italica* v. *tennuissima* (Grun.) O. Mull. | | | | X | X | X | X |
| *M. varians* Agardh | | X | X | X | X | | X |
| *M.* spp. Agardh | X | X | X | X | X | X | |
| *Meridion circulare* Agardh | | | | | | | |

Appendix Table 3-1. (Continued).

| | Years | | | | | | |
|---|---|---|---|---|---|---|---|
| **Taxon** | **87-91** | **92-96** | **97-01** | **02-06** | **07-11** | **12** | **13** |
| *Bicoeca petiolatum* (Stien) Pringsheim | | | X | | | | |
| *Calycomonas pascheri* (Van Goor) Lund | | X | X | X | | | X |
| *Centritractus belanophorus* Lemm. | | | | X | | | |
| *Chromulina nebulosa* Pascher | | | | X | X | X | X |
| *C.* spp. Chien. | X | | X | X | X | | X |
| *Chrysococcus rufescens* Klebs | | | | X | | X | |
| *Chrysolykos planktonicus* Mack | | | | | | X | |
| *Chrysosphaerella solitaria* Lauterb. | X | X | X | X | X | X | X |
| *Codomonas annulata* Lackey | | X | X | X | X | X | X |
| *Dinobryon acuminatum* Ruttner | | | | | X | | |
| *D. bavaricum* Imhof | X | X | X | X | X | X | X |
| *D. cylindricum* Imhof | X | X | X | X | X | X | X |
| *D. divergens* Imhof | X | X | X | X | X | X | X |
| *D. pediforme* (Lemm.) Syein. | | | | X | X | | |
| *D. sertularia* Ehrenberg | X | X | X | X | X | X | |
| *D. sociale* Ehrenberg | | | | | X | | |
| *D.* spp. Ehrenberg | X | X | X | X | X | X | X |
| *Domatomococcus cylindricum* Lackey | | | X | X | X | | X |
| *Erkinia subaequicilliata* Skuja | 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 | X |
| *K. skujae* Ettl | X | | | | | | |
| *K. valkanovii* Conrad | | | | X | X | | |
| *K.* spp. Pascher | X | X | X | X | X | X | X |
| *Mallomonas acaroides* Perty | | X | | X | X | X | X |
| *M. akrokomos* (Naumann) Krieger | X | | X | X | X | X | X |
| *M. allantoides* Perty | | | | X | X | | |
| *M. allorgii* (Defl.) Conrad | | | | X | | | |
| *M. alpina* Pascher | | | X | | X | X | |
| *M. caudata* Conrad | X | X | X | X | X | | X |
| *M. globosa* Schiller | X | | X | X | X | X | X |
| *M. producta* Iwanoff | | | X | X | X | X | X |
| *M. pseudocoronata* Prescott | X | X | X | X | X | X | X |
| *M. tonsurata* Teiling | X | X | X | X | X | X | X |
| *M.* spp. Perty | X | X | X | | X | X | |
| *Ochromonas granularis* Doflein | | | X | X | X | X | |
| *O. mutabilis* Klebs | | | X | X | X | X | X |
| *O.* spp. Wyss | X | X | X | X | X | X | X |
| *Pseudokephyrion concinum* (Schill.) Sch. | | | | X | X | | |
| *P. schilleri* Conrad | | | X | X | X | | X |
| *P. tintinabulum* Conrad | | | X | | | | |
| *P.* spp. Pascher | | | | X | X | | X |
| *Rhizochrisis polymorpha* Naumann | | | X | X | X | X | X |
| *R.* spp. Pascher | X | | | | X | | |
| *Salpingoeca frequentissima* (Zach.) Lem. | | | X | X | | | |
| *Stelexomonas dichotoma* Lackey | X | X | X | X | X | X | X |

|  | **Years** |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| **Taxon** | **87-91** | **92-96** | **97-01** | **02-06** | **07-11** | **12** | **13** |
| *Aphanothece microspora* Nageli |  |  |  |  | X |  |  |
| *A. nidulans* P. Richter |  |  |  |  |  |  | X |
| *Chroococcus dispersus* (Keissl.) Lemm. |  |  | X |  | X | X |  |
| *C. giganteous* W. West |  |  |  | X |  |  |  |
| *C. limneticus* Lemmermann | X |  | X | X | X | X | X |
| *C. limneticus* v. *elegans* G. M. Smith |  |  |  |  |  | X |  |
| *C. limneticus* v. *subsalsa* Lemm. |  |  |  |  | X | X |  |
| *C. minor* Kuetzing | X |  |  | X | X | X | X |
| *C. prescottii* Druet & Daily |  |  |  |  | X | X | X |
| *C. turgidus* (Kuetzing) Lemmermann | X | X |  |  |  |  |  |
| *C.* spp. Nageli | X | X | X | X | X | X | X |
| *Coelosphaerium kuetzingiana* Nageli | X |  |  |  |  |  |  |
| *C. neagleanum* Unger |  |  |  | X | X |  |  |
| *Dactylococcopsis irregularis* Hansgirg | X | X |  | X | X |  |  |
| *D. musicola* Hustedt |  |  |  |  | X |  |  |
| *D. raphidiopsis* Hansgirg |  |  |  |  | X |  |  |
| *D. rupestris* Hansgirg |  |  | X |  |  |  |  |
| *D. smithii* Chodat and Chodat |  |  | X | X | X |  |  |
| *D.* spp. Hansgirg |  |  | X |  |  |  |  |
| *Gloeocapsa docortians* (A.Br.) Richter |  |  |  |  | X |  |  |
| *Gomphospaeria lacustris* Chodat | X | X |  | X |  |  |  |
| *Lyngbya contorta* Lemmermann | X | X |  |  |  |  |  |
| *L. limnetica* Lemmermann | X | X |  |  |  |  |  |
| *L. ochracea* (Kuetzing) Thuret |  |  | X | X | X | X |  |
| *L. subtilis* W. West | X | X |  |  |  |  |  |
| *L. tenue* Agardh |  |  |  | X | X |  | X |
| *L.* spp. Agardh | X | X | X | X | X | X | X |
| *Merismopedia tenuissima* Lemmermann |  |  | X |  |  |  |  |
| *Microcystis aeruginosa* Kutzing | X | X | X | X | X | X | X |
| *Oscillatoria amoena* (Kuetzing) Gomont |  |  |  | X |  |  |  |
| *O. amphibia* Agardh |  |  |  | X | X |  | X |
| *O. geminata* Meneghini | X | X | X | X | X | X | X |
| *O. limnetica* Lemmermann | X | X | X | X | X | X | X |
| *O. splendida* Greville |  | X | X | X |  |  |  |
| *O. subtilissima* Kuetzing |  |  | X | X | X | X | X |
| *O.* spp. Vaucher | X | X | X | X | X | X |  |
| *Phormidium angustissimum* W. & W. | X | X |  |  |  |  |  |
| *P. spp.* Kuetzing | X | X |  |  |  |  |  |
| *Raphidiopsis curvata* Fritsch & Rich | X | X | X | X | X |  | X |
| *R. mediterranea* Skuja |  |  | X |  |  |  |  |
| *R. spp.* Fritsch & Rich |  |  |  |  | X |  |  |
| *Rhabdoderma sigmoidea* Schm. & Laut. | X |  |  |  |  |  |  |
| *Spirulina subsala* Oersted |  |  |  | X | X |  |  |
| *Synecococcus lineare* (Sch. & Lt.) Kom. | X | X | X | X | X |  | X |
|  |  |  |  |  |  |  |  |
| **Class: Euglenophyceae** |  |  |  |  |  |  |  |
| *Euglena acus* Ehrenberg | X |  | X | X | X | X |  |

Appendix Table 3-1. (Continued).

| | Years | | | | | |
|---|---|---|---|---|---|---|
| **Taxon** | **87-91** | **92-96** | **97-01** | **02-06** | **07-11** | **12** | **13** |
| *G. penardiforme* (Lindemann) Schiller | | | X | X | X | | |
| *G. quadridens* (Stein) Schiller | X | X | | X | X | | |
| *G.* spp. (Ehrenberg) Stein | X | X | | | | | |
| *Gymnodinium aeruginosum* Stein | | | X | X | X | | X |
| *G. neglectum* (Schilling) Lindemann | | | | | X | X | |
| *G.* spp. (Stein) Kofoid & Swezy | X | | X | X | X | X | X |
| *Peridinium aciculiferum* Lemmermann | X | | | | X | X | |
| *P. bipes* v *travectum* (Ehrenberg) Lefevre | | | | | X | X | |
| *P. cinctum* (Muller) Ehrenberg | | | | X | X | X | X |
| *P. godlewskii* Wolzynska | | | | | X | | |
| *P. inconspicuum* Lemmermann | X | X | X | X | X | X | X |
| *P. intermedium* Playfair | | | X | X | X | X | X |
| *P. limbatum* (Stokes) Lemmermann | | | | X | X | | |
| *P. pusillum* (Lenard) Lemmermann | X | X | X | X | X | X | X |
| *P. quadridens* Stein | | | | | X | X | |
| *P. umbonatum* Stein | X | X | | | | | |
| *P. willei* Huitfeld-Kass | | | | X | X | | X |
| *P. wisconsinense* Eddy | X | X | X | X | X | X | X |
| *P.* spp. Ehrenberg | 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 | | | | | |
| | | | | | | | |