FORT COBB RESERVOIR WATER QUALITY INVESTIGATIONS JUNE 2002

U.S. Bureau of Reclamation
Fort Cobb Master Conservancy District
U.S. Fish and Wildlife Service

FORT COBB RESERVOIR WATER QUALITY INVESTIGATIONS

Agreement No: 97-AA-60-09790

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Submitted to:

U.S. Bureau of Reclamation
Oklahoma-Texas Area Office
Austin, Texas

Fort Cobb Master Conservancy District
Anadarko, Oklahoma

U.S. Fish and Wildlife Service
Region II
Albuquerque, New Mexico

June 2002

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ACKNOWLEDGMENTS

This entire study, from the initial planning meeting to review of the final report, would not have been possible without a number of people whose assistance was invaluable and greatly appreciated. The author would like to acknowledge: Jeff Baumberger, Michael Irlbeck and Don Moomaw - U.S. Bureau of Reclamation; Darin Clift and Lana Ryburn - Fort Cobb Reservoir Master Conservancy District; Ken Collins, Suzanne Dudding, Steve Hensley, Kevin Stubbs, and Colleen Lux - U.S. Fish and Wildlife Service; Robert Taylor - Texas A&M University; and Leslie Smith - Caddo Tribe. Two people deserve special thanks for their considerable and unerring service throughout every phase of the project: Quintin Opitz - Fort Cobb Reservoir Master Conservancy District and William Lints - U.S. Fish and Wildlife Service.

I. INTRODUCTION

A. Background

Fort Cobb Reservoir was constructed in 1959 by the U.S. Bureau of Reclamation for flood control, municipal water supply, fish and wildlife propagation and recreation. The dam is located at river mile 7.4 on Cobb Creek, a tributary of the Washita River, in Caddo County, Oklahoma (Lat 35° 09' 45", Long 98° 27' 00"). Cobb Creek and two other principle tributaries (Lake Creek and Willow Creek) drain approximately 314 square miles into the reservoir. Outflows from the reservoir include municipal pipelines to Chickasha and Anadarko, and an outlet for Cobb Creek. At normal pool elevation (1342.0' NGVD), the reservoir is about 7 miles long, has a capacity of 80,000 acre-feet, an area of 4,100 acres, a shoreline length of about 45 miles and a maximum depth of around 60 ft. The water in Fort Cobb Reservoir is managed by the Fort Cobb Master Conservancy District, with offices in Anadarko, Oklahoma.

Land use within the Fort Cobb watershed is primarily agricultural, with 52% cropland and 42% range and pasture land. The remaining land surface can be broken down into various other rural categories, with less than 0.5% considered urban (U.S. Department of Agriculture, Natural Resources Conservation Service, 2001). Livestock estimates are not available for the watershed specifically, however those for Caddo County include around 130,000 head of cattle, 12,000 hogs and 1,500 head of sheep. These livestock numbers can be compared to a human population of about 31,000.

Recent events in the Fort Cobb watershed, such as increased human development near the reservoir and the construction of large confined animal feeding operations (CAFOs), have raised questions about the present status and the future of Fort Cobb Reservoir water quality. The presence of sandy soils and a relatively shallow water table throughout much of the watershed led to concerns regarding the potential for adverse impacts to surface and/or groundwater due to increased loading of nutrients or other contaminants. Contamination of surface or groundwater would almost certainly impact Fort Cobb Reservoir. In addition to the effects that contamination could have on municipal water supplies, there is a large amount of wetland, riparian and deep-water fish and wildlife habitat associated with the reservoir that is also supported by surface and groundwater.

B. Study Objectives

In 1997, the U.S. Bureau of Reclamation, the Fort Cobb Master Conservancy District and the U.S. Fish and Wildlife Service agreed to conduct a joint, 3-year study to: (1) establish a baseline for surface water quality entering Fort Cobb Reservoir; and, (2) determine the present trophic status of Fort Cobb Reservoir and it's vulnerability to potential changes in water quality, particularly nutrients, that might result from future development within the watershed. The purpose of this report is to summarize the results of that study.

II. SITE DESCRIPTION

A. Fort Cobb Reservoir

During this study, water level elevation (NGVD) in Fort Cobb Reservoir (Figure 1) ranged from a high of 1346.5' in March of 1998 to a low of 1339.3' in September and October of that same year. Corresponding maximum and minimum surface areas were 4,556 and 3,384 acres, respectively. Total monthly discharge from the reservoir ranged from 20,450 acre-feet in April, 1998 to 890 acre-feet in January, 1999. The calculated flushing rate (i.e. the time required for the volume of the reservoir to be discharged) ranged from 124 days in April, 1998 to 2,424 days in January, 1999. Annual cycles of water level elevation, surface area, total discharge and flushing rate were well defined and qualitatively related (Figure 2). Quantitative differences among years are due to differences in inflow, however little inflow data are available. Rainfall contributes significantly to inflow and hence to reservoir hydrology. Figure 3 shows that average rainfall at the dam is highest in the spring, just prior to the period of highest maximum air temperatures, and is lowest in winter, during the period of lowest maximum air temperatures. In this part of the world, "average" rainfall, for any given time period, is a rather abstract notion as shown in Figure 3. In general, for time periods as short as this study, rain comes when it comes, and is not bound by averages. One must remember that one of the primary functions of this reservoir is to convert the seemingly erratic nature of actual rainfall and inflow into the smooth and more disciplined cycles illustrated in Figure 2.

B. Tributaries

Three perennial streams (Cobb Creek, Lake Creek and Willow Creek), each flowing primarily along a north/south axis, enter the upper end of Fort Cobb Reservoir (Figure 4). Only the largest of these (Cobb Creek) has a permanent gaging station, located about 4 miles upstream from the headwaters of the reservoir. Discharge in each of the three tributaries is very dynamic and can be illustrated by data from the Cobb Creek gaging station. For example, during the three years from October 1, 1997 to September 30, 2000, mean daily discharge ranged from 3.9 cfs on September 9, 1998 to 1430 cfs on March 16, 1998. During the period of record, from 1969 to present, maximum instantaneous flow was 12,000 cfs on June 4, 1995, while a mean daily flow of 0 cfs was recorded for August 18-19, 1970 and May 26-30, 1971.

We measured discharge on various occasions in each of the three main tributaries, as well as in Crooked Creek, Camp Creek, Eakly Creek and an unnamed, intermittent creek that flows directly into the reservoir (Figure 5). Some characteristics of these streams at the times our measurements were taken are summarized in Table 1. In general, Cobb, Willow and Lake Creeks are broad, shallow, sandy streams. Crooked and Camp Creeks are small, permanent, spring-fed tributaries to lower Cobb Creek. Eakly is a small, intermittent tributary to Lake Creek. Noname Creek is very small, intermittent, and appears to be fed by shallow groundwater during periods of rainfall. It was included in the study because of its proximity to a large swine CAFO directly up gradient from it's source. Figure 6 shows the average contribution of each stream to the total surface water inflow into Fort Cobb Reservoir on the dates our discharge measurements were taken.

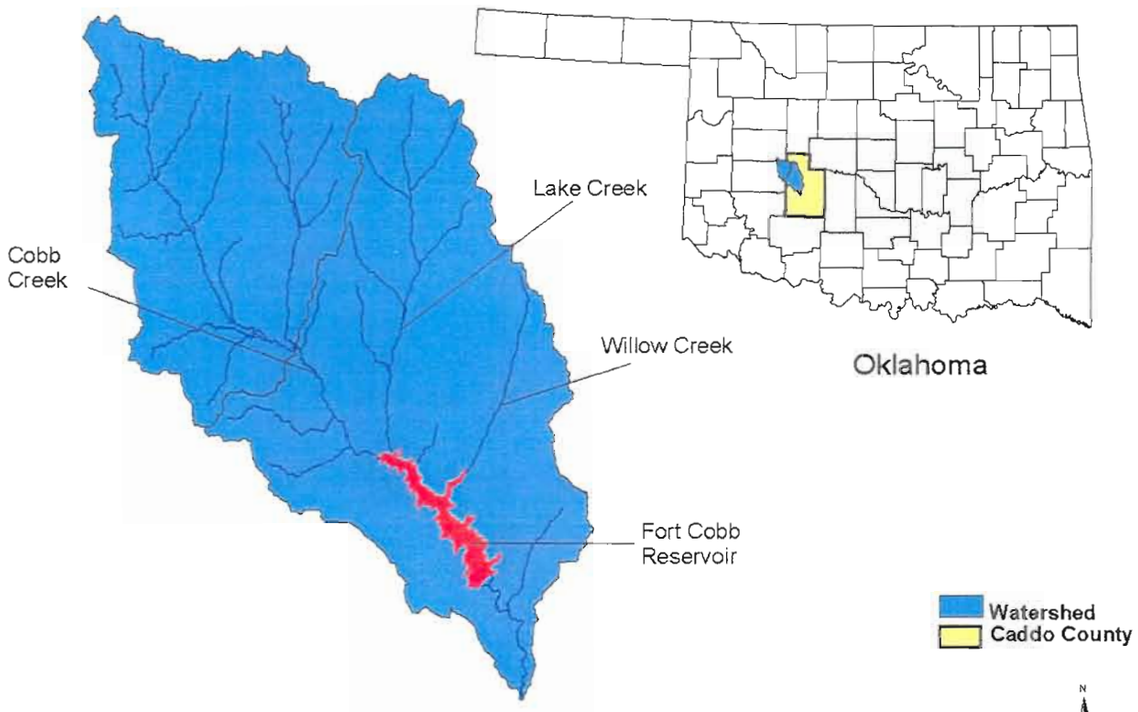


Figure 1. Location of Fort Cobb Reservoir and tributaries

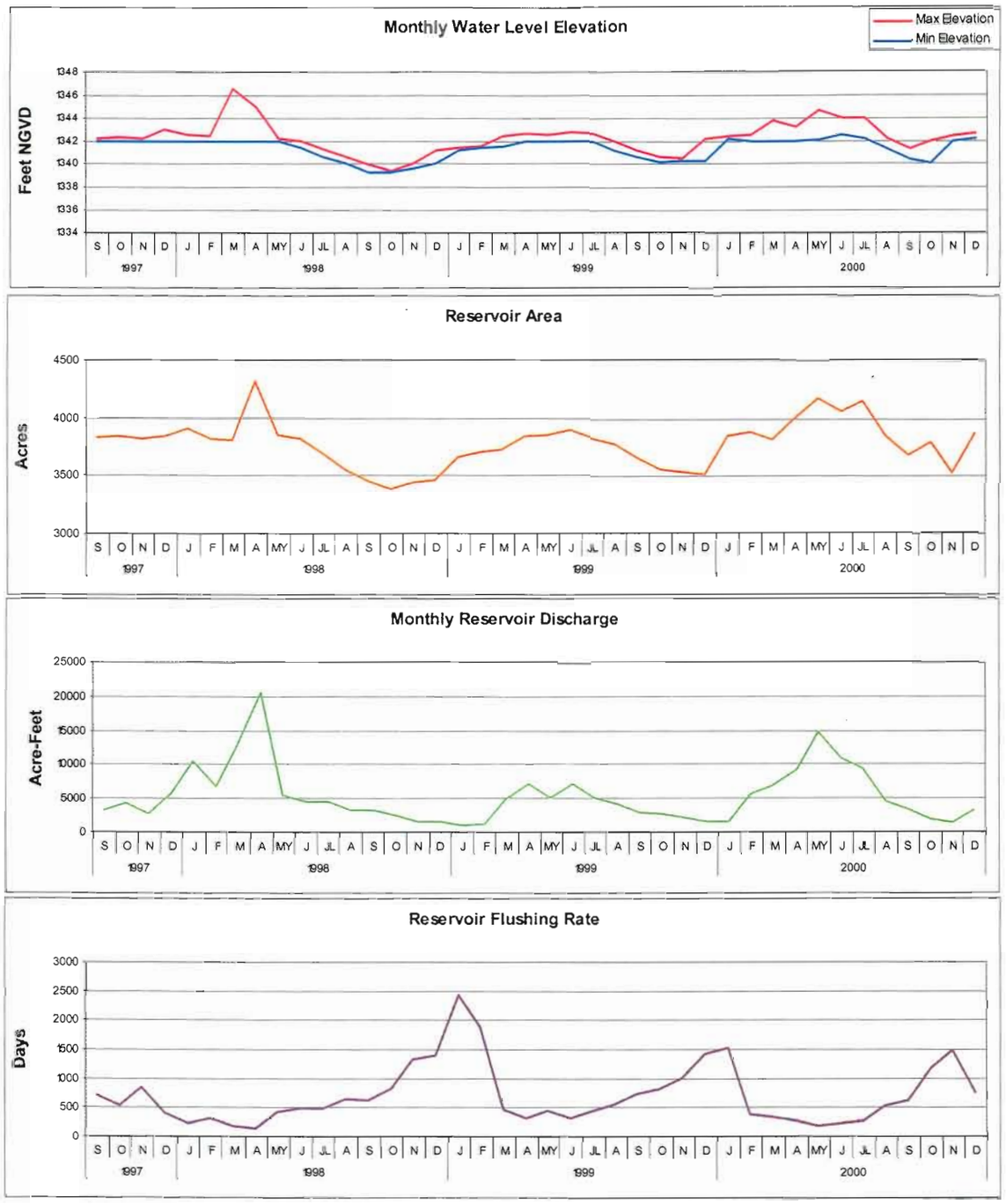
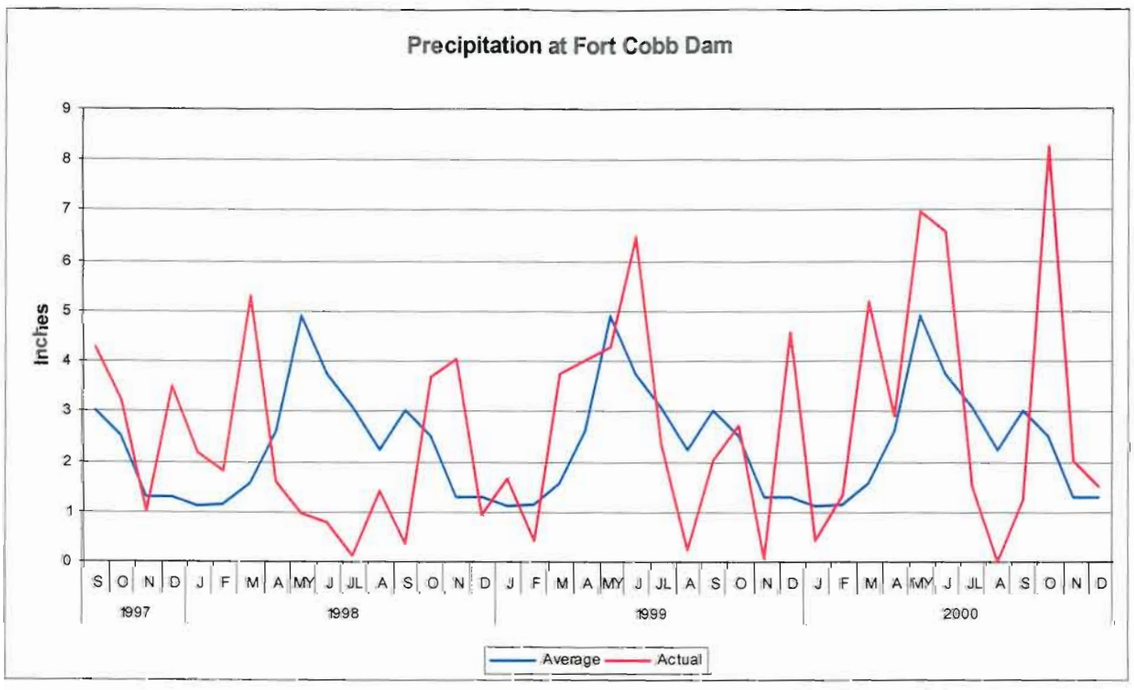


Figure 2. Annual water cycles in Fort Cobb Reservoir during the present study period.



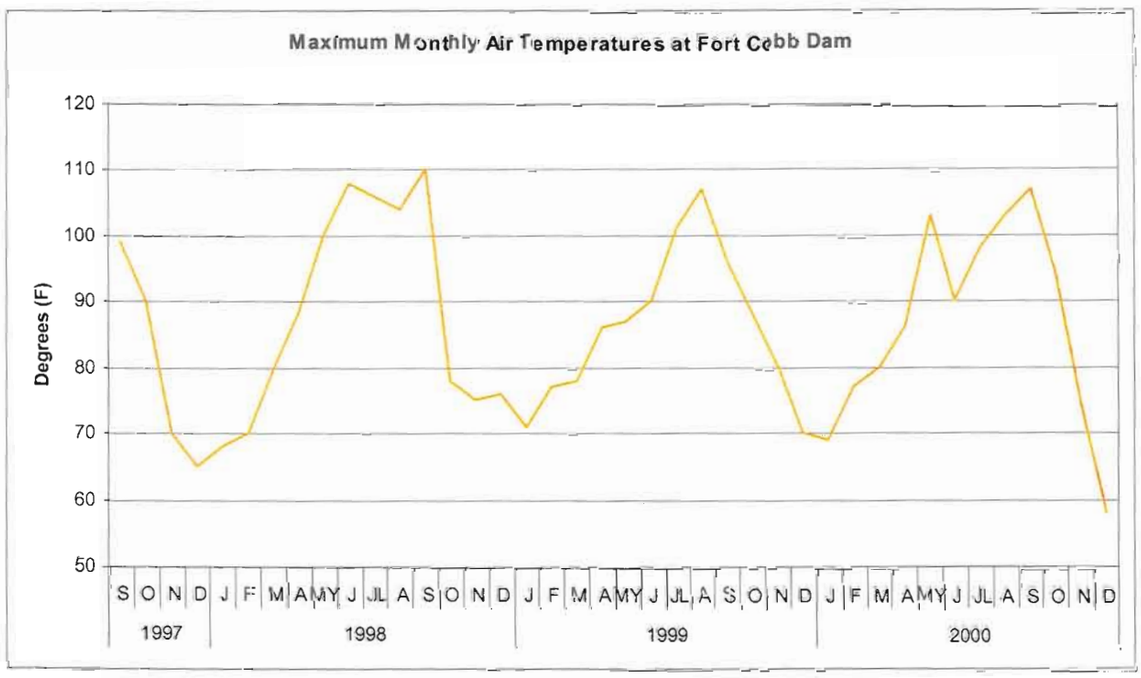


Figure 3. Annual cycles of mazimum air temperatures and rainfall at Fort Cobb Reservoir during the present study period.

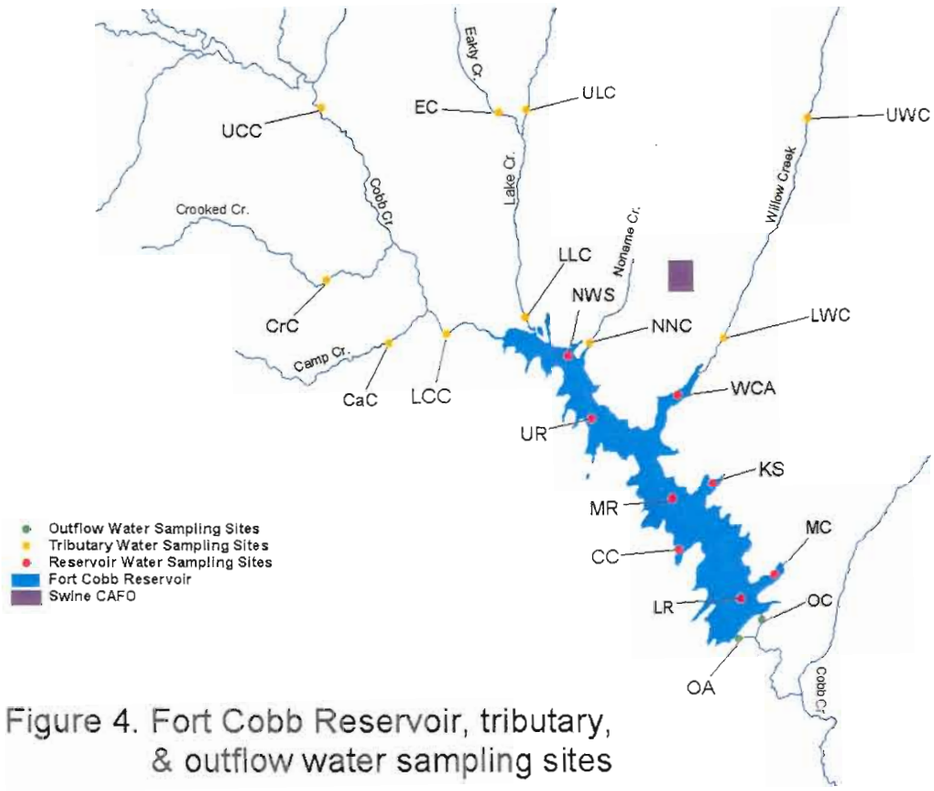


Figure 4. Fort Cobb Reservoir, tributary, & outflow water sampling sites

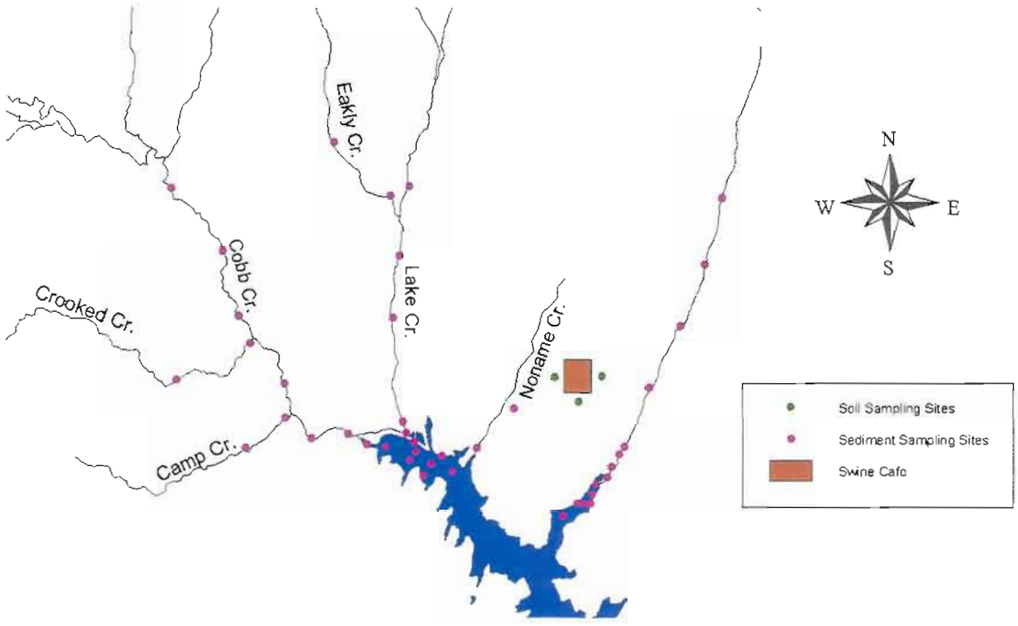


Figure 5. Watershed Soil and Tributary Sediment Sampling Points

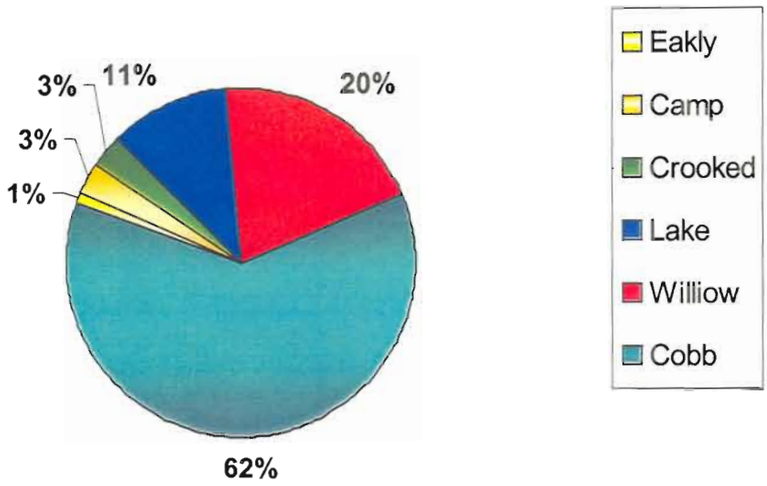


Figure 6. Average contribution of each tributary to total surface water inflow to Fort Cobb Reservoir based on instantaneous discharge measurements taken during base flow conditions

Table 1. Summary of Hydrologic and morphometric characteristics of tributaries to Fort Cobb Reservoir on dates that flow measurements were taken.

Location	Discharge (cfs)		Stream Width (ft)		Max Stream Depth (ft)
	Min	Max	Min	Max	
Cobb Cr.	8.3	90.6	24	27	2.0
Willow Cr.	3.4	21.2	9	20	1.2
Lake Cr.	4.0	10.1	11	14	1.4
Crooked Cr.	0.4	1.8	3	7	1.2
Camp Cr.	0.5	2.5	5	8	0.5
Eakly Cr.	0.0	0.4	0	2	0.3
Noname Cr.	0.0	0.2	0	1	0.2

III. METHODS

A. Tributaries

1. Water

Ten tributary stations were established for the purpose of sampling surface water quality directly upstream of Fort Cobb Reservoir (Table 2 & Figure 4). Two stations were located on each of the three primary tributaries (Cobb, Willow and Lake Creeks) in order to determine if there were significant changes in constituents between the upstream site and the point where each emptied into the reservoir. Two perennial tributaries to Cobb Creek (Crooked and Camp

Creeks), and one intermittent tributary to Lake Creek (Eakly Creek) were sampled to determine if they contributed significantly to any changes in water quality that might be observed between the upstream and downstream sites on the primary streams. One additional intermittent stream (Noname Creek) , that flowed directly into the reservoir, was sampled at the mouth because of it's potential hydrologic connection to a large swine CAFO located near it's source (Figure 4).

The water quality constituents measured at the tributary stations were divided into two groups, with each group having it's own sampling schedule. Samples for Water A (Table 3) were taken on 12 dates (Table 4), ostensively at quarterly intervals, but also on a schedule that would include every month of the calendar year during the study period. Hence, Water A sampling commenced on November 3, 1997 and ended on June 22, 2000. Water B samples (Table 3) were taken on 4 dates (Table 4), at intervals designated to include four seasons of the year.

Table 2. Samples sites on Fort Cobb Reservoir, its tributaries and outflows.

Abbreviation	Location	Latitude	Longitude
UWC	Upper Willow Creek	35 17' 28"	98 26' 23"
LWC	Lower Willow Creek	35 14' 06"	98 27' 53"
ULC	Upper Lake Creek	35 17' 28"	98 31' 47"
LLC	Lower Lake Creek	35 14' 51"	98 31' 49"
UCC	Upper Cobb Creek	35 17' 29"	98 35' 39"
LCC	Lower Cobb Creek	35 14' 04"	98 33' 12"
EC	Eakly Creek	35 17' 28"	98 31' 56"
CrC	Crooked Creek	35 17' 27"	98 35' 11"
CaC	Camp Creek	35 13' 60"	98 34' 12"
NNC	No Name Creek	35 13' 59"	98 30' 24"
OA	Outflow A	35 09' 29"	98 27' 24"
OC	Outflow C	35 10' 01"	98 26' 46"
NWS-S	Northwest Sector - Surface	35 13' 41"	98 30' 39"
UR-S	Upper Reservoir - Surface	35 12' 54"	98 30' 16"
UR-B	Upper Reservoir - Bottom	"	"
WCA-S	Willow Creek Arm - Surface	35 13' 07"	98 28' 51"
WCA-B	Willow Creek Arm - Bottom	"	"
MR-S	Middle Reservoir - Surface	35 11' 44"	98 28' 59"
MR-B	Middle Reservoir - Bottom	"	"
KS-S	Kardokas Slough - Surface	35 11' 55"	98 27' 54"
CC-S	Carnegie Cove - Surface	35 10' 46"	98 28' 37"
MC-S	Marina Cove - Surface	35 10' 29"	98 26' 47"
LR-S	Lower Reservoir - Surface	35 10' 15"	98 27' 38"
LR-B	Lower Reservoir - Bottom	"	"

Samples for Water A analyses were collected upstream of bridges (well above the redneck trash throwing limit) by wading into the stream and filling a narrow mouth, chemically-cleaned, glass container (I-CHEM 249-1000) by hand. The mouth of the container was held in the current a few inches below the surface, rinsed three times with sample water, then filled leaving just enough head space to allow mixing. Immediately following water sample collection, temperature and pH were measured *in situ* using a Cole-Parmer, Model 8110-20 thermistor thermometer and an Oakton, Model pHTestr2, waterproof pH meter with sealed combination electrode.

Water B samples were collected from the same locations as Water A, using methods outlined in Section 8.2.8 of the Environmental Protection Agency's "Method 1669:Sampling Ambient Water for Trace Metals at EPA Water Quality Criteria Levels" (Telliard, 1995). One filtered (for "dissolved") and one unfiltered (for total recoverable) sample was collected from just below the surface in mid-stream, using a battery- powered peristaltic pump, tubing, and an in-line 0.45 micron membrane filter. One glass (for mercury) and one polyethylene bottle was filled
for each sample. A complete set of pre-cleaned and appropriately sealed equipment required for each sampling site was received from the analytical laboratory prior to the sampling trip. At each site, the equipment was removed from the sealed containers, water was pumped directly from the stream into the sample containers (first with, then without, the in-line filter) using adequate flushing and rinsing, and the containers were closed and resealed. Samples were returned to the analytical laboratory without further handling.

Table 3. Constituents analyzed in water, soil, sediment and fish samples.

Water A			
	Conductivity	Total Phosphorus	Total Nitrogen
	Turbidity	Soluble Reactive Phosphorus	Nitrate - N
	Chlorophyll a	Total Alkalinity	Nitrite - N
	Chemical Oxygen Demand	Chloride	Ammonia - N
		Sulfate	
Water B *			
	Calcium	Silica	Boron
	Magnesium	Arsenic	Vanadium
	Sodium	Copper	Cadmium
	Potassium	Zinc	Molybdenum
	Manganese	Selenium	Mercury
	Aluminum	Nickel	Cobalt
	Iron	Lead	Silver
	Barium	Chromium	Antimony
	Strontium		
	* Total and dissolved concentrations were determined for each element.		
Soil/Sediment			
	Nitrogen	Iron	Chromium
	Phosphorus	Barium	Boron
	Total Organic Carbon	Strontium	Vanadium
	Grain Size (clay, silt, sand)	Sulfur	Cadmium
	Calcium	Arsenic	Molybdenum
	Magnesium	Copper	Mercury
	Potassium	Zinc	Cobalt
	Manganese	Selenium	Lead
	Aluminum	Nickel	Beryllium
Fish			
	Phosphorus	Arsenic	Vanadium
	Magnesium	Copper	Cadmium
	Manganese	Zinc	Molybdenum
	Aluminum	Selenium	Mercury
	Iron	Nickel	Beryllium
	Barium	Lead	
	Strontium	Chromium	
	Sulfur	Boron	

Once collected, samples for Water A analyses were transported to the laboratory where aliquots were filtered through Whatman GF/C glass-fiber filters. Filters were placed in 13x1.5 cm tissue culture tubes and 90% acetone added for chlorophyll extraction. Subsequent analyses for ammonia-N, nitrite-N, nitrate-N, soluble reactive phosphorus (SRP), chloride and sulfate were performed on the filtrate, while total-N, total-P, chemical oxygen demand (COD), turbidity, conductivity and total alkalinity were performed on the remaining unfiltered sample. The filtering apparatus and filtrate containers were acid-cleaned prior to use and rinsed with sample before filling.

Table 4. Water quality sampling dates on Fort Cobb Reservoir, tributaries and outflows.

	Dates	Tributaries	Reservoir	Outflows
Water A				
	1997	11/3	11/13	11/3
	1998	2/10	2/23	2/23
		5/2	5/13	5/13
		8/3	8/11	8/3
		10/29	10/23	10/29
	1999	1/4	1/11	1/4
		4/20	4/6	4/20
		7/12	7/23	7/12
		9/11	9/21	9/11
		12/13	12/6	12/13
	2000	3/15	3/9	3/15
		6/22	6/15	6/22
Water B				
	1998	1/15	-	1/15
		7/21	-	7/21
	1999	4/20	-	4/20
		10/19	-	10/19

Water A analyses generally followed methods outlined in "Standard Methods for the Examination of Water and Wastewater" (Greenberg *et al.,* editors, 1992). Total alkalinity was determined by titrating a 100 ml sample with 0.10N sulfuric acid to a pH 4.5 end point utilizing a Cole-Parmer Model 5996-80 pH meter with a sealed combination electrode. This pH meter, as well as the Oakton Model pHTestr2 used *in situ,* was calibrated before each use using Cole-Parmer standard buffer solutions of pH 4.01, 7.00 and 10.00. Conductivity was determined with a Cole-Parmer Model 1500-32 conductivity meter equipped with a matching 1500-60 probe. The instrument was standardized before each use with solutions of 445 and 700 micromhos. Turbidity was measured with a HACH Model 2100P Turbidimeter, calibrated according to the instruction manual with HACH stabilized formazin standards (Sadar, 1996a, 1996b, 1997). Chlorophyll a concentrations were calculated by the "trichromatic method" using optical density measurements obtained on 10 ml 90% acetone extracts , using a 1.0 cm light path. The

spectrophotometer used for chlorophyll analysis, and for all colorimetric and turbidimetric procedures in this study, was a HACH Model DR/3000. The barium chloride, turbidimetric method was used to measure concentrations of sulfate. A calibration curve, that spanned the range of concentrations encountered, was used to convert the optical density readings obtained with HACH SulfaVer 4 reagent. All colorimetric procedures, whether using HACH proprietary reagents or reagents prepared in our laboratory, were run using calibration curves made from freshly prepared standard solutions. Chemical oxygen demand (COD) was determined by measuring the color change in a standard potassium dichromate solution following a 2-hour digestion in a closed micro-reactor (Gibbs, 1993). Chloride was determined by titrating a 100 ml sample with 0.0141N mercuric nitrate using diphenylcarbazone as an end point indicator. Soluble reactive phosphorus (SRP) was measured using the ascorbic acid (combined reagent) method. Samples for total phosphorus (Total-P) were digested for 30 min. in a pressure cooker at 15 psi in a mixture of sulfuric acid and potassium persulfate. Following pH and volume adjustment, the digest was analyzed for SRP as described above. A direct colorimetric method, utilizing ammonia salicylate and ammonia cyanurate reagents, was used to determine ammonia-nitrogen (ammonia-N). Nitrite-nitrogen (nitrite-N) was also determined colorimetrically by the diazotization method. For nitrate-nitrogen (nitrate-N) analysis, cadmium was used to quantitatively reduce nitrate to nitrite in the sample, followed by analysis of the latter by diazotization. An alkaline persulfate digestion was used to convert all forms of nitrogen in a sample to nitrate-N. This was followed by the chromotropic acid determination of nitrate-N, resulting in an estimate of total-nitrogen (Total-N). HACH reagents and standards were used in the determination of all nitrogen forms.

All Water B analyses were performed by the Trace Element Research Laboratory (TERL), Department of Oceanography, College of Geosciences, Texas A&M University. This laboratory is under contract with the U.S. Fish and Wildlife Service, and as such, is required to adhere to strict standards of analytical methodology and quality assurance/quality control procedures. The Patuxent Analytical Control Facility, Patuxent Wildlife Research Center, U.S. Geological Survey-Biological Resources Division, is responsible for the scientific oversight of this and other contract laboratories. Complete descriptions of analytical procedures are available upon request from either of these sources; what follows is intended as a brief overview of analytical methods. Digestion of water samples for "total recoverable metals" (other than mercury) involved a two-hour digestion at 85 degrees Centigrade in polyethylene containers with ultrapure nitric and hydrochloric acids at a ratio of 0.5% and 1.0%, respectively. Samples for "total recoverable mercury" were digested with nitric acid, sulfuric acid, potassium permanganate and potassium persulfate in polypropylene tubes in a water bath at 90-95 degrees Centigrade. Sample aliquots for digestions were taken after vigorous shaking of the original sample bottles to assure resuspension of solids that may have settled. Filtered samples, and digests of unfiltered samples, were analyzed for various elements by inductively coupled plasma optical emission spectroscopy (Ba, Ca, Fe, K, Mg, Na, S, Si), atomic fluorescence spectroscopy (As, Hg, Se), or inductively coupled plasma-mass spectroscopy (Ag, Al, B, Be, Cd, Co, Cr, Cu, Li, Mn, Mo, Ni, Pb, Sb, Sr, V, Zn).

2. Sediment/Soil

Forty-two sediment samples were taken from Fort Cobb Reservoir tributaries for chemical analysis on June 2, 3 and 4, 1999. In each primary tributary (Cobb, Lake and Willow

Creeks), samples were taken at intervals along their longitudinal axis, beginning at the upstream water-sampling station and terminating at a point well into the reservoir (Figure 6). The purpose for this sampling scheme was to provide a transect in each stream that ran from the sandy substrates of the flowing water sites, through the alluvial deposits at the mouth of each stream, and out into the fine-grained substrates of the reservoir. Two samples were also taken from each of the small streams.

Samples of the upper 5-cm of substrate were collected by hand into 1000 ml, certified-clean, wide-mouth, polyethylene containers (I-CHEM, 311-1000). At the shallow (<2.0 ft.), flowing water sites, samples were taken by wading into the deepest portion of the stream and scraping the substrate into the jar with the lid. At the deepest (10 - 15 ft.) reservoir sites, samples were obtained in a similar manner by snorkeling.

Soil samples were taken from the vicinity of the large swine CAFO (Figure 6) on two occasions, June 4, 1999 and January 17, 2000. On each date, two surface samples (0-5 cm) were taken from the west, south and east fencelines of the quarter-section occupied by the swine facility and it's waste application field (SW¼, sec 16, T.9N, R.12W). Soils in this area are classified as Eufaula fine sand, rolling (EfD) and Konawa loamy fine sand, 1 to 5 percent slope, eroded (KoC2). The former is considered unsuitable for cultivation, while the latter is listed as useful for cotton, peanuts, small grains and sorghum (Moffatt, 1973). All fields adjacent to the fencelines sampled were (or recently had been) under cultivation.

Sediment and soil samples were cooled (not frozen) and shipped to TERL for the analyses listed in Table 3. Samples were homogenized at the laboratory and unusual objects such as sticks, leaves and large stones were removed. Moisture content was determined by weight loss upon freeze drying and reported as percent of the original wet sample weight. Total organic carbon (TOC) was determined by combustion in an oxygen atmosphere with subsequent measurement of the carbon dioxide produced by an infrared detector. Analysis of grain size distribution incorporated wet-sieving and the pipette method to separate samples into sand, silt and clay fractions. Nitrogen was determined colorimetrically after digestion of freeze dried samples. Samples for remaining elemental analysis (except mercury) were wet digested with 1:4 v:v nitric:hydrochloric acids (Aqua Regia) and converted into acidic digest solutions for analysis by various atomic spectroscopy methods. As and Se were analyzed using atomic fluorescence spectroscopy. Cd and Pb were determined by graphite furnace atomic absorption spectroscopy. Inductively coupled plasma optical emission spectroscopy was used for Al, B, Ba, Be, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Ni, P, S, Sr, V and Zn. Samples for mercury analysis were digested with nitric acid, sulfuric acid, potassium permanganate and potassium persulfate in a water bath at 90-95°C. Digests were then analyzed by cold-vapor atomic absorption spectroscopy.

3. Bacteria

Samples for bacterial testing were taken from the 10 tributary sampling stations (Figure 4) on seven occasions between June 8, 1998 and April 10, 2000. Samples were collected from just below the stream surface by inverting a sterile bottle (HACH 24950), plunging it into the stream, letting it fill underwater to the 100 ml. mark, and replacing the cap (Greenberg *et al.* eds., 1992). HACH PathoScreen® medium was added aseptically to each bottle within 12 hours of collection and the mixture incubated in a water bath at 30 °C. The reaction in each bottle was

noted after 24 and 48 hours. The PathoScreen® procedure (Manja *et al.,* 1982) is a Presence/Absence test for hydrogen sulfide-producing bacteria, which have been shown to be associated with fecal contamination and total coliform bacteria (Kromoredjo and Fujioka, 1991). Unlike most other bacterial screening tests, the PathoScreen® test is simple and reliable to use in the field (Grant and Ziel, 1996).

4. Quality Assurance/Quality Control

The purpose of Quality Assurance/Quality Control (QA/QC) is to insure the validity and/or assess the limitations of the data collected during the course of a study. There are three concerns regarding the quality of chemical data, *i.e.* precision, accuracy and contamination of samples during collection, handling and analysis. We used field duplicates to assess the precision of field sampling and laboratory duplicates to assess analytical precision. At least one field and laboratory duplicate was included for each constituent analyzed for each Water A and Water B sampling trip. Laboratory duplicates were analyzed for each soil/sediment constituent, but no field duplicates were included in the sample set. Accuracy was evaluated by analyzing standards, and in the case of selected Water A constituents, also by splitting samples with the Oklahoma City/County Health Department Laboratory in Oklahoma City, Oklahoma. Standards were included with every batch of Water A and Water B samples analyzed. These were separate and independent from the ones used to calibrate or standardize an instrument or analytical procedure. Where available, certified soil and sediment standards were used for sediment/soil analytes. Possible sample contamination during collection and handling was determined by the use of field blanks. Reagent blanks were used to detect contamination during analysis. One set of field blanks was included with each Water A and Water B sampling trip; an initial blank at the outset of sampling and a terminal blank at the end. Field blanks were carried through every step of the sampling and handling procedures, came in contact with the same equipment as the samples, and were analyzed as part of the sample set. One reagent blank was used for each analytical procedure for each sampling trip. Field blanks are not practical for soil/sediment sampling but procedural blanks were included for every elemental soil/sediment analyte.

B. Outflows

1. Water

Two outflow stations (Table 2 & Figure 4) were established for the purpose of sampling the quality of water as it leaves Fort Cobb Reservoir en route to the cities of Anadarko (Outflow A) and Chickasha (Outflow C). Water for Outflow A leaves the reservoir via an outlet located near the southwest end of the dam, while water for Outflow C is drawn from a small cove on the opposite (northeast) side of the reservoir. Samples for Water A and Water B analyses (Table 3) were taken on the dates shown in Table 4 from small (1-inch) hydrants attached directly to the main pipelines. When taking samples, the hydrants were allowed to run for at least 15 minutes in order to flush the entire 1-inch line before filling the sample containers. Temperature and pH were taken directly from the hydrants immediately following collection of the water samples. These measurements, and other methods pertaining to sample collection, handling and analysis are the same as those described in Section III.A.1.

2. Bacteria

Samples for bacterial testing were taken from Outflow A and C hydrants on the same dates that the tributaries were sampled. See Section III.A.3 for a description of equipment and procedures used.

3. Quality Assurance/Quality Control

Outflow samples were included as part of each Water A or Water B sample set and as such are subject to the QA/QC procedures described in Section III.A.4.

C. Reservoir

1. Water

Eight stations were established for the purpose of sampling water quality in Fort Cobb Reservoir (Table 2 & Figure 4). Four of the stations (Northwest Sector, Upper Reservoir, Middle Reservoir and Lower Reservoir) were located about equidistant along the main axis of the reservoir from the headwaters to the dam, while the other four (Willow Creek Arm, Kardokas Slough, Carnegie Cove and Marina Cove) were chosen to represent the largest embayments. Samples for Water A analyses (Table 3) were collected from the surface at each station with a Wildco®, 3-liter, PVC water bottle. Temperature and pH of the surface water were measured *in situ* with the same equipment previously described for the tributary and outflow stations. In order to provide a vertical as well as horizontal dimension to the water sampling, the water bottle was used to collect samples for Water A analyses at a depth of 1-meter from the bottom at the Willow Creek Arm, Upper Reservoir, Middle Reservoir and Lower Reservoir sites. Dates for reservoir Water A sampling are in the same months as those for tributary Water A, and no samples were taken for Water B analyses (Table 4). From the point of collection with the water bottle, all subsequent methods for sample handling and analysis were the same as those described in Section III.A.1.

2. Sediment

Sixteen reservoir sediment samples were taken from the vicinity of the eight water sampling sites (Figure 4) for chemical analysis on January 17, 2000. A Wildco®, stainless steel core sampler, fitted with a Lexan insert and nosepiece, was lowered from a boat and allowed to penetrate the substrate to a depth of several centimeters. Upon retrieval, the upper 5-cm of sediment was removed from the liner and placed in a 1000-ml, certified-clean, wide-mouth, polyethylene container (I-CHEM, 311-1000). Subsequent handling and analysis of sediment was performed according to methods described in Section III.A.2.

3. Fish

Three species of fish, each representing a different ecological niche in the reservoir food-web, were captured from shoreline areas along the entire length of the reservoir, and analyzed for whole-body elemental content (Table 3). Channel catfish (*Ictalurus punctatus*), common carp (*Cyprinus carpio*) and walleye (*Stizostedion vitreum*) were taken from overnight gill net sets on May 31, 2000. Six individuals of each species were weighed and measured in the field, wrapped in aluminum foil, placed on ice, and frozen later that same day at the locker plant in Fort Cobb, Oklahoma. Frozen fish were sent to TERL where they were ground, homogenized and aliquots removed for analysis. Powdered, homogenized tissue was weighed into closed, Teflon reaction vessels where it was digested with nitric acid at 130 C. Digests were later analyzed for most elements by inductively coupled plasma optical emission spectroscopy (ICP). Exceptions were As, Cd and Pb which were analyzed by graphite furnace atomic absorption spectroscopy, Se by atomic fluorescence spectroscopy, and Hg by cold-vapor atomic absorption spectroscopy.

4. Limnology

Twelve synoptic, limnological surveys were conducted on Fort Cobb Reservoir between January 28, 1998 and December 14, 2000. As in the case of Water A sampling, the surveys were ostensively carried out at quarterly intervals, however the schedule was adjusted in order that every month of the calendar year was represented during the study period.

Vertical profiles of temperature (°C), conductivity (micromhos/cm) and dissolved oxygen (% saturation) were taken on each survey at the eight water sampling stations (Figure 4) by lowering a Hydrolab MinniSonde® from the surface to the bottom of the reservoir and recording the data at 1-meter intervals on a Hydrolab Surveyor® 4. All readings were taken on the same day, and the Hydrolab system was calibrated according to instructions in the User's Manual immediately prior to use.

Vertical profiles of ambient, visible light (≈425-665 nanometers) were taken on each survey at the eight water sampling stations (Figure 4) using a KAHLSICO Model 268WD305 underwater irradiameter and matching deck cell. Voltage input to the system was carefully monitored, and the instrument was zeroed prior to use, according to the operating instructions. Paired instantaneous readings, of light incident to the water surface and at depth, were taken at 1-meter intervals from the water surface to a depth where incident light was reduced to less than 1%. All readings were taken in duplicate, on the same day, under clear skies, in direct sunlight, between 1000 and 1400 hours Central Standard time. Paired readings were used to calculate the *in situ* extinction coefficient (η) from the expression $\ln I_0 - \ln I_z = \eta z$, where I_0 and I_z are light intensity at the surface and at depth z, respectively (Wetzel and Likens, 2000).

Vertical profiles of phytoplankton photosynthesis and community respiration were taken at four of the water sampling stations (Upper Reservoir, Willow Creek Arm, Middle Reservoir and Lower Reservoir) during each survey. Duplicate composite samples of surface water (0-3 m) were collected with a 3-inch PVC pipe (fitted with a ball valve at the lower end), placed in 5-gallon, plastic, water coolers, and mixed thoroughly. A series of initial, light and dark, 300 ml, BOD bottles was filled with water from each cooler, taking care to exclude all air bubbles before stoppering. Initial bottles were immediately "fixed" for dissolved oxygen (DO) measurements using the azide modification of the Winkler technique (Greenberg *et al.*, 1992). Light bottles were suspended in the reservoir at depths of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 and 4.0 meters for 24

hours, while dark bottles were placed in light-proof containers and incubated at the same location for the same time period. A discussion of the light and dark bottle methodology, using changes in DO concentrations, can be found in Wetzel and Likens (2000). Phytoplankton standing crop in each of the composite samples at the beginning of the light/dark bottle experiments was estimated by determining concentrations of chlorophyll a (See Section III.A.1) and by direct microscopic cell/colony counts of subsamples taken from the cooler at the time light and dark bottles were filled. Samples for microscopic examination were preserved in the field with Lugol's solution and later submitted to Dr. Robert Lynch, Health Sciences Center, Department of Occupational and Environmental Health, University of Oklahoma, for phytoplankton identification and enumeration. Values of phytoplankton standing crop and metabolic rates are averages of duplicate samples.

5. Bioassays

Nutrient enrichment bioassays were conducted on nine occasions between June 7, 1998 and August 6, 2000 at the Lower Reservoir water sampling station (Figure 4). The bioassays were designed to: (1) determine qualitatively if nitrogen, phosphorus, light, or any combination of these, were limiting to phytoplankton productivity, and if so, to define the seasonal aspect of such limitation; and (2) estimate semi-quantitatively the potential effect that increased additions of individual nutrients would have on phytoplankton standing crop and productivity.

Duplicate composite samples of surface water (0-3 m) were taken with the PVC pipe and ball sampler, placed in 5-gallon, plastic, water coolers and mixed. Four 2-liter, clear, glass jugs were filled from each cooler and designated as follows: (1) Control - nothing added; (2) Nitrogen Treatment - 1000 ppb NO_3-N added as KNO_3; (3) Phosphorus Treatment - 400 ppb PO_4-P added as $KH_2\ PO_4$; and (4) Nitrogen + Phosphorus Treatment - 1000 ppb NO_3-N and 400 ppb PO_4-P added. Following the nutrient additions, jugs were stoppered and suspended in the reservoir at a depth of 0.5 m for 4 days. Additional samples were taken from the coolers on Day-0 to determine initial concentrations of chlorophyll, SRP, total soluble N and turbidity. On Day-4, initial, light and dark bottles were filled with water from each jug. Light and dark bottles were suspended in the reservoir at 0.5 m for 24-h, where, following removal, respiration and gross photosynthesis were determined for each treatment using changes in DO. Samples were taken from each treatment jug on Day-4 to determine changes in chlorophyll, SRP, total soluble N and turbidity that occurred during the 4-day *in situ* incubation. Methods for all analyses are the same as those previously described in Section III.A.1 and III.C.4.

6. Quality Assurance/Quality Control

QA/QC procedures for Water A and sediment samples have been previously described in Section III.A.4. Procedural blanks - to detect contamination of samples during laboratory handling and analysis, laboratory duplicates - to estimate analytical precision, and standard reference materials - to evaluate analytical accuracy, were all used in conjunction with the fish sampling. QA/QC for data taken during the limnological surveys and bioassays consisted of strict adherence to manufacturer's recommendations for maintenance and calibration of instrumentation and additional instructions relative to specific methodologies.

D. General

Statistical analyses of data collected during all phases of this study followed methods described by Steel and Torrie (1960) and were performed on a 32 MB PC using SYSTAT® 9 software for Windows. Comparisons of means between two groups of data (*e.g.* surface *vs* bottom or upstream *vs* downstream) employed Student's *t* test. Comparisons involving more than two groups of data (*e.g.* elemental concentrations in three fish species) utilized an Analysis of Variance followed by Tukey's *hsd* procedure. Correlations between two variables (*e.g.* elemental concentrations *vs* organic matter in sediment) were determined by calculating Pearson's coefficient, *r*. Unless otherwise noted, the word "significant" in this report refers to a statistical probability of less than 0.05.

IV. RESULTS AND DISCUSSION

A.Tributaries

1. Water

Sampling precision, as shown by the results of duplicate samples (Appendix A-1), can be viewed in two ways. First, there is an *absolute* difference that can be expected from two samples, taken either from the same bottle in the laboratory or from the same site, at the same approximate time, in the field. Second, there is a *relative* difference between the same two samples that is expressed as the absolute difference divided by the mean of the two samples. This is usually expressed as the RPD or relative percent difference. Both views are instructive and should be considered when evaluating the precision of laboratory and field sampling. For example, when ambient concentrations of any constituent are near the detection limit of the method employed, relatively minor absolute differences will result in rather large relative differences. This can be illustrated with the data for nitrite-nitrogen. The test for nitrite-N has a detection limit of 1 ppb. Often times, ambient concentrations of nitrite-N are relatively low, in the neighborhood of 1-10 ppb. Therefore, the average RPD for a series of duplicate nitrite-N samples may be fairly high, when in fact the absolute differences were relatively minor. A similar situation exists with a number of the trace elements. In short, to evaluate overall precision for a constituent, the range of concentrations included in the duplicate sample set should represent the range of concentrations in the field data, which in turn must be compared to the limits of detection for that constituent. In theory, the difference between the means of the laboratory duplicates and the field duplicates would be the "real" sampling error. This value represents the real difference one can expect when sampling a particular constituent in the field. It can also be noted that sampling for "total" constituents is not generally as precise as that for their "dissolved" counterparts. This supports the notion that suspended particulate matter is not homogeneously distributed in the water column.

Analytical accuracy for each Water A and Water B constituent is summarized as the percent recovery from the standards that were run with each batch of samples (Appendix A-2). In most cases, the 95% confidence interval was within or very near the range of 90%-110%

recovery, a range we consider to be satisfactory. The only noteworthy exceptions involved three of the four nitrogen determinations. Both nitrate and nitrite nitrogen would appear to be underestimated by as much as 15 to 20 percent in this study, while total nitrogen may be overestimated by as much as 10 or 15 percent. No adjustments to the nitrogen data have been made; they are reported as analyzed.

Contamination of samples during collection, handling and analysis appeared to be minimal with respect to Water A and Water B analytes. Mean concentrations in both initial and terminal field blanks were below or very near the detection limits of all constituents with the exception of arsenic and zinc (Appendix A-2). The mean values shown for zinc were greatly influenced by only one sampling trip in which values were above detection limits. As for arsenic, both initial and terminal blanks appeared to be significantly contaminated on every sampling trip. While we are uncertain where this contamination might have occurred, we recommend that the arsenic data (for water) in this report be regarded with caution.

Tributary temperatures ranged from a January, 1999 low of 1.2 °C on upper Cobb Creek to a high of 32.7 °C on upper Lake Creek in August, 1998 (Appendix B-1). The temperature range among tributary stations on any given sampling date was greatest throughout the summer, while monthly means followed a relatively smooth seasonal pattern (Figure 7). Temperatures tended to increase slightly from the upstream to downstream stations at all times of the year in Willow, Lake and Cobb Creeks. Because of the broad, shallow morphology of the tributaries, air temperature and solar radiation are important factors influencing short-term spatial and temporal water temperature variations.

Conductivity is a good indicator of the total concentration of dissolved inorganic constituents in a water sample. Tributary values ranged from 267 micromhos/cm in upper Willow Creek on 9/11/1999 to 842 micromhos/cm in lower Cobb Creek on 11/03/1997 (Appendix B-2). The low in Willow Creek occurred during a period of high flow and significant surface runoff, following a localized rainfall event. It will be noted in later discussions that this particular sample is somewhat of an outlier with respect to several other constituents. Overall, there was a significant increase in conductivity, averaging 100 micromhos/cm, between the upper and lower stations in Willow Creek (Figure 8), indicating an increase of ionic constituents to this stream from either groundwater or a surface water source. No significant difference was found between the upper and lower stations in Lake or Cobb Creeks (Figure 8). It should also be noted for future reference, that Cobb Creek has markedly higher conductivities than any other tributary in the Fort Cobb Reservoir watershed.

Chemical oxygen demand (COD) is used as a relative indicator of the total organic matter content of a sample, and may include both dissolved and particulate fractions. Upper Willow, lower Lake, Crooked and Camp Creeks all had COD values below the detection limit of 1 ppm on one or more occasions, while a maximum COD of 40 ppm occurred in August, 1998 in upper Lake Creek (Appendix B-3). There were no significant differences between upper and lower stations in Willow, Lake or Cobb Creeks (Figure 8), due in part to the large variations in concentrations in upper Willow and Lake Creeks. Crooked and Camp Creeks appear to be consistently lowest in organic matter content, whereas Lake and Noname are highest.

Turbidity is often intuitively viewed as the opposite of clarity. Specifically, it is an

expression of the optical property of water that causes light to be scattered and absorbed rather than transmitted in a straight line. It is caused by suspended matter which may be inorganic or organic, living or non-living. Turbidity values at tributary stations ranged across three orders of magnitude, from a low of 2.1 NTU in Camp Creek on 4/20/1999 to a high of >2,000 NTU on 9/11/1999 in upper Willow Creek (Appendix B-4). The latter value was associated with the rainfall induced, high water event mentioned previously. Although this value is somewhat atypical in our data set, it is probably representative of conditions that occur more frequently throughout the year in this watershed. Hard rains, followed by heavy surface runoff and localized flooding are fairly common in this area, even though we did not encounter these conditions but once during our tributary sampling. It should be noted that the high turbidity we encountered at upper Willow Creek in September, 1999 prevented us from performing several of our other routine analyses on this sample. If one considers the turbidities we encountered in tributaries on a logrithmetic scale, the majority (55%) fall in the range 10-100 NTU. Thirty seven percent range from 1-10 NTU and 8% were greater than 100 NTU. It is probably safe to conclude that the values from this study are representative of turbidities in each of the tributaries during low or base flow conditions.

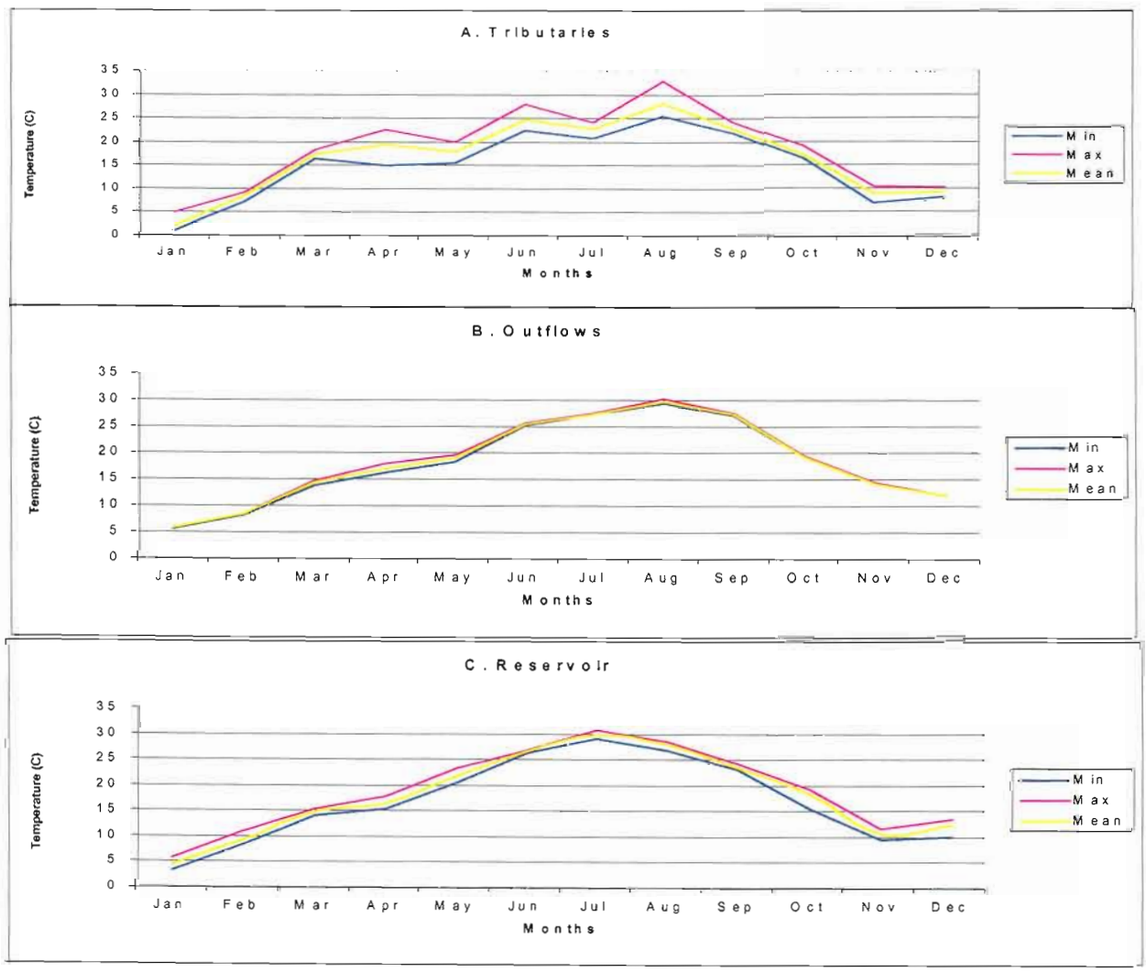


Figure 7. Water temperatures in trubutaries (A), outflows (B), and Fort Cobb Reservoir (C).

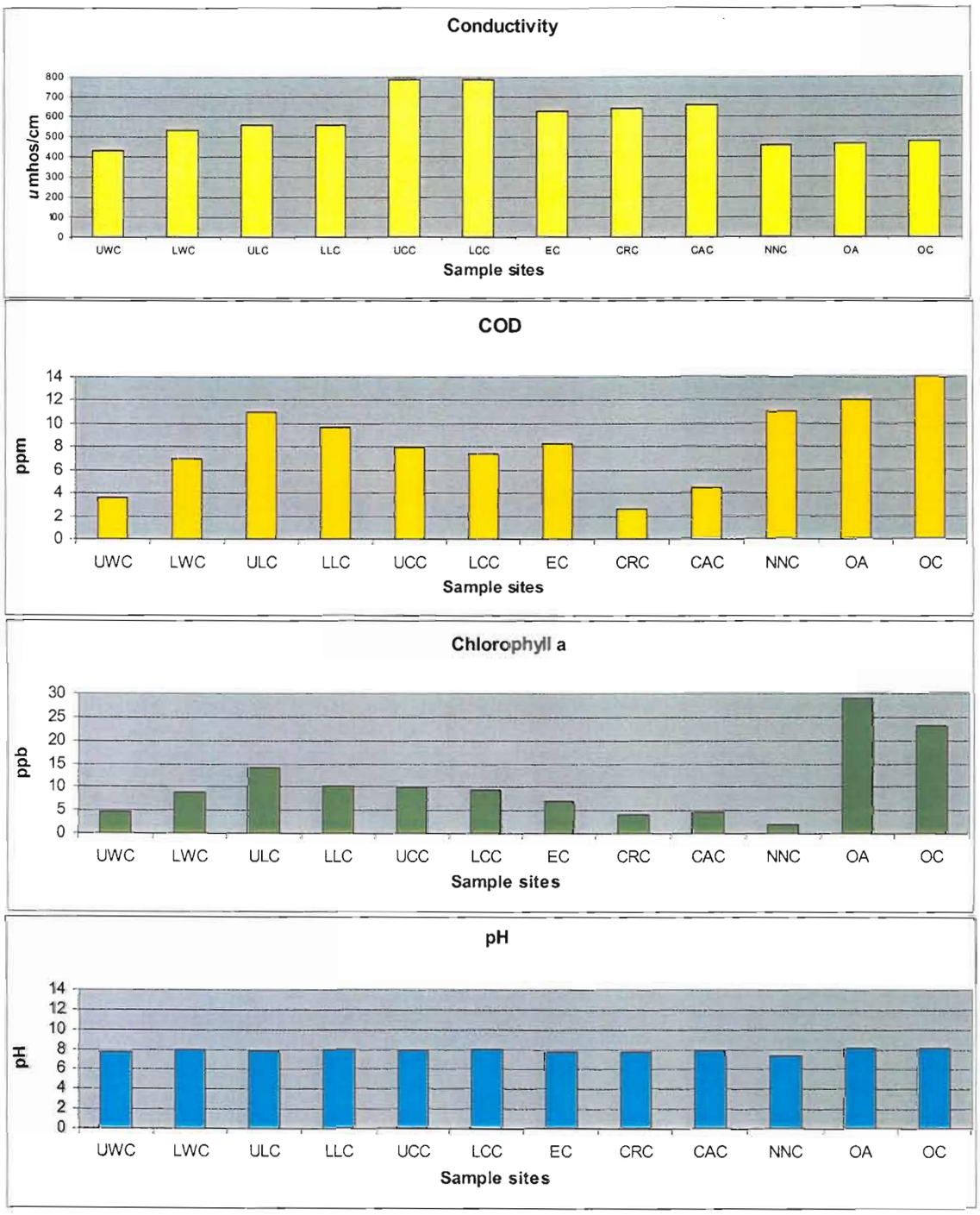


Figure 8. Mean conductivity, pH, COD, and chlorophyll a concentrations at each tributary and outflow sampling station.

All green plants contain chlorophyll a, hence it's extensive use as an indicator of phytoplankton biomass in aquatic studies. In stream environments, chlorophyll measurements include not only phytoplankton, but also dislodged periphyton and fragments of higher plants that may be carried along by the current. Chlorophyll a ranged from less than 0.2 ppb in Noname Creek on 12/13/1999 to 33 ppb in upper Lake Creek on 9/11/1999 (Appendix B-5). There was a significant increase from upper to lower Willow Creek, while upper and lower Lake and Cobb Creeks were not significantly different (Figure 8). The smaller, spring-fed tributaries (Crooked, Camp and Noname Creeks) were consistently lowest (< 10 ppb) in chlorophyll concentrations.

Since pH is a logrithmetic expression, the "average" values shown in Figure 8 represent in fact geometric means of the hydrogen ion concentration at the various tributary locations. pH ranged between 7.0 in both Crooked and Noname Creeks to 8.7 in lower Lake Creek (Appendix B-6). There was no significant difference in pH between the upper and lower stations on Willow, Lake or Cobb Creeks. There appeared to be a tendency for all stations to exhibit either a "high" or "low" pH, depending on the sampling date. Since pH can be influenced by the removal or addition of carbon dioxide, it is consequently affected by the history of photosynthesis and/or respiration in the system. For example, the series of low pH values observed on 12/13/1999, may have followed a period of high respiration and low photosynthesis, whereas the measurements on 10/29/1998 may reflect the opposite conditions.

All tributaries exhibited the same relative composition with respect to the major cations, calcium, magnesium, sodium and potassium (Figure 9). There was no significant difference between the total and dissolved fractions of these four elements, therefore concentrations have been combined and treated the same for all purposes. Based on concentrations expressed as milliequivalents per liter (meq/L), calcium was the predominant cation at all stations, ranging between 46% (Noname Creek) and 72% (Crooked Creek) of the total. Magnesium was second at all stations (range 15% to 33%), followed by sodium (11% to 19%). Potassium was not abundant, ranging from less than 1% at Crooked Creek to 2% of the total in Noname Creek. There was a significant difference in calcium, magnesium and sodium concentrations between upper and lower Willow Creek (Figure 10). This accounts for the increase in conductivity between the two stations that was noted earlier. There was little difference between the upper and lower stations on Lake and Cobb Creeks with respect to any of the major cations; however, as seen in Figure 10, marked differences in cations did exist among various tributaries. Cobb Creek was consistently highest in calcium (Appendix C-1), magnesium (Appendix C-2) and sodium (Appendix C-3), a condition that was reflected in the conductivity measurements as mentioned earlier. Potassium concentrations were about an order of magnitude lower than the other three major cations, and appeared to be more randomly distributed among all the tributaries (Appendix C-4).

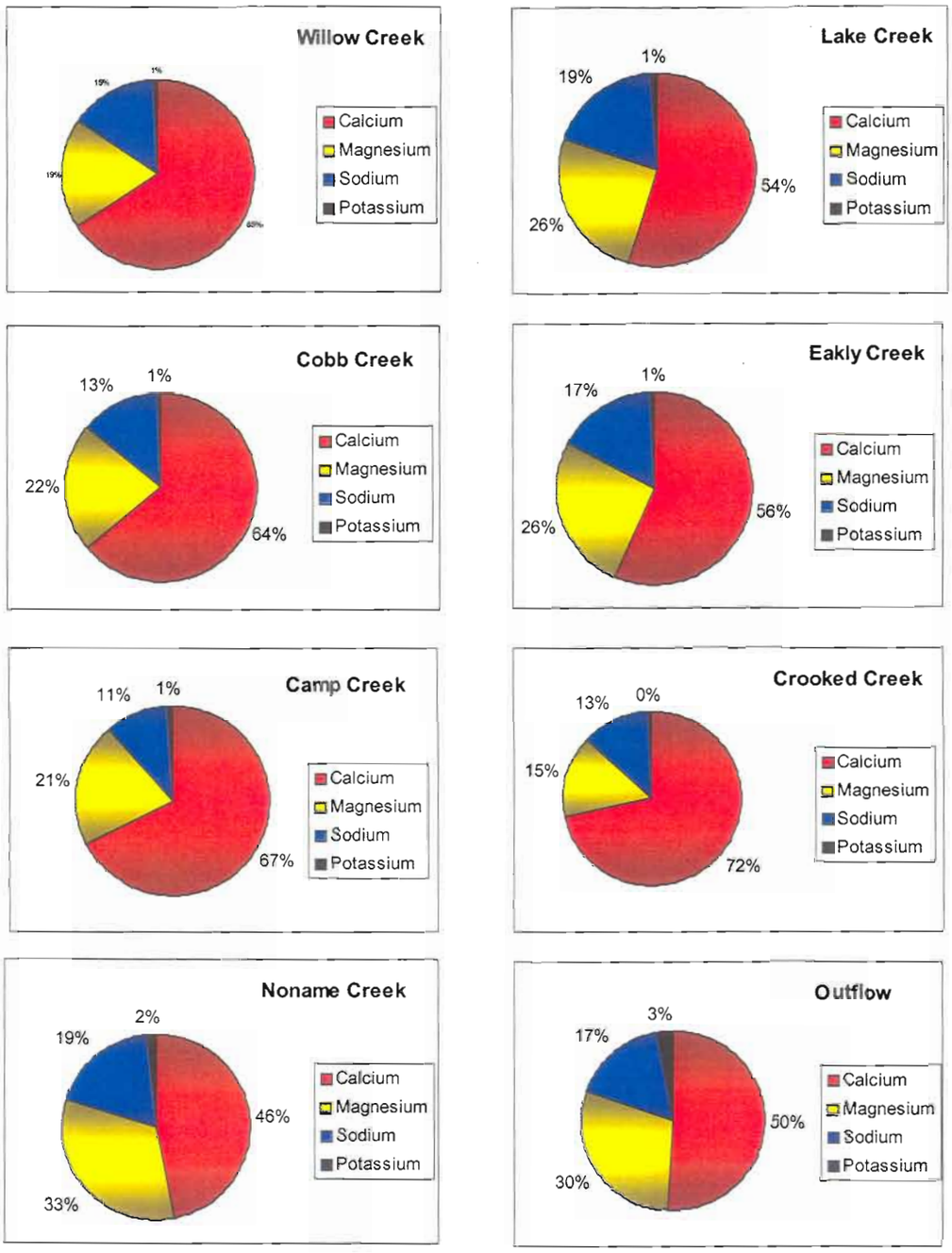


Figure 9. Mean relative composition of major cations (Meq/L) in tributaries and outflow.

Of the three major anions, total alkalinity was predominant, ranging between 54% of the total in Cobb Creek to 84% in Eakly Creek (Figure 11). Alkalinity in these waters reflects primarily the sum of the carbonate and bicarbonate ions, and at the pH values that exist in these tributaries, bicarbonate would be the most common ionic form. Sulfate was the second most abundant anion at all locations, and its relative importance ranged from 10% in Eakly Creek to 42% in Cobb Creek. Relative concentrations of chloride ranged from 2% in Crooked Creek to 16% in Noname Creek. Concentrations (ppm) of all three major anions increased significantly between upper and lower Willow Creek (Figure 12), whereas there was no significant difference between the upper and lower stations in either Lake or Cobb Creeks. Eakly Creek was consistently highest in total alkalinity, while the lowest measurement occurred during the 9/11/99 runoff event on upper Willow Creek (Appendix B-7). The most marked differences among the tributaries with respect to major anions were the consistently high sulfate concentrations in Cobb Creek (Appendix B-8) and high chloride values in Noname Creek (Appendix B-9).

Nitrogen is a major component of all living organisms. In natural waters, the forms of nitrogen of greatest interest are, in order of decreasing oxidation state, nitrate, nitrite, ammonia and organic nitrogen. All of these forms, as well as nitrogen gas, are biologically (and sometimes chemically) interconvertible, and together make up what is commonly referred to as the "nitrogen cycle'. It should be remembered that the chemical concentration of each form is dynamic, that individual molecules of each are constantly being transformed, and that an analysis of a water sample is merely a "snapshot" of the concentrations for that moment in time. Nitrate, an important plant nutrient, was the most abundant form of inorganic nitrogen in all tributaries (Figure 13). Concentrations ranged from 200 ppb in lower Lake Creek on 8/3/98 to 3800 ppb in Eakly Creek on 11/3/97 (Appendix B-10). Concentrations of nitrate-N were significantly higher in upper *vs* lower Willow Creek, while no significant differences were noted between upper and lower stations on Lake or Cobb Creeks (Figure 13). At pH values less than 9.0, most of the ammonia in freshwater exists in the ionic form (ammonium), and as such is an important source of nitrogen for plants. While ammonia was the second most abundant inorganic form of nitrogen in the tributaries (Figure 13), it's concentrations were markedly lower than that of nitrate, ranging from less than 10 ppb at nearly all stations on one or more occasions to 340 ppb in upper Willow Creek on 9/11/99 (Appendix B-11). There were no significant differences in ammonia concentrations between the upper and lower stations in any of the three major tributaries. Nitrite is often the least abundant form of inorganic nitrogen in natural waters, and the tributaries to Fort Cobb Reservoir were no exception (Figure 13). Concentrations ranged from 1 ppb in lower Lake Creek to 103 ppb in Eakly Creek (Appendix B-12). No significant nitrite differences were found between the upper and lower stations at Willow, Lake and Cobb Creeks. Whereas the three aforementioned forms of inorganic nitrogen are assumed to be in the dissolved state, the procedure for determining total nitrogen includes both dissolved and particulate material. Therefore, if one were to subtract nitrate, ammonia and nitrite from the total nitrogen value, one would be left with an estimate of total particulate and dissolved organic nitrogen. Total nitrogen ranged from less than 100 ppb at three locations on 7/12/99 to 19,000 ppb in upper Willow Creek on 9/11/99 (Appendix B-13). This maximum, which was associated with the rainfall/runoff event previously noted, was atypical. Most values were (88%) were between 1000 and 5000 ppb.

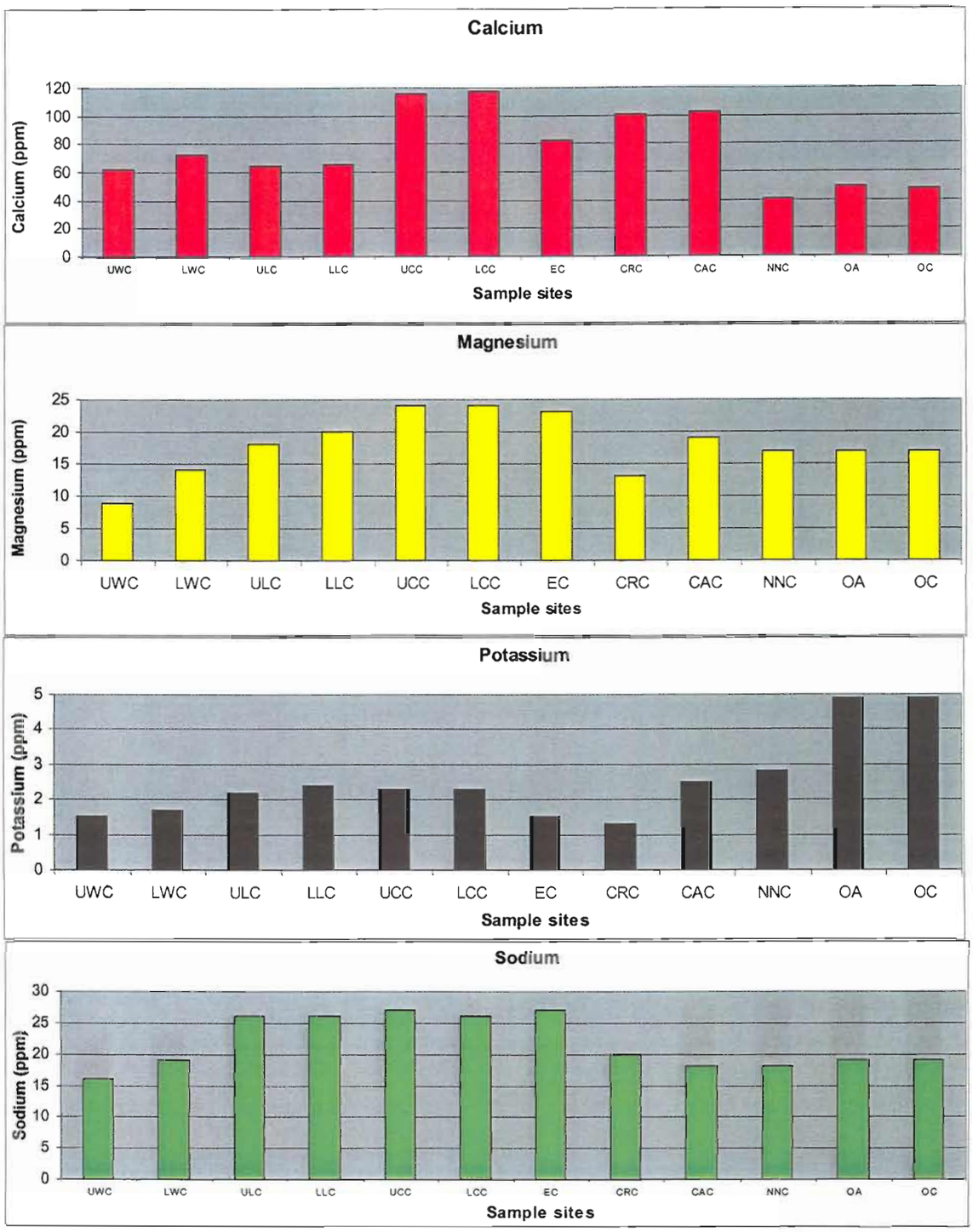


Figure 10. Mean concentration of major cations at each tributary and outflow sampling station.

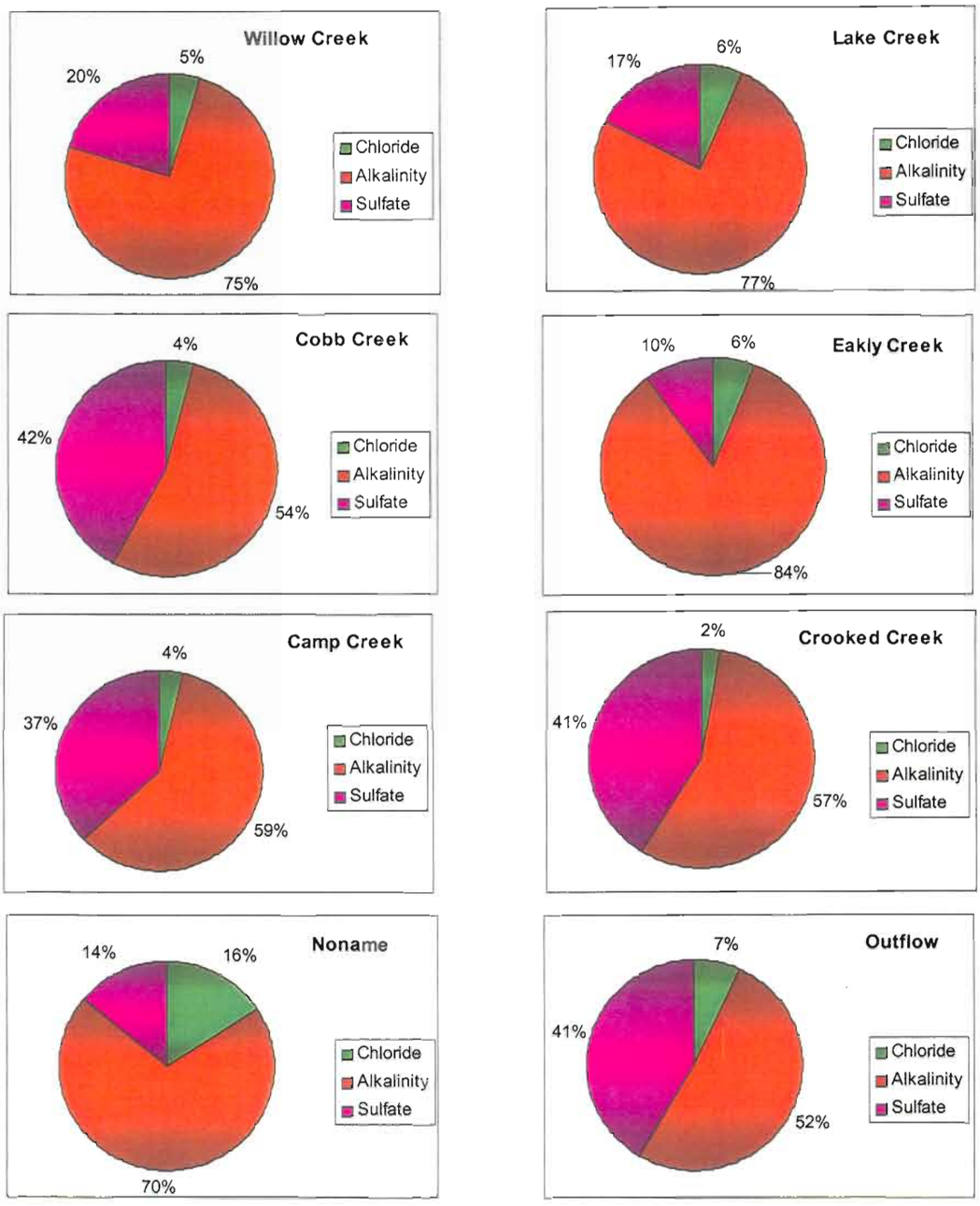


Figure 11. Mean relative composition of major anions (Meq/L) in tributaries and outflow.

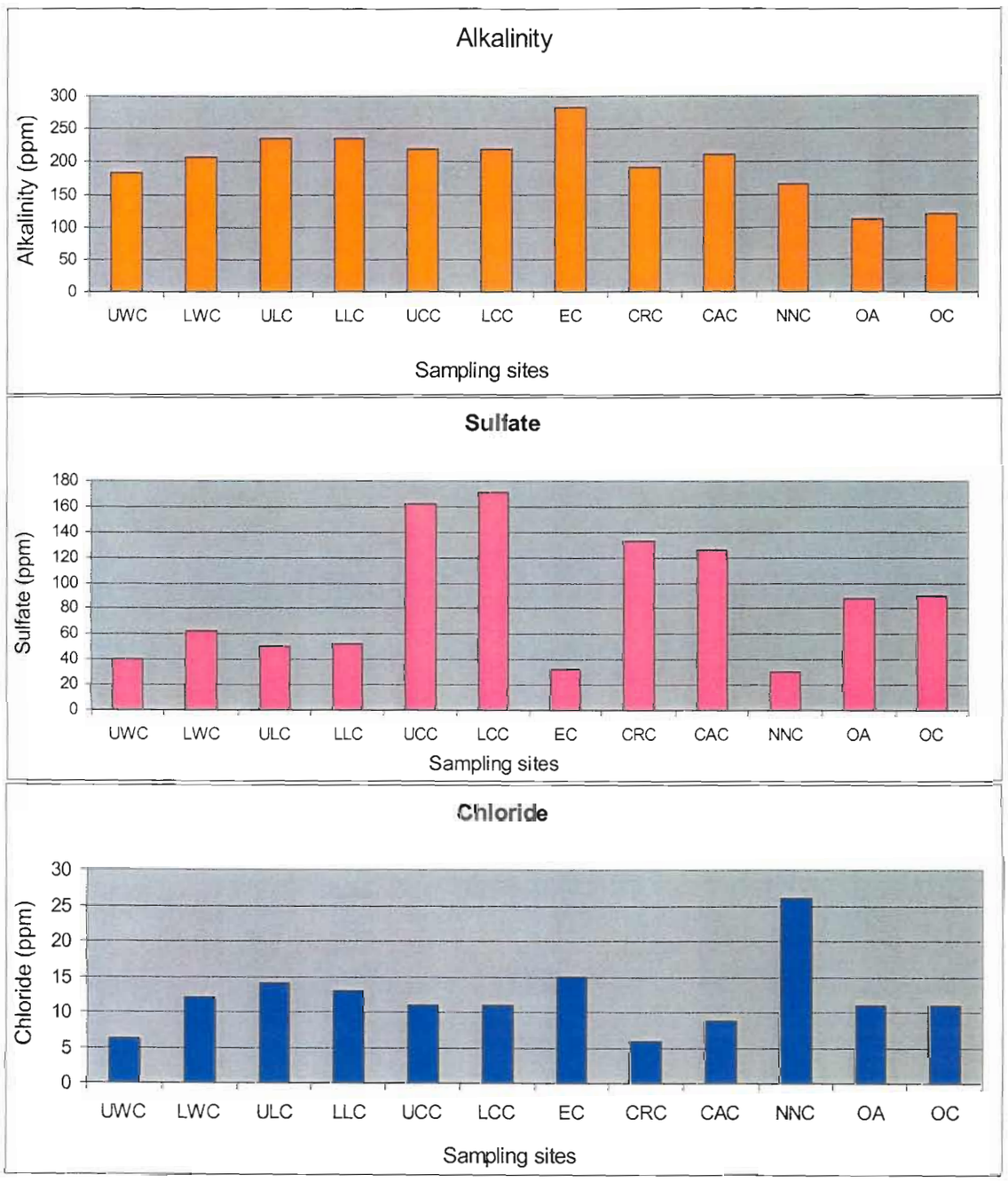


Figure 12. Mean concentration of major anions at each tributary and outflow station.

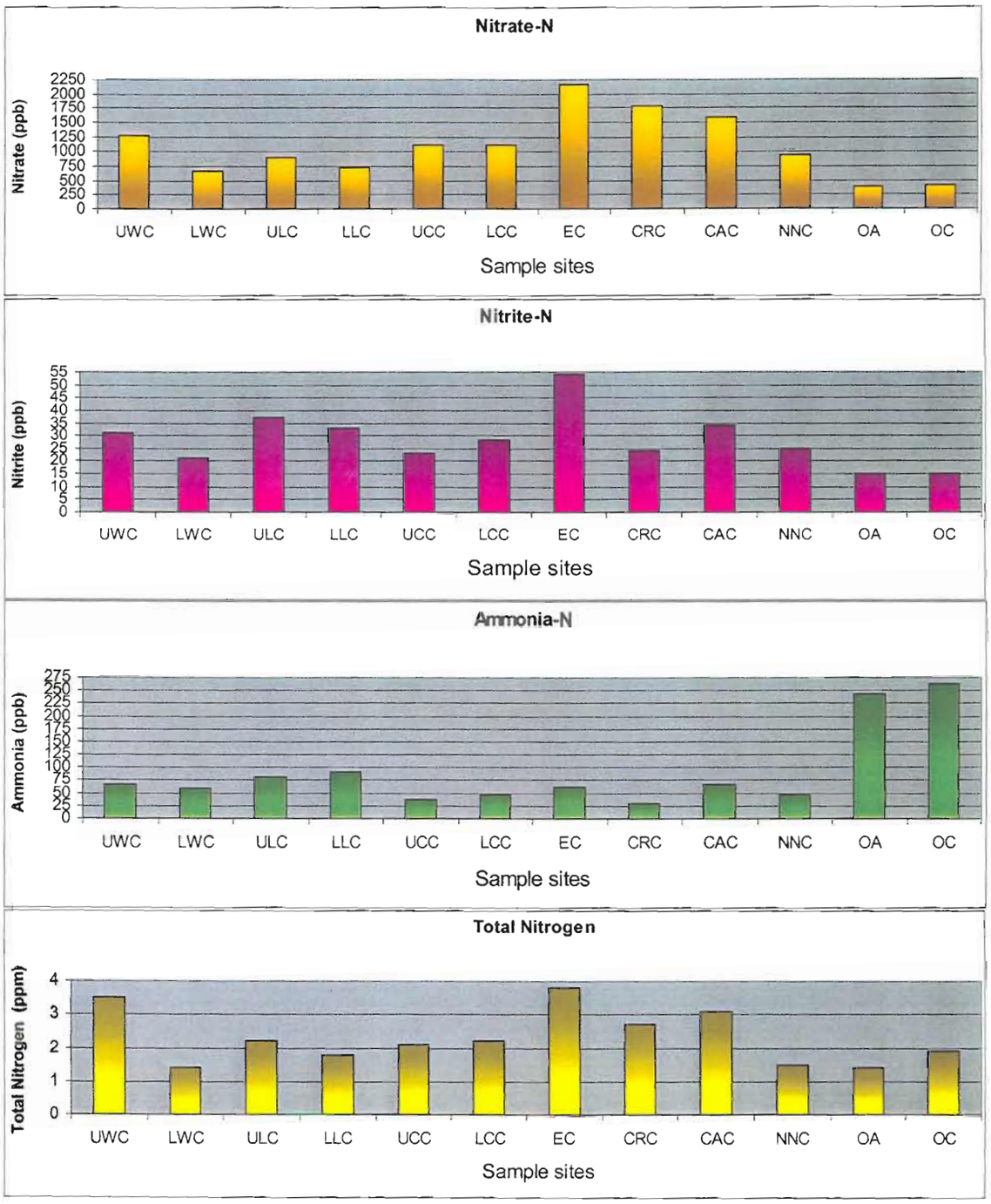


Figure 13. Mean concentration of nitrate, ammonia, nitrite, and total nitrogen at each tributary and outflow station.

There were no significant differences between upper and lower stations in Willow, Lake or Cobb Creeks (Figure 13). Using station averages, inorganic nitrogen (nitrate+ammonia+nitrite) comprised between 39% of the total nitrogen at upper Willow Creek and 68% of the total in Crooked Creek (Figure 14).

In comparison with the other major nutritional and structural elements found in living organisms (C,H, O, N), phosphorus is the least abundant and the most commonly limiting to biological productivity in freshwater ecosystems. Phosphorus occurs in a number of organic and inorganic compounds in natural waters; however in practice, forms of phosphorus are usually defined analytically (see Greenberg *et al.* 1992). As the name implies, total phosphorus is meant to include all forms of the element in a water sample - organic, inorganic, particulate and dissolved. The actual determination of "total" phosphorus is dependent upon which of the several commonly-used methods of digestion is chosen, and can range from the most drastic perchloric acid digestion to the less rigorous persulfate oxidation method. The former will strip even the most difficult forms of phosphorus from complex matrices such as soil or sediment, while the latter removes the more easily oxidized forms in a sample. In short, values for total phosphorus are defined by the digestion method employed. In this study, we used the persulfate digestion method; therefore, our results are undoubtedly lower than those that would have been obtained by one of the more rigorous methods. Total phosphorus ranged from 57 ppb in Noname Creek on 12/13/99 to 1830 ppb during the runoff event in upper Willow Creek on 9/11/99 (Appendix B-14). There were no significant differences between upper and lower stations in Willow, Lake or Cobb Creeks (Figure 15). Soluble reactive phosphorus (SRP) is believed to be comprised largely of the orthophosphate ion, with traces of easily hydrolyzed condensed phosphate, and as such represents phosphorus that is readily available to aquatic plants for primary productivity. SRP ranged from <10 ppb in upper Willow Creek on 8/3/98 to 290 ppb in lower Lake Creek on 5/2/98 (Table B-15). The upper and lower stations on Willow, Lake and Cobb Creeks were not significantly different with respect to concentrations of SRP (Figure 15). Using average values at each station, SRP comprised from 44 to 61 per cent of the total phosphorus in the tributaries (Figure 16).

In this report, major and minor trace elements are arbitrarily defined as those whose concentrations are expressed in parts per million and parts per billion, respectively. Among the major trace elements, only two (aluminum and iron) differed significantly between their total and dissolved concentrations. Soluble concentrations of aluminum were less than the detection limit (0.05 ppm) in every sample, while concentrations of total aluminum ranged from less than 0.05 ppm at times in Noname, Camp and Crooked Creeks to 2.24 ppm on 1/15/98 in upper Lake Creek (Appendix C-5). Average concentrations of total aluminum ranged from 0.09 ppm in Crooked Creek to 0.77 ppm in upper Lake Creek (Figure 17). Dissolved iron concentrations were less than the detection limit (0.02 ppm) at every station except Noname Creek, and total iron ranged from 0.05 ppm in Crooked Creek on 7/21/98 to 2.0 ppm in Noname Creek on 10/19/99 (Appendix C-6).

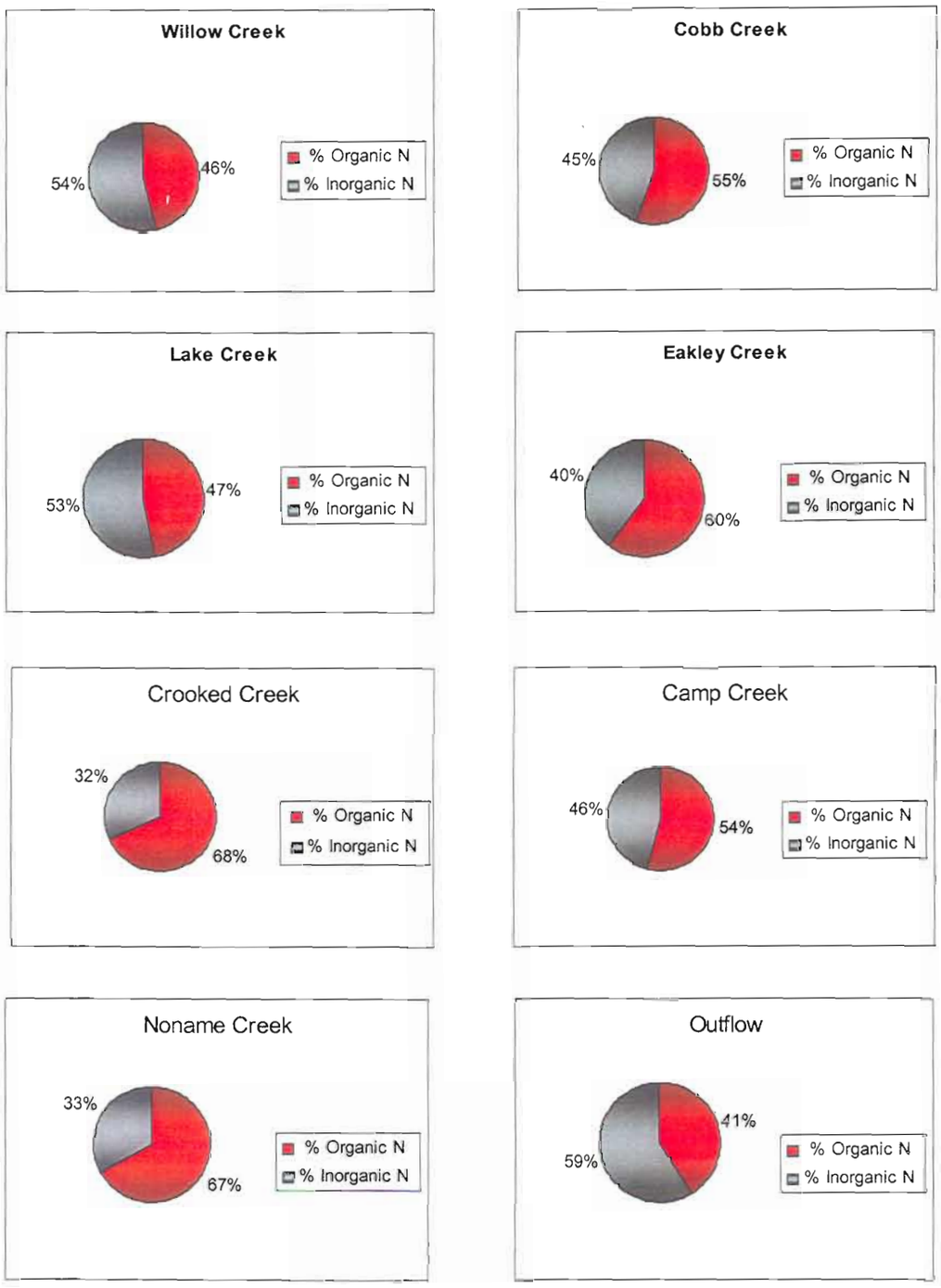


Figure 14. Mean relative composition of organic and inorganic nitrogen in tributaries and outflow.

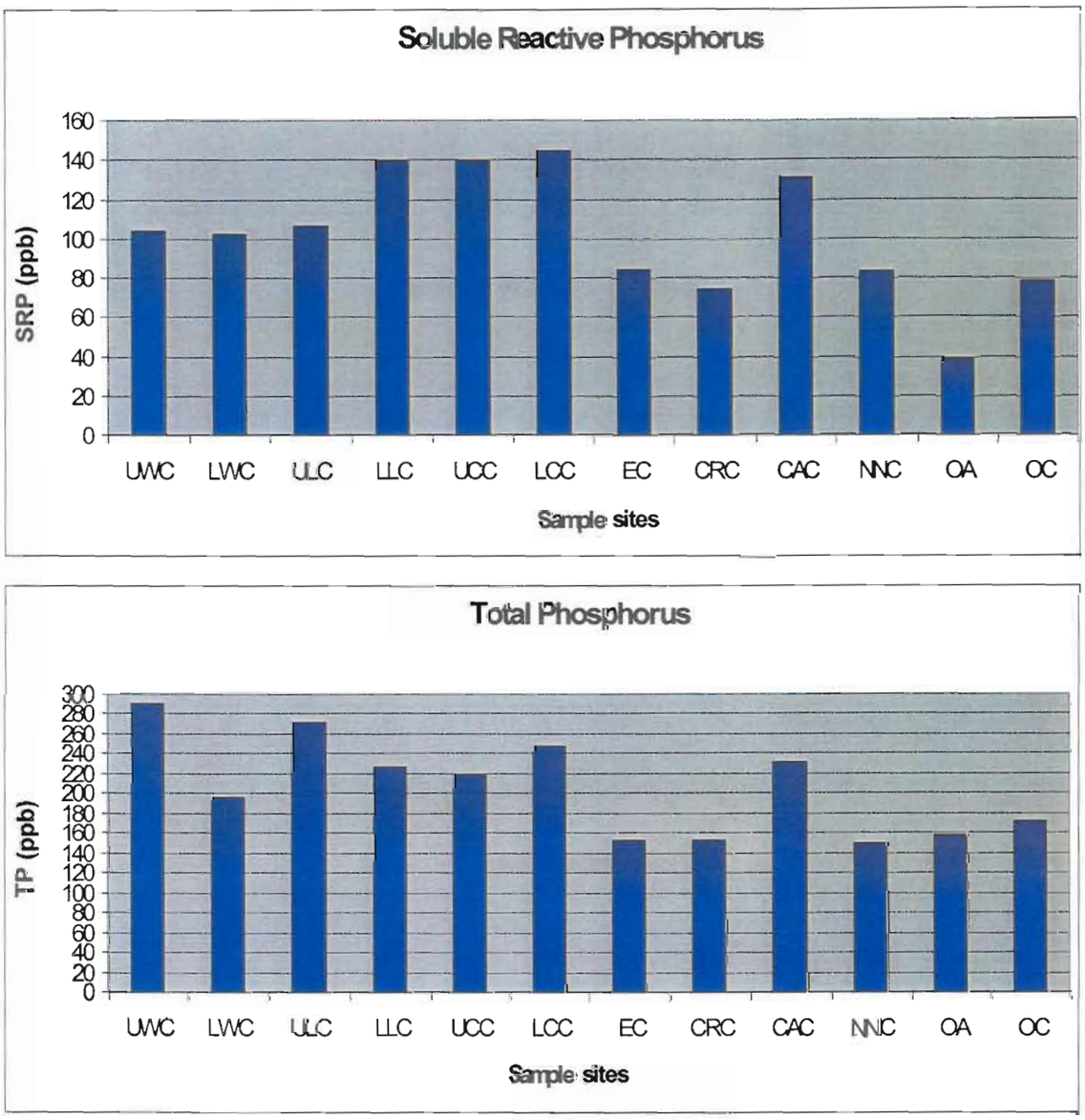


Figure 15. Mean concentration of soluble reactive phosphorus and total phosphorus at each tributary and outflow sampling station.

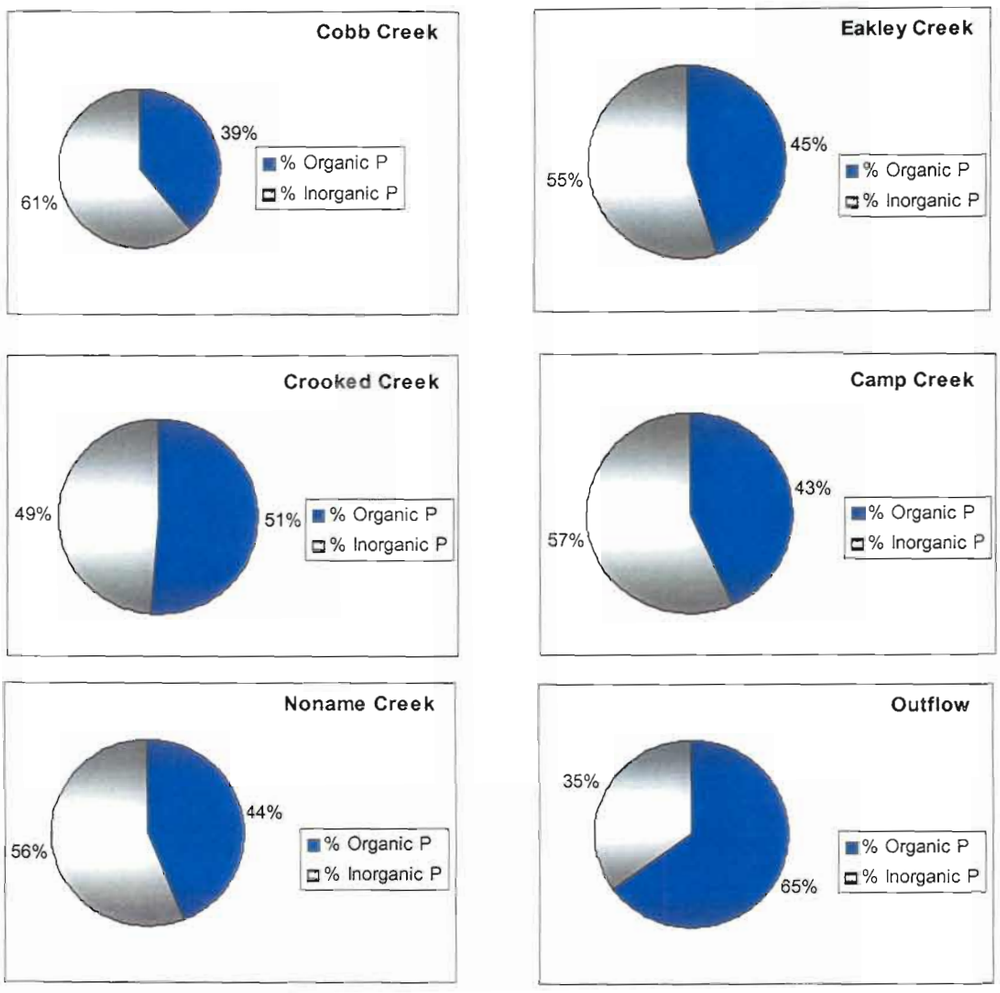


Figure 16. Mean relative composition of organic and inorganic phosphorus in tributaries and outflow.

Total iron averaged between 0.09 ppm in Crooked Creek to 1.3 ppm in Noname Creek (Figure 17). Detectable concentrations were encountered in both the total and dissolved samples for the remainder of the major trace elements, and no significance differences were found between the two fractions in the tributaries. Manganese (Appendix C-7) was highly variable with respect to both location and sampling date; and as with iron, the average concentration of manganese in Noname Creek was markedly higher than at any other site (Figure 18). Barium (Appendix C-8) and silica (Appendix C-9) were more uniformly distributed with respect to season and location. Average concentrations of barium ranged from 0.08 ppm in Noname Creek to 0.20 ppm in Eakly Creek, while averages for silica ranged between 9.8 ppm in Eakly Creek and 12 ppm in Camp and Noname Creeks (Figure 18). The spatial distribution of strontium (Appendix C-10) was somewhat different than that of the other major trace elements. First, there was a significant increase between upper and lower Willow Creek and a significant decrease from upper to lower Cobb Creek (Figure 18). There were no significant differences between the upper and lower stations on Willow, Lake or Cobb Creeks for aluminum, iron, manganese, barium or silica. Second, average concentrations of strontium in Cobb Creek were an order of magnitude higher than at any other location (Figure 18). There are no water quality standards in Oklahoma for any of the major trace elements except barium. Concentrations of barium in the tributaries were roughly an order of magnitude less than the 1.00 ppm standard for public and private water supplies.

The minor trace elements can be grouped into four general categories. First, is a group in which none of the total or dissolved samples contained concentrations that were above the detection limit of the methods used. All samples for total and dissolved mercury were below 0.005 ppb (Appendix C-11), while all those for cadmium contained less than 0.05 ppb (Appendix C-12). For all practical purposes, all samples for molybdenum were less than 1.0 ppb; the two exceptions appeared to be somewhat anomalous (Appendix C-13). There is no state water quality standard for molybdenum, and concentrations of mercury and cadmium appear to be at least an order of magnitude lower than the most conservative standards listed for these two elements. A second group of elements is one in which detectable concentrations occurred only in the "total" samples. All dissolved lead concentrations were essentially less than 0.05 ppb, while total concentrations ranged from < 0.05 ppb in Noname and Camp Creeks to 3.0 ppb in Eakly Creek (Appendix C-14). Dissolved silver was less than 0.05 ppb in every sample, whereas total concentrations were between < 0.05 ppb at several sites and 0.43 ppb in lower Lake Creek (Appendix C-15). Antimony was below or only slightly exceeded the detection limit of 0.05 ppb in all dissolved samples, while samples for total ranged between < 0.05 and 0.62 ppb (Appendix C-16). Chromium was somewhat problematic in that detectable concentrations appeared in the dissolved phase on only one occasion, and in the total samples on just two occasions. All detectable concentrations of chromium, in both the total and dissolved fractions, were very near the detection limit of 1.0 ppb (Appendix C-17). Concentrations of silver and chromium were at least an order of magnitude less than Oklahoma water quality standards, as were most of those for lead. There is no standard for antimony. A third group of elements was comprised of those in which detectable concentrations were found in both the dissolved and total fractions, and in which the total concentrations were significantly greater than the dissolved.

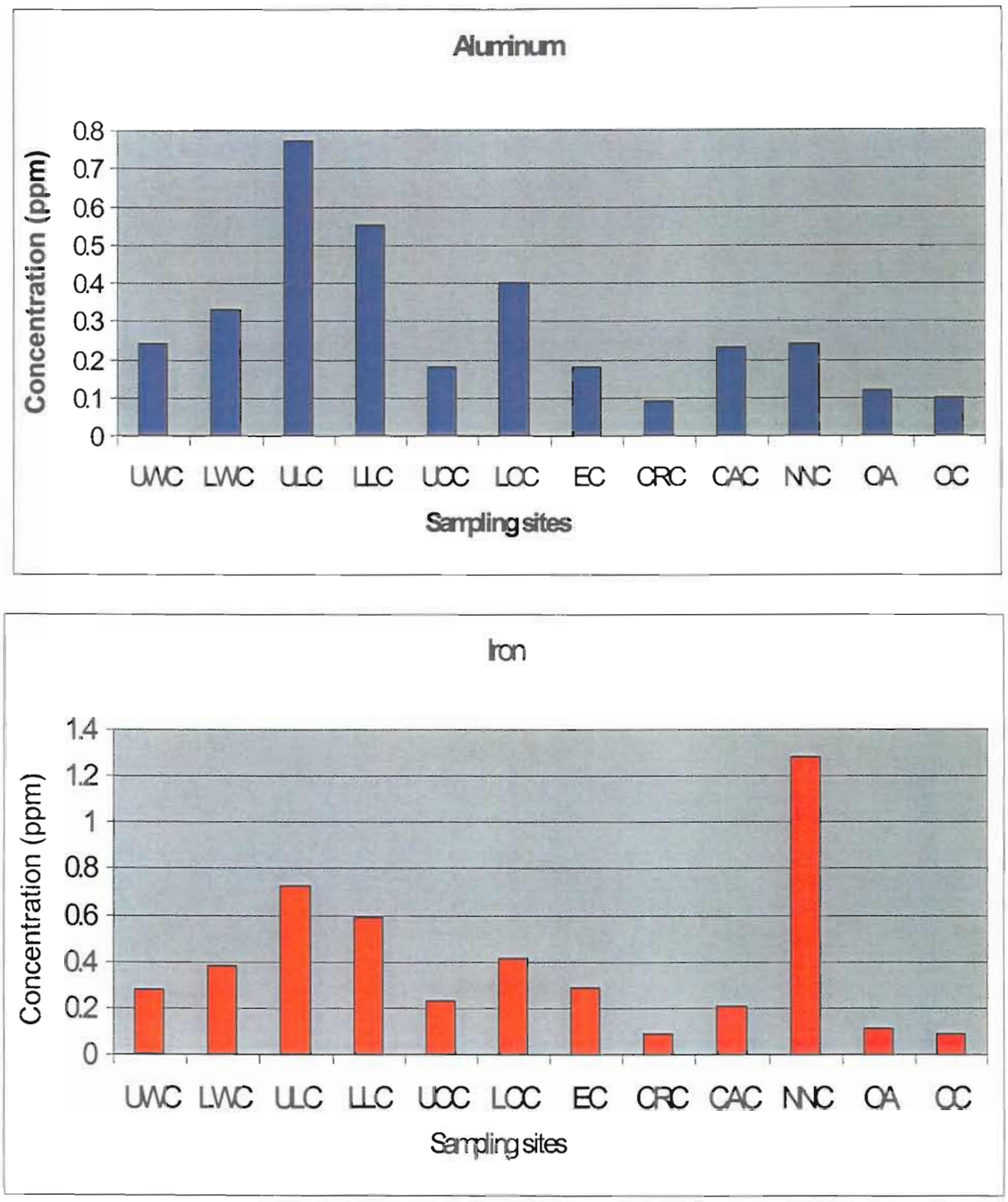


Figure 17. Mean concentrations of aluminum and iron at each tributary and outflow sampling station.

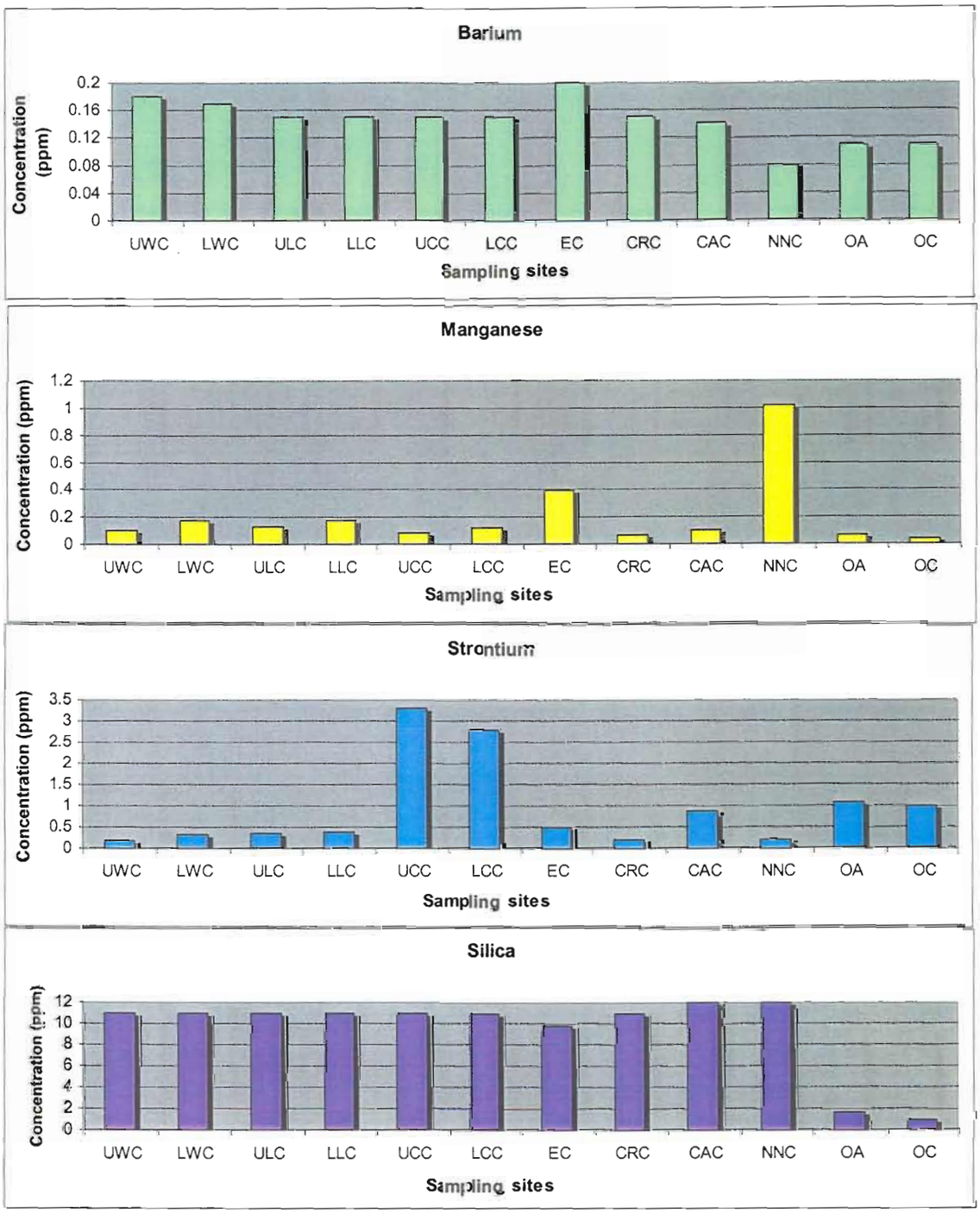


Figure 18. Mean concentrations of barium, manganese, strontium, and silica at each tributary and sampling station.

Concentrations of total and dissolved copper (Appendix C-18) averaged 0.92 and 0.69 ppb, respectively. Zinc (Appendix C-19) averaged 4.1 ppb total, and 2.4 ppb dissolved, while averages for total and dissolved cobalt (Appendix C-20) were 0.37 and 0.23 ppb, respectively. There is no water quality standard for cobalt, and those for copper and zinc are an order of magnitude greater than concentrations found in this study. The fourth and final group of elements consists of those in which consistently detectable concentrations of both total and dissolved fractions cannot readily be separated, either statistically or by virtue of their QA/QC results. Boron (Appendix C-21), which ranged from <20 to 90 ppb, and vanadium (Appendix C-22), which ranged between < 0.05 and 18.1 ppb, are not included in the state water quality standards. Nickel (Appendix C-23), at < 0.5 to 2.87 ppb, was two orders of magnitude lower than the state standard, while selenium (range < 0.05 to 0.62 ppb) was one order of magnitude lower than the most conservative standard (Appendix C-24). Arsenic ranged from 1.28 to 25.2 ppb (Appendix C-25). All values > 10 ppb occurred in each of the principle tributaries on one sampling date (7/21/98). The most conservative standard for arsenic (40 ppb) is for waters designated as public and private water supplies. As stated earlier, the arsenic data are somewhat suspect due to the presence of apparent contamination shown in the field blanks.

2.Sediment/Soil

Laboratory precision for the sediment samples, as shown by the results of duplicate analyses (Appendix A-3), was very good - except for boron, cadmium and molybdenum. The RPD for these three elements ranged from 20 to 35 per cent, while RPD for the remaining constituents was less than 10%. Elemental composition of sediment is related to various physical properties of the material such as total organic carbon (TOC) and/or grain size (de Groot, 1995). For this reason, the utility of field duplicates to evaluate sampling precision is somewhat limited, since two samples taken from the same vicinity may contain different elemental concentrations simply because of differences in TOC or clay content. Since the tributary sediment sampling was designed to include samples from a wide range of grain sizes, followed by geochemical normalization of the results, field duplicates were considered unnecessary in this study. Standard reference materials were available for just over half of the elemental constituents analyzed in sediment (Appendix A-3). Recoveries from sediment depend on the form (or matrix) in which a particular element occurs, and the digestion procedure that is used to dislodge (or dissolve) the element. If the digestion procedure is not sufficiently rigorous, not all of the element will be removed from the sample matrix, and recovery will be incomplete. Recoveries were consistently low for certain metals such as chromium, vanadium and beryllium. Recovery of the remaining elements appeared to be satisfactory, ranging between about 80 and 100 per cent. Laboratory blanks for each of the elements were below the detection limit in all cases, suggesting no contamination of the samples during digestion or analysis.

As previously stated, it was assumed *a priori* that the bulk concentration (ppm) of any element in a sediment or soil sample would be strongly dependent on the granular composition or the organic matter content of that sample - *i.e.* elements are attracted and adhere to organic matter and the finest particles. However, in every study before normalization is carried out, this assumption should be validated by examining the existing data (Hebert and Keenleyside, 1995). In our study, we had an excellent range and distribution of particle sizes, from 2.5% sand in the Willow Creek delta to 100% sand in the upper reaches of Willow, Cobb and Lake Creeks and the

watershed soil. TOC ranged from less than 0.10% in upper Willow, Lake and Cobb Creeks to nearly 2.0 % in both the Lake and Willow Creek deltas. As recommended by de Groot (1995), we selected aluminum as a surrogate (or reference) for the fine-grained fraction of the sediment/soil, and determined the correlations between the concentrations of each element *vs* aluminum and TOC in samples from each of the three major watersheds. The results (Table 5) verify conclusively that concentrations of elements in these tributaries are highly dependent upon the concentration of TOC and fine grain size particles as represented by aluminum. In Willow and Lake Creeks, every element was significantly correlated with aluminum at the $p<0.01$ level. In Cobb Creek, concentrations of four elements (calcium, cadmium, sulfur and selenium) were independently distributed with respect to aluminum. This suggests that in the Cobb Creek watershed, some other factor(s) is responsible for regulating the concentration of these four elements in the sediments. Once the relationship between the various elements and the representative of the fine-grained fraction (aluminum) was verified, the data were geochemically normalized with the following equation: (concentration of element in ppm/concentration of aluminum in ppm) X 10,000.

Table 5. Correlation coefficients between concentrations of each element and total organic carbon (TOC) and aluminum (Al) in sediment samples from Fort Cobb Reservoir and its three principle tributaries.

Element	Willow Creek (n=14)		Lake Creek (n=12)		Cobb Creek (n=8)		Reservoir (n=16)	
	TOC	Al	TOC	Al	TOC	Al	TOC	Al
Aluminum	0.993	1.000	0.984	1.000	0.893	1.000	0.912	1.000
Arsenic	0.944	0.942	0.872	0.928	0.615	0.752	0.408	0.565
Boron	0.960	0.972	0.969	0.967	0.871	0.979	0.552	0.724
Barium	0.996	0.994	0.984	0.998	0.913	0.998	0.950	0.984
Beryllium	0.994	0.999	0.983	0.997	0.905	0.998	0.927	0.944
Calcium	0.983	0.974	0.896	0.923	0.653	0.555	0.932	0.875
Cadmium	0.979	0.981	0.985	0.992	-0.175	-0.199	0.887	0.887
Cobalt	0.980	0.977	0.982	0.994	0.893	0.992	0.783	0.917
Chromium	0.995	0.999	0.987	0.998	0.918	0.984	0.917	0.996
Copper	0.995	0.996	0.979	0.995	0.911	0.994	0.912	0.994
Iron	0.995	0.998	0.978	0.996	0.895	0.952	0.929	0.997
Mercury	-	-	-	-	-	-	-	-
Potassium	0.994	1.000	0.981	0.997	0.890	1.000	0.906	0.995
Magnesium	0.993	0.994	0.976	0.989	0.915	0.999	0.889	0.990
Manganese	0.866	0.848	0.960	0.972	0.887	0.991	0.974	0.841
Molybdenum	-	-	-	-	-	-	0.889	0.862
Nitrogen	0.999	0.996	0.989	0.988	0.906	0.996	0.992	0.912
Nickel	0.995	0.996	0.989	0.999	0.882	0.998	0.933	0.996
Phosphorus	0.994	0.991	0.981	0.994	0.884	0.997	0.976	0.947
Lead	0.996	0.998	0.983	0.998	0.893	0.997	0.869	0.984
Sulfur	0.958	0.967	0.748	0.782	0.392	0.504	0.935	0.803
Selenium	0.820	0.791	0.869	0.933	-0.560	-0.535	0.981	0.925
Strontium	0.969	0.969	0.865	0.897	0.890	0.992	0.942	0.9927
Vanadium	0.994	0.998	0.989	0.996	0.899	0.903	0.935	0.991
Zinc	0.992	0.998	0.987	0.998	0.772	0.862	0.916	0.994

Using the normalized soil and sediment data from the Willow Creek watershed (Table 6), one can determine which elements are being enriched in the benthic sediments of Willow Creek

and it's delta. Concentrations of ten elements (Cd, Cr, Fe, K, N, P, Pb, Se, V and Zn) were actually higher in the watershed soil than in the sediment, suggesting that somehow these elements are depleted in the benthic environment, perhaps either by uptake or solution. Concentrations of five elements (As, Co, Cu, Mn and Ni) were unchanged between soil and sediment, indicating that once these elements are moved physically from the watershed into the stream, they are neither

Table 6. Average concentrations of elements in watershed soil and benthic sediment. Values are normalized to aluminum (ppm element/ ppm Al) x 10,000. An asterisk (*) indicates a significant difference between Willow Creek watershed soil and sediment. Different lower case letters indicate significant differences among the three creeks.

	Soil	Sediment			
Element	Willow Creek Watershed	Willow Creek	Lake Creek	Cobb Creek	Reservoir
Aluminum	10,000	10,000	10,000	10,000	10,000
Arsenic	3.7	4.2 [a]	4.4 [a]	3.7 [a]	4.6
Boron	4 *	8.0 [a]	6.9 [a]	9.4 [a]	2.7
Barium	59 *	71 [a]	77 [a]	69 [a]	75
Beryllium	0.5 *	0.55 [a]	0.53 [a]	0.57 [a]	0.54
Calcium	1,700 *	4,800 [a]	7,500 [a]	16,000 [b]	9,400
Cadmium	0.17 *	0.06 [a]	0.07 [a]	0.37 [a]	0.1
Cobalt	4.1	4.1 [a]	3.6 [a]	5.4 [a]	4.0
Chromium	16 *	13 [a]	12 [a]	21 [b]	11
Copper	6.5	6.8 [a]	5.6 [b]	7.1 [a]	7.1
Iron	13,000 *	10,000 [a]	9,500 [a]	16,000 [b]	9,500
Mercury		-	-	-	-
Potassium	1,900 *	1,400 [a]	1,400 [a]	1,700 [b]	1,400
Magnesium	2,000 *	2,900 [a]	2,700 [a]	3,600 [b]	2,500
Manganese	230	290 [a]	320 [a]	430 [b]	250
Molybdenum		-	-	-	-
Nitrogen	1,000 *	590 [a]	610 [a]	590 [a]	810
Nickel	8.8	9.2 [a]	8.3 [a]	11 [b]	8.2
Phosphorus	320 *	200 [a]	210 [a]	290 [b]	200
Lead	7.9 *	5.3 [a]	5.4 [a]	6.9 [b]	6.6
Sulfur	190 *	340 [a]	250 [a]	420 [a]	1,000
Selenium	0.12 *	0.07 [a]	0.07 [a]	0.08 [a]	0.13
Strontium	11 *	28 [a]	45 [a]	87 [b]	90
Vanadium	22 *	19 [a]	16 [a]	31 [b]	17
Zinc	35 *	27 [a]	24 [a]	44 [b]	23

depleted nor enriched. Concentrations of only seven elements (B, Ba, Be, Ca, Mg, S and Sr) appeared to be geochemically enriched in the sediment. Mean sediment:soil ratios of these elements ranged from 1.1 to 2.8, with calcium and strontium being the highest.

Normalized concentrations (Table 6) were also used to compare sediments in the Willow, Lake and Cobb Creek Basins. Concentrations of nine elements (As, B, Ba, Be, Cd, Co, N, S and Se) were similar in all three waterways. In the case of one element (Cu), Lake Creek was lower

than either Willow or Cobb Creeks. For the remaining twelve elements (Ca, Cr, Fe, K, Mg, Mn, Ni, P, Pb, Sr, V and Zn), Cobb Creek was higher than Willow and Lake Creeks. In other words, with the exception of copper, the sediments in Willow and Lake Creeks and their deltas were similar, whereas sediment in the Cobb Creek system was significantly enriched with respect to over half of the elements tested. Among the more prominent increases found in the Cobb Creek sediments were calcium and strontium, two elements that were shown to be geochemically enriched from watershed soils, and that were also noted to be markedly higher in the water samples from Cobb Creek.

3.Bacteria

Results of the bacterial testing (Table 7) are not difficult to summarize. Hydrogen sulfide-producing bacteria were present in every sample taken from the tributaries. A strong positive reaction was observed in every case within the initial 24-hour incubation period, suggesting that a substantial inoculum of viable organisms was consistently present at all locations. Specifically, the PathoScreen medium used is selective for such organisms as *Salmonella, Citrobacter, Proteus, Edwardsiella* and *Klebsiella* which have been shown to be associated with fecal contamination and total coliform bacteria. A positive test does not confirm the presence of human pathogens, but is merely an indicator that the potential does exist. *Salmonella,* which is considered the most important zoonotic cause of food-borne infection (Havelaar, 1986), may be excreted by humans and healthy wild and domestic animals. Three of the four major environmental

Table 7. Results of PathoScreen medium bacterial testing in Fort Cobb Reservoir tributaries and outflows. A + indicates the presence of hydrogen sulfide-producing bacteria. An asterisk (*) indicates the tributary was dry on that date.

	Date						
Location	6/8/1998	9/14/1998	12/5/1998	3/16/1999	7/19/1999	10/5/1999	4/10/2000
UWC	+	+	+	+	+	+	+
LWC	+	+	+	+	+	+	+
ULC	+	+	+	+	+	+	+
LLC	+	+	+	+	+	+	+
UCC	+	+	+	+	+	+	+
LCC	+	+	+	+	+	+	+
EC	+	*	+	+	+	*	+
CrC	+	+	+	+	+	+	+
CaC	+	+	+	+	+	+	+
NC	+	*	+	+	+	+	*
OA	+	+	+	+	+	+	+
OC	+	+	+	+	+	+	+

sources of *Salmonella* listed by Havelaar (1986) are present in the Fort Cobb Reservoir watershed: (1) wastewater from municipal sewage; (2) manure from domestic livestock; and (3) fecal material from wild animals. While the actual nature and source of bacteria are unknown, and may actually vary with season and locale, fecal contamination is pervasive throughout the Fort Cobb Reservoir watershed.

B. Outflows

1. Water

Outflow temperatures varied from a January, 1999 low of 5.6 °C in Outflow C to a high of 30.1 °C at the same location in August, 1998 (Appendix B-1). Except for early spring (March-May), temperatures at the two outflows varied by less than a degree. The seasonal temperature pattern in the outflows was very similar to that observed in the tributaries (Figure 7).

Outflow conductivity varied from 418 micromhos/cm in Outflow A on 8/3/98 to 536 micromhos/cm in Outflow C on 7/12/99 (Appendix B-2). There was no significant difference in conductivity between the two outflows over the course of the study. Mean values for Outflows A and C were 465 and 477 micromhos/cm, respectively. With the exception of Noname Creek, outflow conductivities were markedly less than those in any of the tributaries (Figure 8). This clearly indicates that there is another important source of water entering the reservoir between the mouths of the principle tributaries and the outflows. Since no other surface water enters the reservoir, the source has to be groundwater.

Chemical oxygen demand (COD) was consistently higher in the outflows than in the tributaries (Figure 8), ranging from a low of 3 ppm in Outflows A and C on 10/29/98 to a high of 32 ppm in Outflow C on 8/3/98 (Appendix B-3). Mean concentrations of 12 and 14 ppm in Outflows A and C respectively, were not significantly different. Increased CODs in the outflows, relative to the tributaries, are no doubt a reflection of organic matter synthesis by phytoplankton in the reservoir environment.

Turbidity in the outflows was highly variable, ranging across two orders of magnitude, from a low of 2.2 NTU in Outflow C on 5/13/98 to 109 NTU in Outflow A on 3 /15/2000 (Appendix B-4). On the whole, turbidity values were somewhat lower in the outflows than in the tributaries. Over half (52%) were in the range 1-10 NTU, as compared to 37% of the tributary readings in the same range.

Chlorophyll a concentrations in the outflows, which ranged from a low of 0.79 ppb in Outflow C on 5/13/98 to a high of 74 ppb in Outflow A on 8/3/98 (Appendix B-5) undoubtedly reflect phytoplankton entrained in the discharge from the reservoir. Mean values of 29 and 23 ppb in Outflows A and C respectively, were not significantly different, and were 2 to 3 times higher than those found in the tributaries (Figure 8).

pH ranged from 7.6 in Outflow C on 8/3/98 to 9.0 at the same site on 11/3/97 (Appendix B-6). Both locations had an average pH of 8.1, which was higher than the mean at any of the tributary stations (Figure 8).

Outflows A and C exhibited the same relative composition as the tributaries with respect to concentrations of the major cations, calcium, magnesium, sodium and potassium (Figure 9). There were no significant differences in the concentrations of these ions between the two outflow sites, nor between the total and dissolved forms. As discussed earlier, in reference to conductivity, there was an overall decrease in total ionic concentration from the tributaries to the outflows. Specifically, calcium was the most notable reduction (Figure 10). Potassium actually increased about two-fold, while magnesium and sodium decreased slightly. There is an

interesting similarity between the mean conductivities at Noname Creek (454 micromhos/cm) and the outflows (471 micromhos/cm) and the cationic composition at the two locations (Figures 9 and 10). This might suggest that both sites reflect the influence of localized groundwater.

As in the case of the tributaries, alkalinity was the predominant anionic constituent in the outflows (Figure 11); however, at the higher pH values in the latter, carbonate would play a more important role than in the former. Concentrations of alkalinity in outflows A and C were not significantly different, and their mean value (115 ppm) was notably lower than those in any of the tributaries (Figure 12). Sulfate, the second most abundant anion, was not significantly different in the two outflows, and averaged 88 ppm in the outflows. This was about midway between the concentrations in the Cobb Creek watershed and those in Willow and Lake Creeks (Figure 12). Chloride, which averaged 11 ppm in both outflows, was the least important of the major anions (Figure 11).

There were no significant differences between outflow stations with respect to any of the nitrogen forms analyzed. As in the tributaries, nitrate-N was the most abundant inorganic form in the outflows, however mean concentrations were markedly less (Figure 13). In contrast, Figure 13 shows that concentrations of ammonia-N were 2- to 3-fold higher in the outflows than in the tributaries. Nitrite-N was uniformly quite low in the outflows. There was a slight shift in the ratio of organic to inorganic N from tributaries to the outflows (Figure 14). In the former, organic N accounted for between 46 and 68 per cent of the total nitrogen, whereas in the latter, organic N was reduced to 41%.

Total phosphorus in the outflows ranged from <10 ppb in Outflow A on 8/3/98 to 940 ppb at the same location on 3/15/00 (Appendix B-14), while that for soluble reactive phosphorus was from <10 ppb on two occasions in Outflow A to 362 ppb in Outflow C on 8/3/ 98 (Appendix B-15). There was no significant difference in either form of phosphorus between the two outflows. There appeared to be an overall reduction in both total phosphorus and SRP between the principle tributaries and the outflows (Figure 15), although the magnitude was not great. There was a slight increase in the proportion of organic to inorganic phosphorus from the tributaries to the outflows (Figure 16). In the former, organic phosphorus ranged from 39 to 56 per cent, while in the latter it comprised and average of 65%.

Among the major trace elements in the outflows, three (aluminum, iron and manganese) differed significantly between their total and dissolved concentrations. Soluble aluminum was below the detection limit (0.05 ppm) in every outflow sample, while total aluminum ranged from < 0.05 to 0.135 ppm (Appendix C-5). Soluble iron was also at or below the detection limit (0.02 ppm) in every sample, whereas detectable concentrations of total iron, ranging from 0.05 to 0.238 ppm were encountered on every occasion (Appendix C-6). Soluble manganese ranged from 0.001 to 0.015 ppm while totals varied between 0.012 and 0.089 ppm (Appendix C-7). No significant difference was found between the total and dissolved fractions of the other three major trace elements (barium, silica and strontium). Concentrations of barium were relatively constant throughout the four seasons, ranging from 0.092 to 0.124 ppm (Appendix C-8). Silica was a little more variable with a range of 0.43 to 2.5 ppm (Appendix C-9). Strontium was also quite consistent, ranging between 0.94 and 1.2 ppm (Appendix C-10). No significant differences occurred between Outflows A and C for any of the major trace elements. Several marked differences could be noted when mean concentrations of the major trace elements in the outflows

were compared to those in the tributaries. Except for Crooked Creek, aluminum and iron were generally reduced in the outflows (Figure 17). The most striking difference was the case of silica, where outflow concentrations were roughly an order of magnitude less than those found in any of the tributaries (Figure 18). Outflow concentrations of manganese and barium both appeared to be slightly less than in the tributaries, while strontium was intermediate between the highs noted earlier in Cobb Creek and the remaining tributaries (Figure 18).

Results of the minor trace element analyses can be grouped in the same manner as previously used to discuss results of the tributary samples. First, is a group of elements in which none of the samples analyzed for either the total or the dissolved fraction yielded meaningful concentrations that were above the detection limits of the laboratory methods used. All samples for total and dissolved mercury were below the 0.005 ppb detection limit (Appendix C-11), while those for cadmium all contained less than 0.05 ppb (Appendix C-12). Both total and dissolved molybdenum appeared near or below the detection limit of 1.0 ppb (Appendix C-13). For the outflows, both chromium (Appendix C-17) and silver (Appendix C-15) can be added to this first group. In the outflow, lead appeared to be the only element in the second group, *i.e.* the one in which detectable concentrations occurred only in the "total" samples. With one exception, dissolved lead concentrations were below 0.05 ppb while total concentrations ranged from 0.14 to 0.70 ppb (Appendix C-14). The third group of elements is comprised of those in which detectable concentrations occurred in both the dissolved and total fractions, and in which the latter was significantly higher than the former. Dissolved antimony ranged from < 0.05 to 0.27 ppb while totals were between 0.28 and 0.40 ppb (Appendix C-16). Dissolved copper was from 0.50 to 1.1 ppb and total from 0.70 to 1.5 ppb (Appendix C-18). Zinc samples from the outflows appeared to be contaminated, probably from the metal used in the hydrants, and values for both total and dissolved (Appendix C-19) should be disregarded. The final group of elements is made up of those whose total and dissolved concentrations cannot be separated. Cobalt (Appendix C-20) ranged from 0.08 to 0.20 ppb, boron (Appendix C-21) from 47 to 77 ppb, vanadium (Appendix C-22) from 2.0 to 5.6 ppb and nickel (Appendix C-23) from < 0.50 to 1.8 ppb. Selenium (Appendix C-24), which ranged from < 0.05 to 0.19 ppb, did not reach concentrations as high as those found in many of the tributary samples. Likewise, the range for arsenic (Appendix C-25) was somewhat reduced in the outflows, but concentrations should be viewed with caution. Overall, it appears that a few changes in concentrations of minor trace elements did occur between the inflow from the tributaries and the outflows. However, concentrations of these elements remained well below the applicable state water quality standards.

2.Bacteria

Hydrogen sulfide-producing bacteria were present in every outflow sample taken (Table 7). A positive reaction with the PathoScreen® medium was observed within 24 hours in every case. Although a positive test does not confirm the presence of human pathogens or fecal contamination, it does indicate the presence of total coliform bacteria from some source (Grant and Ziel, 1996). There are state water quality standards regarding total coliform and fecal coliform bacteria in waters designated by the state as Public and Private Water Supplies and Primary Body Contact Recreation. These standards are based on quantitative determinations of the number of bacteria present per 100 ml of water and were beyond the scope of this investigation. The fact that these organisms are present in outflows that are used as municipal water supplies, and presumably in the reservoir itself, should be noted.

C. Reservoir

1. Water

Reservoir surface temperatures ranged from 3.2 °C in January 1999 to 30.7 °C in July of that same year (Appendix B-1). Temperatures increased from the headwaters to the dam between late summer and mid-winter (August-December), then decreased in the same direction (downstream) during the remainder of the year (January-July). The largest temperature differences between the upper and lower ends of the reservoir (> 3 °C) occurred during the period of warming. The annual cycle (Figure 7) was similar to that found in the tributaries and outflows.

Reservoir conductivity varied from 404 micromhos/cm in August 1998 to 642 micromhos/cm in February of that same year (Appendix B-2). In general, reservoir conductivities were much less variable than those found in the tributaries, and were slightly more variable than the outflows. There were no significant differences in conductivity between the surface and bottom water samples, indicating that in general, no vertical stratification of water masses was present in the reservoir. There was however, a significant decrease in conductivity between the upper reservoir and the dam (Figure 19), a fact that supports the earlier suggestion that water from another source (groundwater?) must contribute substantially to Fort Cobb Reservoir's overall water budget.

Chemical oxygen demand (COD) varied from < 1 ppm at several reservoir stations in July of 1999 to 29 ppm in the Northwest Sector later in December of that same year (Appendix B-3). Aside from a slightly higher average value in the Northwest Sector, conditions throughout the reservoir did not vary greatly (Figure 19). No significant differences in COD were noted between the surface and bottom samples. COD in the upper reservoir areas (including the Willow Creek Arm) was consistently higher than the tributaries which fed directly into them only a short distance away, suggesting a rapid synthesis of organic matter once water moved from the streams into the reservoir.

Turbidity was less variable in the reservoir than in the tributaries, with only one value greater than 100 NTU, and a majority of readings (71%) in the range of 10-100 NTU (Appendix B-4). There was a significant decrease in turbidity between the upper reservoir stations, including Willow Creek Arm, and the lower portion of the reservoir, including Kardokas, Carnegie and Marina Coves. Part of this difference was due to the presence of wind-induced, resuspended, bottom sediment in the shallower, more exposed, upper reaches of the reservoir, and part was due to the presence of more phytoplankton in the headwaters areas. At the Upper Reservoir station and the Willow Creek Arm, no significant difference in turbidity was found between the surface and the bottom samples, indicating that suspended matter was vertically well mixed. At the Middle and Lower Reservoir stations, there was significant differences between the surface and bottom samples, suggesting that some vertical layering of suspended matter was occurring in the deeper water.

Chlorophyll, as noted earlier, is an indicator of phytoplankton standing crop; and even more quantitatively it is an indicator of the potential for primary productivity in a body of water.

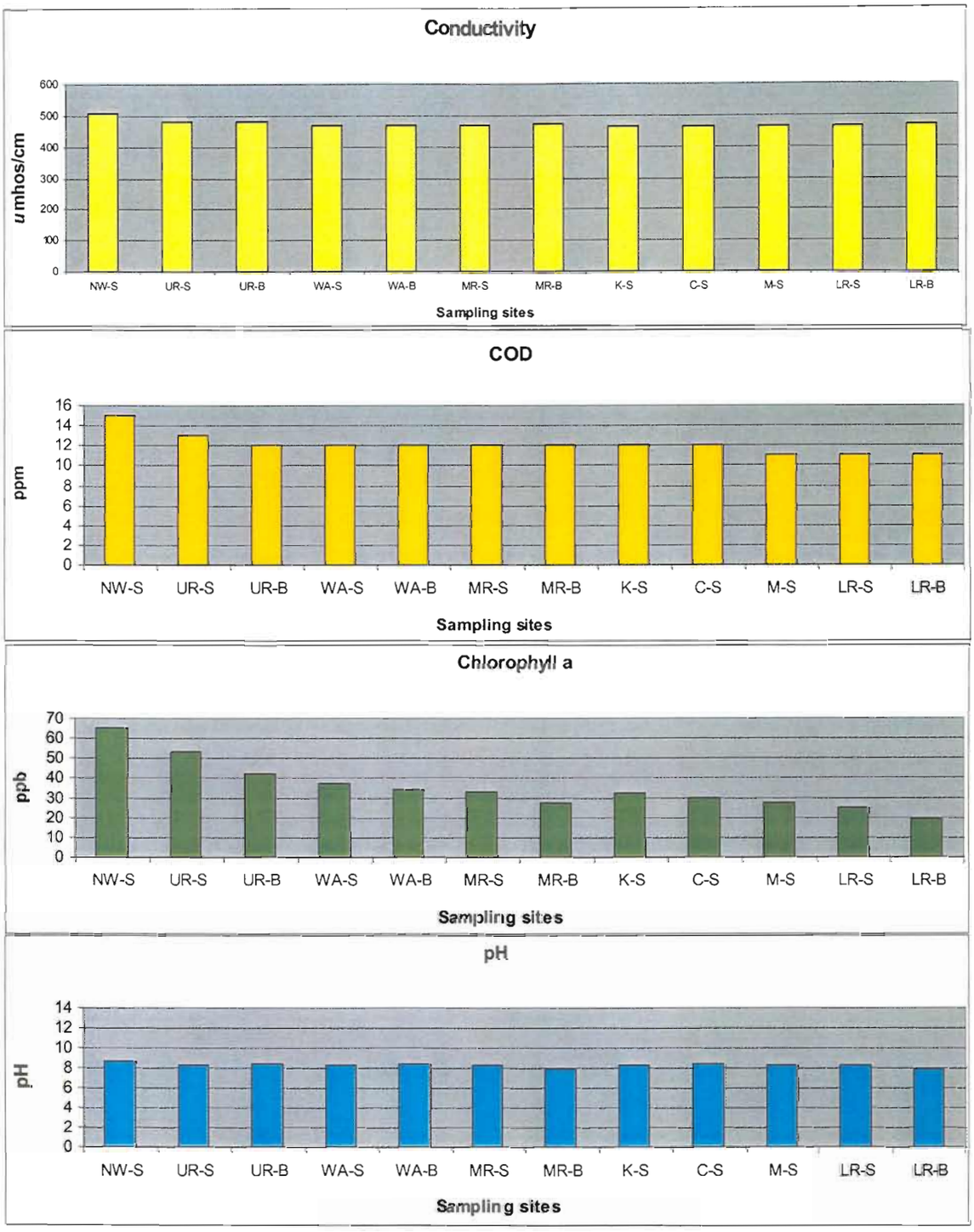


Figure 19. Mean conductivity, pH, COD, and chlorophyll a concentrations at each reservoir sampling station.

Therefore, the quantity and distribution of chlorophyll in the reservoir is important. First, one should note that even though there was a broad range of concentrations in the reservoir during the course of the study (3.1 to 136 ppb), there was a marked increase over concentrations found in the tributaries during the same time period (Appendix B-5). Second, the highest concentrations were found in the upper portions of the reservoir, and there was a year-round, significant decrease from the upper to the lower portions of the reservoir (Figure 19). Third, except for the Lower Reservoir station, there was no significant difference between the concentrations in the surface and bottom samples. One may conclude from these data that: (a) nutrient-rich water, relatively devoid of phytoplankton, enters the upper reservoir via the three main tributaries; (b) following a rapid "bloom" of intense growth in the upper reservoir, phytoplankton standing crop gradually declines as water moves downstream towards the dam; and, © in general, vertical mixing keeps the phytoplankton homogeneously distributed throughout the water column, except at the deepest locations.

Reservoir surface pH ranged from a low of 7.2 at the Middle Reservoir station on 3/9/00 to 8.8 at several stations on 7/23/99 (Appendix B-6). There were no significant differences with respect to location on the reservoir, rather a tendency for all stations to show rather uniform values that fluctuated with sampling date. As previously noted, pH can be influenced by net changes in carbon dioxide concentrations resulting from phytoplankton respiration and photosynthesis. Therefore, the series of "low" values encountered on 3/9/00 may have followed an extended period of respiration, whereas a series of "high" readings such as occurred on 7/23/99 may reflect a short-term history of intense photosynthesis. Overall, pH was markedly higher in the reservoir than in the tributaries (Figure 19), perhaps the result of a more active photosynthetic community in the former, perhaps also because of fundamental changes in water chemistry brought about by the infusion of groundwater into the system.

Except for an occasional elevated value in the Northwest Sector, concentrations of total alkalinity were rather uniform throughout the reservoir on any given date (Appendix B-7). As in the case of pH, there were periods marked with relatively "high" and "low" concentrations. There were no significant differences, either horizontally or vertically, within the reservoir (Figure 20), however, on every sampling date, there was a substantial decrease in total alkalinity between the tributaries and the reservoir. Concentrations of sulfate ranged from 15 ppm at the Lower Reservoir on 4/6/99 to 144 ppm in the Northwest Sector on 10/23/98 (Appendix B-8). Average sulfate concentrations decreased significantly between the upper and lower portions of the reservoir as well as between the surface and the bottom at the Lower Reservoir station (Figure 20). Chloride concentrations varied little in Fort Cobb Reservoir, either spatially or throughout the course of the study. The low was 8.0 ppm in the Northwest Sector on 2/23/98 and the high was 12.75 ppm at three locations on 12/6/99 (Appendix B-9). Mean concentrations throughout the reservoir were very comparable to those in the tributaries and the outflows (Figure 20). As would be expected, the mean relative composition of the major anions in the reservoir was the same as that shown in Figure 11 for the outflows *i.e.* 52% total alkalinity, 41% sulfate and 7% chloride. When compared to the tributaries, this composition most closely resembled that found in Cobb Creek (Figure 11).

Nitrate-N in Fort Cobb Reservoir ranged from < 10 ppb at the Lower Reservoir station on 7/23/99 to 980 ppb at the Middle Reservoir on 5/13/98 (Appendix B-10).

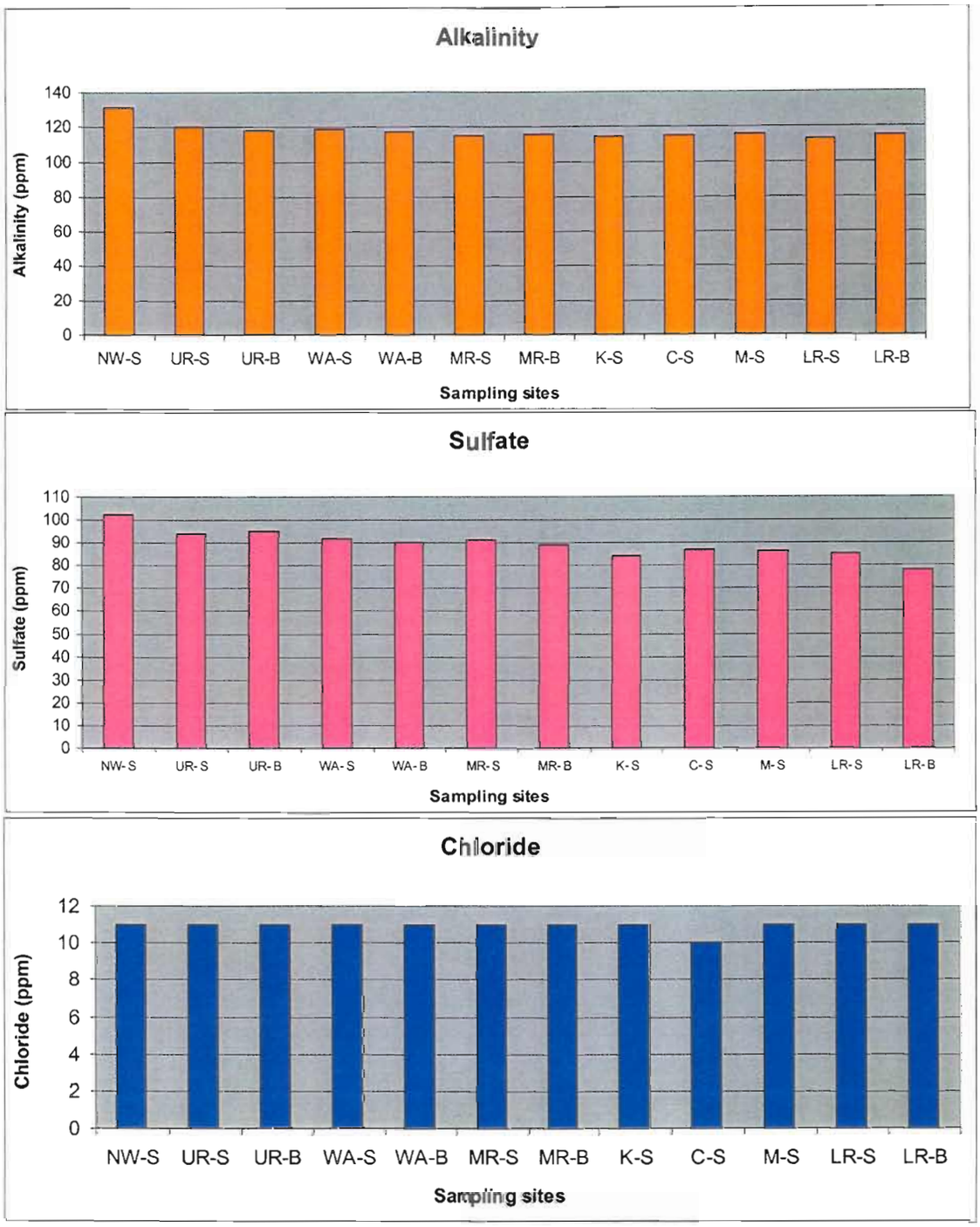


Figure 20. Mean concentration of major anions at each reservoir sampling station.

There appeared to be a rather strong seasonal component to nitrate-N distribution, with lowest concentrations occurring in late summer and highest concentrations in late spring/early summer. There were no significant differences between the upper and lower portions of the reservoir or between surface and bottom samples (Figure 21). Overall, nitrate-N concentrations in the reservoir were greatly reduced in comparison to the tributaries. Concentrations of ammonia-N increased significantly from the upper to the lower end of the reservoir (Figure 21). Seasonal ammonia-N lows corresponded with the late summer lows in nitrate-N, while seasonal highs in ammonia-N preceded those for nitrate-N by occurring in late winter/early spring (Appendix B-11). There were no significant differences between means for surface and bottom samples at any station, however, evidence of strong ammonia-N stratification during certain periods can be noted from the data on specific dates (e.g. on 8/11/98). In general, ammonia-N concentrations in the reservoir were markedly higher than those in the tributaries. Reservoir concentrations of nitrite-N ranged from 1 ppb at various stations on several dates to over 350 ppb near the bottom of the Lower Reservoir station on 8/11/98 (Appendix B-12). Although the spatial distribution was somewhat sporadic on certain dates, there were no significant differences between mean concentrations at any of the stations or between surface and bottom samples (Figure 21). Over the course of the study, nitrite-N concentrations in the reservoir were comparable to those found in the tributaries. Total-N ranged from 450 to 3600 ppb in the reservoir (Appendix B-13). Mean values were comparable throughout the reservoir with no significant differences between the upper and lower reaches or between surface and bottom samples (Figure 21). There appeared to be a slight decrease in reservoir concentrations compared to the tributaries. One of the earlier discussions, relating to chlorophyll distribution in the reservoir, suggested that nutrients entering the headwaters are rapidly incorporated into organic matter by phytoplankton, which in turn gradually decrease in abundance as water moves downstream. Such a hypothesis would seem to be supported by the reservoir nitrogen data as well. In the upper portions of the reservoir, organic nitrogen increases from around 50% of the total (in the tributaries) to about 70% to 80%. The percentage of organic nitrogen then gradually decreases downstream with a concurrent increase in ammonia, which is the first degradation product of organic nitrogen. By the time the water reaches the dam, the organic:inorganic nitrogen ratio is approximately the same as in the tributary streams (Figure 22).

Total phosphorus in Fort Cobb Reservoir was consistently less than that found in the primary tributaries, with a maximum of 752 ppb in the Willow Creek Arm (bottom) on 9/21/99 (Appendix B-14). Mean concentrations of total-P ranged from 105 ppb at the Middle Reservoir surface to 204 ppb at the Northwest Sector (Figure 23). There were no significant differences found between surface and bottom samples nor between the upper and lower reservoir stations. In comparison to the tributaries, SRP was also substantially reduced at all of the reservoir stations. Concentrations below the detection limit (10 ppb) occurred during all seasons, with maxima occurring during July, 1999 (Appendix B-15). Mean concentrations of SRP did not vary significantly throughout the reservoir either vertically or horizontally (Figure 23). However, on specific occasions, notable differences could be detected between surface and bottom samples (e.g. 7/23/99) or between the headwaters and the dam (e.g. 4/6/99). Overall, there are some similarities between the ratios of organic and inorganic phosphorus in the reservoir (Figure 24) and those previously discussed for nitrogen. First, the proportion of organic phosphorus suddenly increases from around 40 to 50 percent in the tributaries to over 70 percent in the upper portions of the reservoir, presumably due to the rapid synthesis of organic matter by phytoplankton.

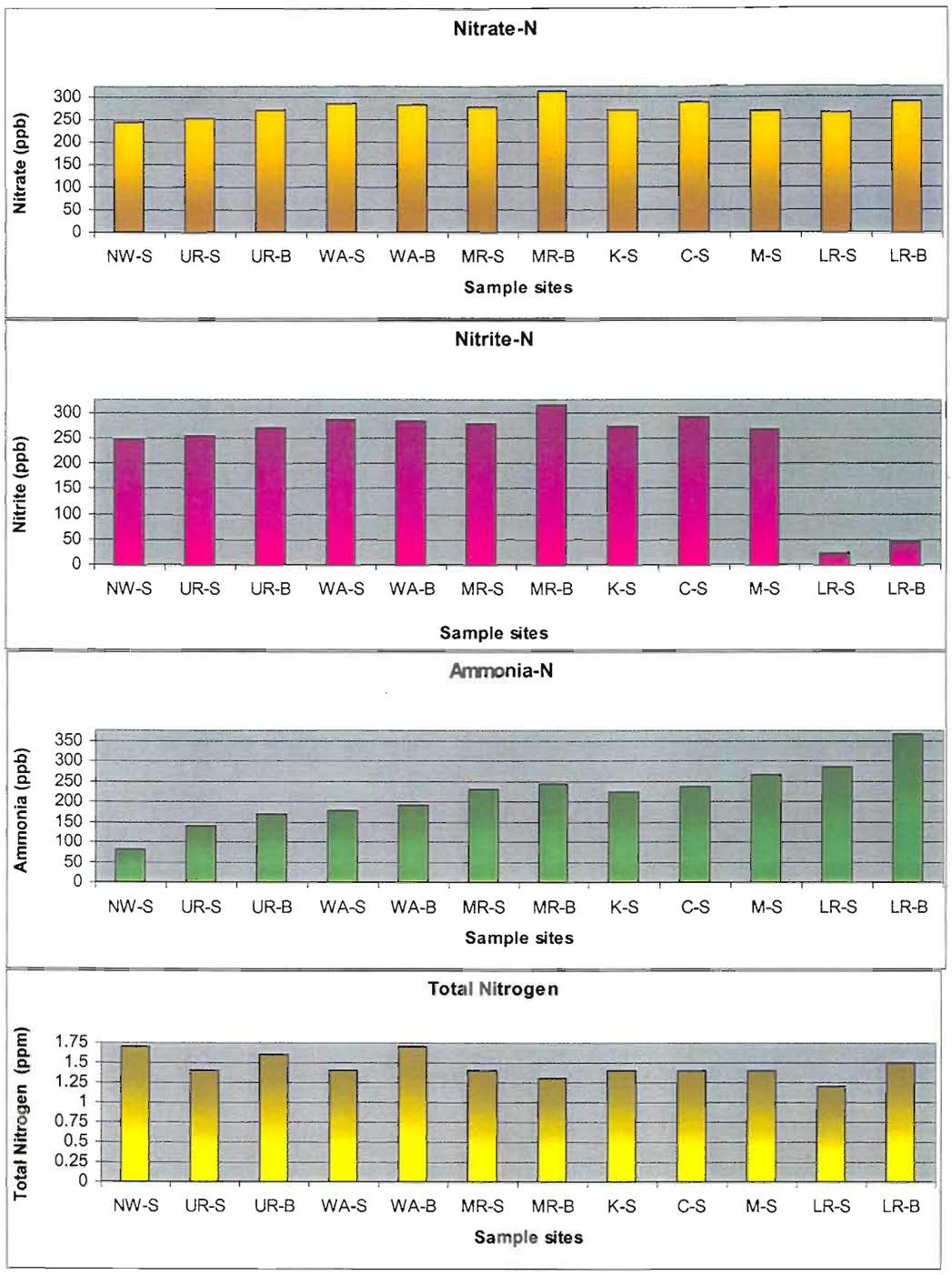


Figure 21. Mean concentration of nitrate, ammonia, nitrite, and total nitrogen at each reservoir sampling station.

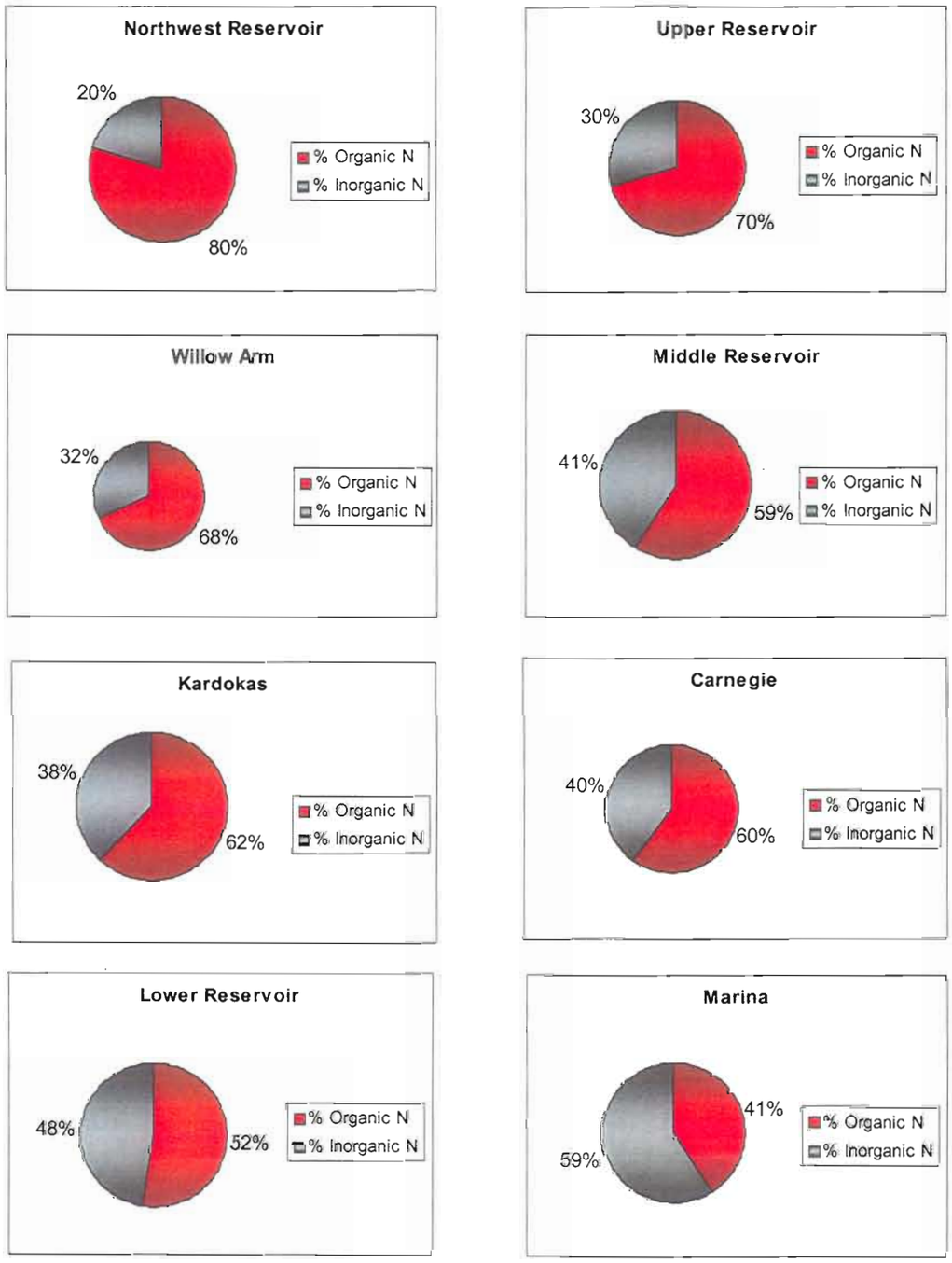
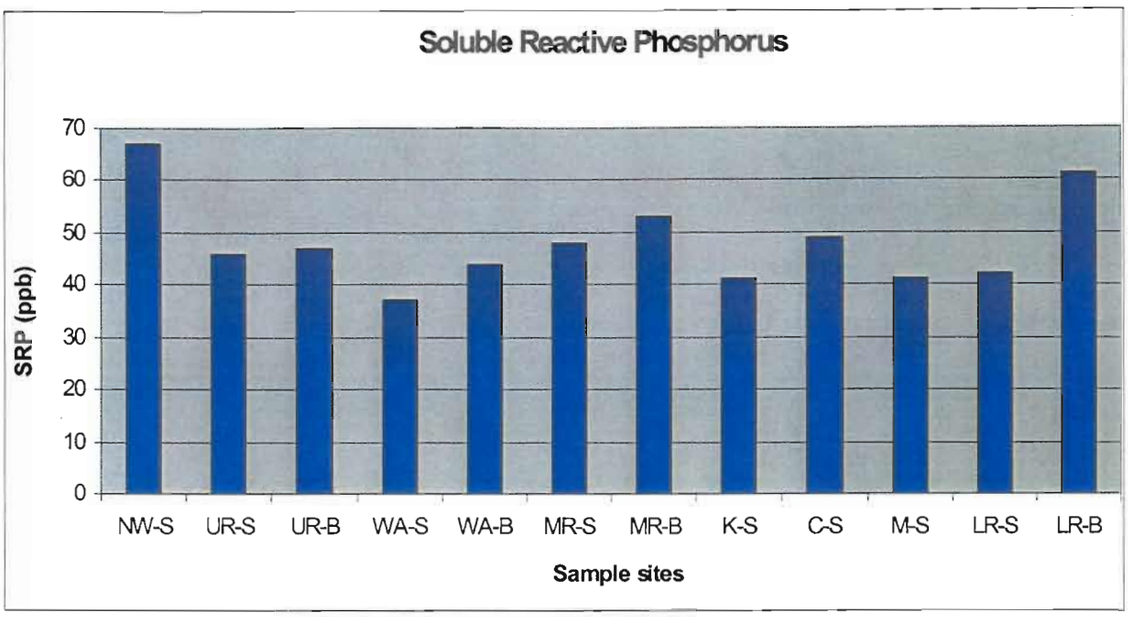


Figure 22. Mean relative composition of organic and inorganic nitrogen at each reservoir sampling station.



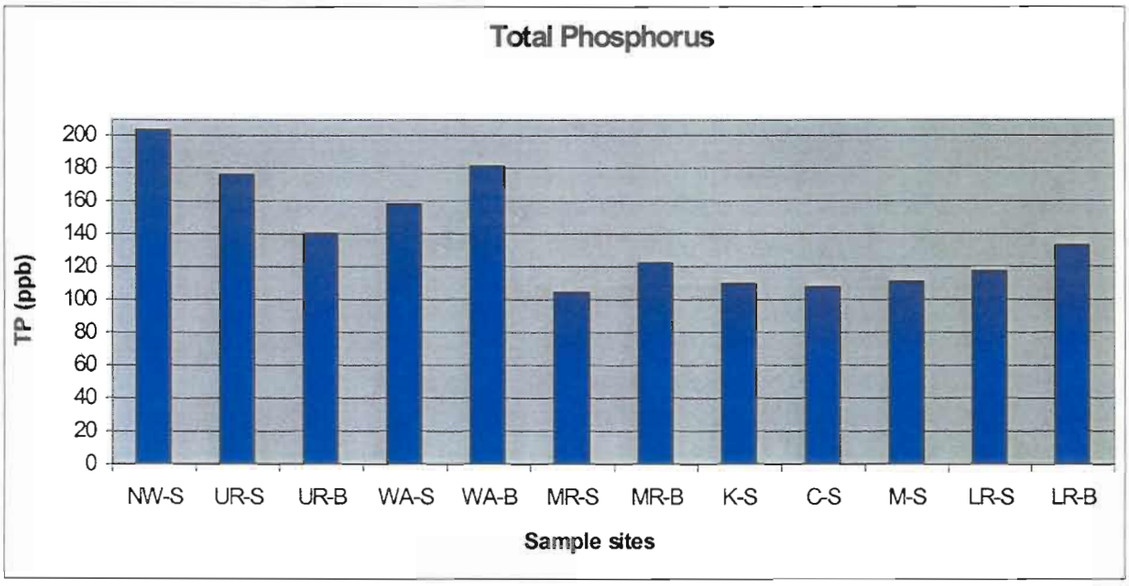


Figure 23. Mean concentration of soluble reactive phosphorus and total phosphorus at each reservoir sampling station.

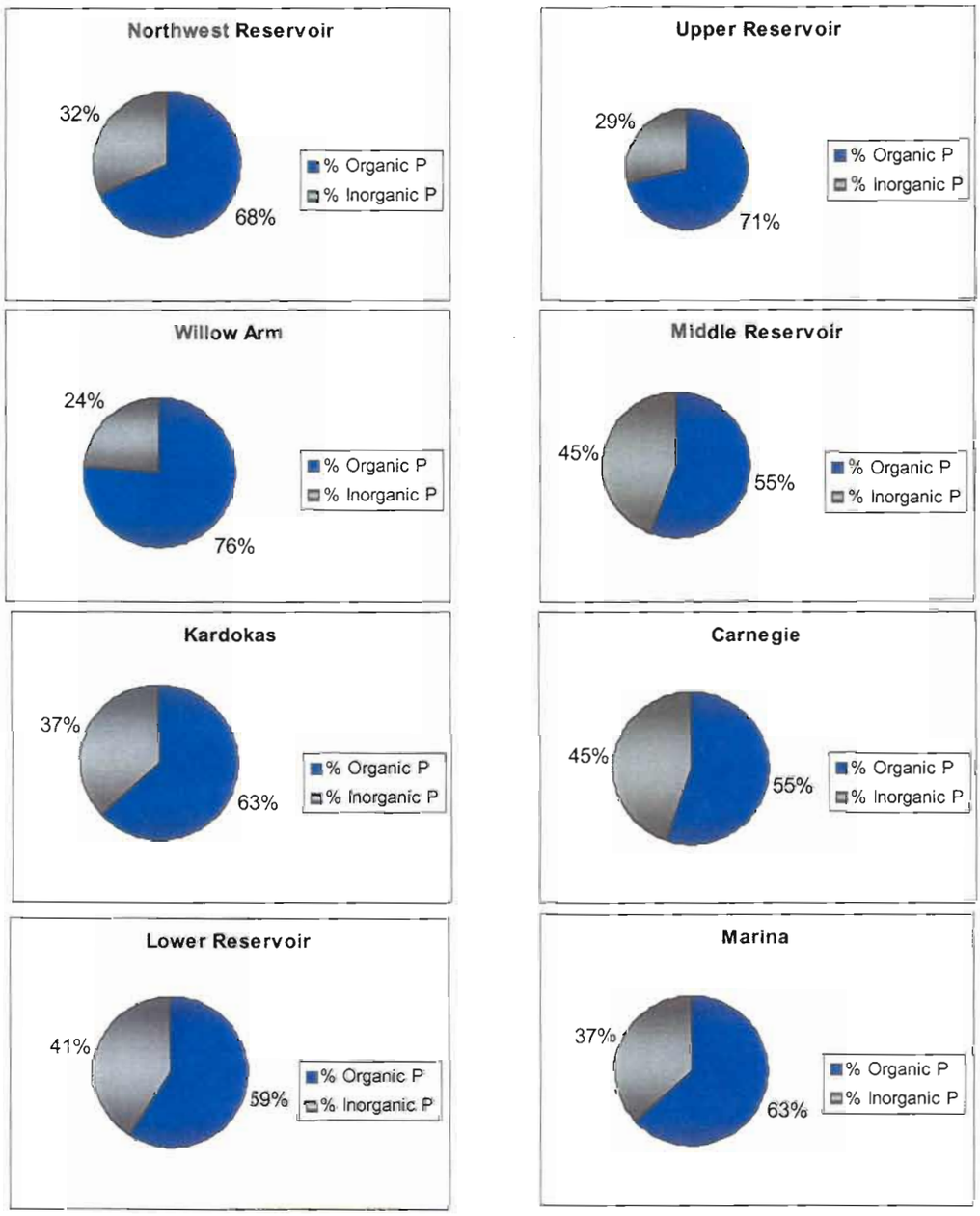


Figure 24. Mean relative composition of organic and inorganic phosphorus at each reservoir sampling station.

Second, as water moves downstream, there is a reduction of total phosphorus, particularly in the surface water (presumably due to the sinking and deposition of organic matter), and the proportion of organic phosphorus is somewhat reduced.

2. Sediment

QA/QC data for reservoir sediment samples are included with data from the tributaries in Appendix A-3 and are therefore subject to the discussion on QA/QC presented in Section IV.A.2. The physical properties of the reservoir sediment samples were more variable than expected. Sand ranged from 4.7% in a sample from the Willow Creek Arm to 97.6% in one from the Marina Cove. TOC varied from 0.3% in the aforementioned Marina Cove sample to 2.9% in a sample from the Lower Reservoir station. This range in texture and organic matter content allowed for the same type of comparison between bulk elemental concentrations (ppm) and TOC and aluminum, that was carried out with the tributary samples. As shown in Table 5, the correlations were quite good. All elements except arsenic were significantly correlated with aluminum at $p<0.01$, and even arsenic was significant at $p<0.05$. Therefore, elemental concentrations in reservoir sediment were geochemically normalized to aluminum as described in Section IV.A.2. Although a statistical comparison between normalized reservoir and tributary concentrations was not carried out, it is apparent from Table 6 that reservoir values were very similar to those in the various tributaries. In short, reservoir sediments appear to reflect the same geochemical nature as their source, without notable enrichment or dilution.

There are presently no official standards or criteria in the United States for elements in aquatic sediment. Ontario recently implemented chemical standards for the management and protection of sediments in that province (Persaud *et al.* 1993), while Long and Morgan (1990) have published guidelines for the "unofficial" evaluation of chemical constituents in sediment samples that are collected by the National Oceanic and Atmospheric Administration's National Status and Trends Program. Both systems are based on extensive reviews of the literature, but use somewhat different approaches for interpretation, and hence are not always in strict agreement. In Table 8, average and maximum bulk concentrations (ppm dry weight) of elements found in sediments from Fort Cobb Reservoir are compared to the criteria listed (or suggested) in these two references. Four elements (cadmium, mercury, lead and zinc) appeared well below the concentrations at which even the slightest risk to aquatic life was predicted. Maximum concentrations of these elements in the reservoir were below the lowest-effect values given in both systems. Three elements (chromium, copper, and nickel) would appear to pose minimal risk to benthic animals, since their average concentrations were only slightly higher that the lowest-effect level of Persaud *et al.* (1993), while their maximum concentrations were well below the moderate- or severe-effect levels of either system. The two elements (iron and manganese) that are listed only by Persaud *et al.* (1993), would appear to pose a somewhat higher risk than those mentioned thus far because of the fact that their mean concentrations exceed the lowest-effect level and their maximum concentrations are near the severe-effect level. The remaining element for which there are guidelines (arsenic) may pose the highest risk of any listed. The mean reservoir concentration is higher than Ontario's lowest-effect level, while the maximum concentration exceeds both Long and Morgan's (1990) ER-L and Persaud *et al.* (1993) severe-effect standard. Substantial disagreement between the two methods with respect to arsenic makes interpretation difficult. In summary, on the basis of these two guidelines, it appears that sediments in Fort Cobb Reservoir are not particularly hazardous to benthic aquatic life in general, but may pose a slight threat to the most sensitive species.

3. Fish

Several elements are essential for various biochemical reactions in fish, and are thus always present in trace amounts. Others are non-essential, but may also be present at detectable concentrations. Different species of fish, taken from the same location, often contain different concentrations of a particular element due to differences in (1) physiology, (2) foraging strategies, or (3) exposure conditions (Wiener and Giesy, 1979; Lowe *et al.* 1985; Campbell, 1994). In Fort Cobb Reservoir, channel catfish were significantly higher in aluminum, boron, iron and manganese than either common carp or walleye (Table 9). Common carp were higher in chromium and zinc than either channel catfish or walleye; and channel catfish and common carp were both higher than walleye in copper, nickel, strontium and vanadium. Despite these *inter*specific variations, the three species exhibited similar concentrations with respect to over half of the elements analyzed.

Table 8. Mean and maximum bulk concentrations (ppm dry weight) of elements in Fort Cobb Reservoir sediment compared to sediment quality guidelines in Long and Morgan (1990) and Persaud et al. (1993).

Element	Fort Cobb Reservoir		Long and Morgan		Persaud et al.		
	Mean	Maximum	ER-L[a]	ER-M[b]	Background[c]	Lowest Effect	Severe Effect
Aluminum	29,595	46,100	-	-	-	-	-
Arsenic	12	39	33	85	4.2	6	33
Boron	6.3	22	-	-	-	-	-
Barium	213	316	-	-	-	-	-
Beryllium	1.6	2.4	-	-	-	-	-
Cadmium	0.22	0.48	5.0	9.0	1.1	0.6	10
Calcium	24,424	37,600	-	-	-	-	
Cobalt	9.1	12	-	-	-	-	-
Chromium	30	44	80	145	31	26	110
Copper	18	27	70	390	25	16	110
Iron	26,222	39,100	-	-	31200	20,000	40,000
Mercury	0.01	0.02	0.15	1.3	0.10	0.2	2.0
Potassium	4135	6,720	-	-	-	-	-
Magnesium	7,118	10,300	-	-	-	-	-
Manganese	654	1,150	-	-	400	460	1,100
Molybdenum	0.70	1.10	-	-	-	-	-
Nickel	2,250.00	3,360	-	-	-	-	-
Nickel	22	32	30	50	31	16	75
Phosphorus	558	925	-	-	-	-	-
Lead	17	26	35	110	23	31	250
Sulfur	2,740	5,570	-	-	-	-	-
Selenium	0.33	0.05	-	-	-	-	-
Strontium	239	370	-	-	-	-	-
Vanadium	46	71	-	-	-	-	-
Zinc	63	95	120	270	65	120	820

[a] Effects Range-Low [b] Effects Range-Medium
[c] Based on Analysis of pre-colonial sediment horizons form the Great Lakes

There are no standardized guidelines or criteria for elemental concentrations in fish. In

general, an evaluation of conditions in Fort Cobb Reservoir can only be determined by comparing the data from this study with other datasets (*e.g.* Schmitt and Brumbaugh, 1990) and recommendations for specific elements from the literature. Arsenic does not normally biomagnify in fish (Winger *et al.* 1990), and it has been observed that accumulations of this element are generally higher in planktivorous fishes than in predators and omnivores (Hunter *et al.* 1981). The concentration of arsenic in every fish sample from Fort Cobb Reservoir was less than the detection limit (0.50 ppm), which is less than the mean of 0.56 ppm for the National Contaminant Biomonitoring Program (NCBP), and well below the NCBP 85th percentile concentration of 1.1 ppm (Table 9). Arsenic is not considered to be a contaminant problem in Fort Cobb Reservoir.

Table 9. Average concentrations (ppm dry weight) of elements in whole body fish from Fort Cobb Reservoir. Different lower case letters indicate significant differences among among the three species.

Element	Channel Catfish (n=6)	Common Carp (n=6)	Walleye (n=6)	All Species NCBP 85th % (n=315)
Aluminum	1066 ^{b}	179 $_{a}$	8.0 $_{a}$	-
Arsenic	< 0.5 ^{a}	< 0.5 $_{a}$	< 0.5 $_{a}$	1.1
Boron	2.6 ^{b}	< 1.0 $_{a}$	< 1.0 $_{a}$	-
Barium	15 ^{a}	6.6 $_{a}$	1.0 $_{a}$	-
Beryllium	< 0.1 ^{a}	< 0.1 $_{a}$	< 0.1 $_{a}$	-
Cadmium	< 0.2 ^{a}	< 0.2 $_{a}$	< 0.2 $_{a}$	0.2
Chromium	1.8 ^{b}	3.3 $_{a}$	< 0.5 $_{c}$	-
Copper	3.9 ^{a}	2.7 $_{a}$	1.3 $_{b}$	4
Iron	806 ^{a}	305 $_{b}$	43 $_{c}$	-
Mercury	0.16 ^{a}	0.4 $_{a}$	0.30 $_{a}$	0.68
Magnesium	1094 ^{a}	1676 $_{a}$	911 $_{a}$	-
Manganese	59 ^{b}	22 $_{a}$	1.4 $_{c}$	-
Molybdenum	< 0.3 ^{a}	< 0.3 $_{a}$	< 0.3 $_{a}$	-
Nickel	5.8 ^{a}	5.6 $_{a}$	0.6 $_{b}$	-
Phosphorus	9108 ^{a}	12180 $_{a}$	8993 $_{a}$	-
Lead	< 0.5 ^{a}	< 0.5 $_{a}$	< 0.5 $_{a}$	0.88
Sulfur	6592 ^{a}	7102 $_{a}$	7497 $_{a}$	-
Selenium	0.8 ^{a}	1.3 $_{a}$	1.1 $_{a}$	2.9
Strontium	74 ^{a}	82 $_{a}$	22 $_{b}$	-
Vanadium	1.8 ^{a}	0.8 $_{a}$	< 0.30 $_{b}$	-
Zinc	48 ^{a}	251 $_{b}$	28 $_{a}$	136

* Values for the 85th percentile from the National Contaminants Biomonitoring Program (Schmitt & Brumbaugh, 1990) are shown for comparison.

Cadmium is highly toxic to fish, and may be present in a variety of industrial and municipal wastes. Except for one common carp, concentrations of cadmium were below the detection limit (0.20 ppm) in every fish sample. Schmitt and Brumbaugh (1990) noted that carp were higher in cadmium than other species in the NCBP data set. Eisler (1985) suggested 0.40 ppm as a dietary threshold concentration for cadmium in food-chain organisms. Since cadmium concentrations in this study were consistently below the NCBP 85th percentile value of 0.20 ppm, cadmium would not appear to be a problem in these waters.

Copper contamination in aquatic environments may result from urban runoff, sewage treatment plants, leachates from municipal landfills and a variety of industrial discharges. The mean concentration of copper in channel catfish and common carp from Fort Cobb Reservoir was greater than the NCBP mean (2.6 ppm) but less than the 85th percentile (Table 9). The National Research Council (1980) recommends 1,200 ppm copper as the dietary threshold concentration for food-chain organisms. Therefore, copper is not considered a problem.

Although mercury is released into the environment through the weathering of natural geologic sources, anthropogenic enrichment has been estimated to be about 10 times the natural rate during the past 100 years (Moore and Ramamoorthy, 1984). Mining operations, the use of mercurials in seed dressings, fungicides, paints and slimicides as well as fossil-fuel combustion are just a few of the sources of mercury to aquatic ecosystems. Mercury concentrations in fish from Fort Cobb Reservoir ranged from 0.11 ppm in one channel catfish to 0.82 ppm in one walleye (Appendix D-1). Although predators normally accumulate the highest amounts of mercury in aquatic food-chains, there were no significant differences in mean concentrations among the three species in this study (Table 9). Since mean concentrations shown in Table 9 are near the NCBP mean of 0.40 ppm and below the 85th percentile value, mercury does not appear to be a contaminant threat in Fort Cobb Reservoir.

Lead is used extensively in today's society and may occur at elevated concentrations in aquatic environments from a variety of sources. Campbell (1994) reported lead concentrations of about 50 ppm in largemouth bass from "contaminated" stormwater ponds, while the same species from "control" ponds contained about 25 ppm. Redear sunfish from the same sites contained 63 and 28 ppm lead, respectively. The National Research Council (1980) recommended 200 ppm lead as the dietary threshold concentration for food chain organisms. Lead ranged from < 0.50 to 1.4 ppm in fish from Fort Cobb Reservoir (Appendix D-1), with only one channel catfish exceeding the NCBP 85th percentile concentration of 0.88 ppm. These data indicate that lead contamination is not a problem.

Selenium has received much attention in recent years as a contaminant in aquatic systems due to its propensity for bioaccumulation and resultant reproductive failure in higher members of the aquatic food chain. The amount of research that has been conducted on the ecological fate and effect of this element has led to consensus guidelines for threshold concentrations in biotic and abiotic components of aquatic ecosystems. Lemly (1993) suggested that 3 ppm be considered the toxic effects threshold for food-chain organisms, and that whole-body concentrations of 4 ppm be considered threshold for mortality of juveniles and reproductive failure in fish. Mean concentrations of selenium in fish from Fort Cobb Reservoir were well below these threshold values, and the NCBP 85th percentile concentration as well (Table 9).

Zinc is a fairly common element that is often found as a contaminant in urban runoff, industrial effluents, landfill leachates and sewage sludge. As seen in Table 9, common carp have a propensity to concentrate unusually high concentrations of zinc, a fact that has been noted previously by other authors (e.g. Lowe *et al.* 1985). Eisler (1993) suggested 180 ppm as the dietary threshold for zinc in food-chain organisms, a concentration well above that which was observed in channel catfish and walleye from Fort Cobb Reservoir. Zinc in largemouth bass from contaminated stormwater runoff ponds averaged 120 ppm (Campbell, 1994). A comparison of zinc concentrations in common carp from Fort Cobb Reservoir with those reported for the same

species in the NCBP by Schmitt and Brumbaugh (1990), revealed a very similar range in values and a very comparable mean (243 ppm).

Nickel is a contaminant often associated with municipal landfills, coal-fired power plants, metal plating industries and sewage sludge. Jenkins (1980) reported that freshwater fish from uncontaminated areas usually contain between < 0.80 and 8.0 ppm. Campbell (1994) found an average of 4.8 ppm in largemouth bass from control areas in his study. Gar from the Savannah River ranged from 9.4 to 27 ppm (Winger *et al.*, 1990) and largemouth bass from stormwater runoff ponds in Florida averaged 10 ppm (Campbell, 1994). There was substantial *inter-* and *intra*specific variation with respect to nickel concentrations in fish from Fort Cobb Reservoir (Appendix D-1). At least one channel catfish and two common carp exceeded 10 ppm. Mean values however (Table 9), were within the range of background concentrations reported by other authors.

Chromium contamination in aquatic environments is often associated with the electroplating industry or with cooling water from electric power generation. Apparently, this element is readily absorbed and rapidly eliminated by fish. Eisler (1986) reported that the significance of chromium residues is unclear, but available evidence suggests that concentrations in excess of 4.0 ppm should be viewed as presumptive evidence of chromium contamination. Only one common carp from Fort Cobb Reservoir exceeded this concentration (Appendix D-1), and Table 9 indicates that mean values for all three species was well below this level.

The ecological significance of the remaining elements shown in Table 9 is unclear. Some, like iron and magnesium are known to be essential, while others like beryllium and vanadium are not well understood. Overall, the whole-body fish data from this study yielded no clear evidence of elemental contaminant problems in Fort Cobb Reservoir. For the most part, concentrations of individual elements ranged in the vicinity of values shown by other authors to be normal or below suggested dietary threshold concentrations for food-chain organisms. These data are consistent with the earlier evaluation of no serious elemental contamination based on concentrations in reservoir sediment.

4. Limnology

The purpose of the limnological profiling was to characterize the vertical and/or horizontal gradients of important physical, chemical and biological properties within Fort Cobb Reservoir. In moderately deep bodies of water in the Temperate Zone, thermally induced density stratification often commences in the spring and persists throughout the summer. These stratified conditions are normally preceded and followed by periods of vertical mixing, often referred to as spring and/or fall "turnover". Wind-induced turbulence and water depth play very important roles in determining how this generalized scenario plays out at specific locations, both within a water body and for the reservoir as a whole.

The most pronounced instance of thermal stratification encountered during this study was on July 13, 1998 (Figure 25). On this date, the surface to bottom temperature gradient was greatest at all eight stations on the reservoir, and ranged from 1.6 °C in Marina Cove to 4.6 °C at the Middle Reservoir station. The surface to bottom temperature gradient during the remaining eleven months

averaged less than 1.0 °C, and except for the Lower Reservoir station, never exceeded 1.5 °C (Table 10). Periods of vertical temperature homogeneity occurred on one or more occasions at

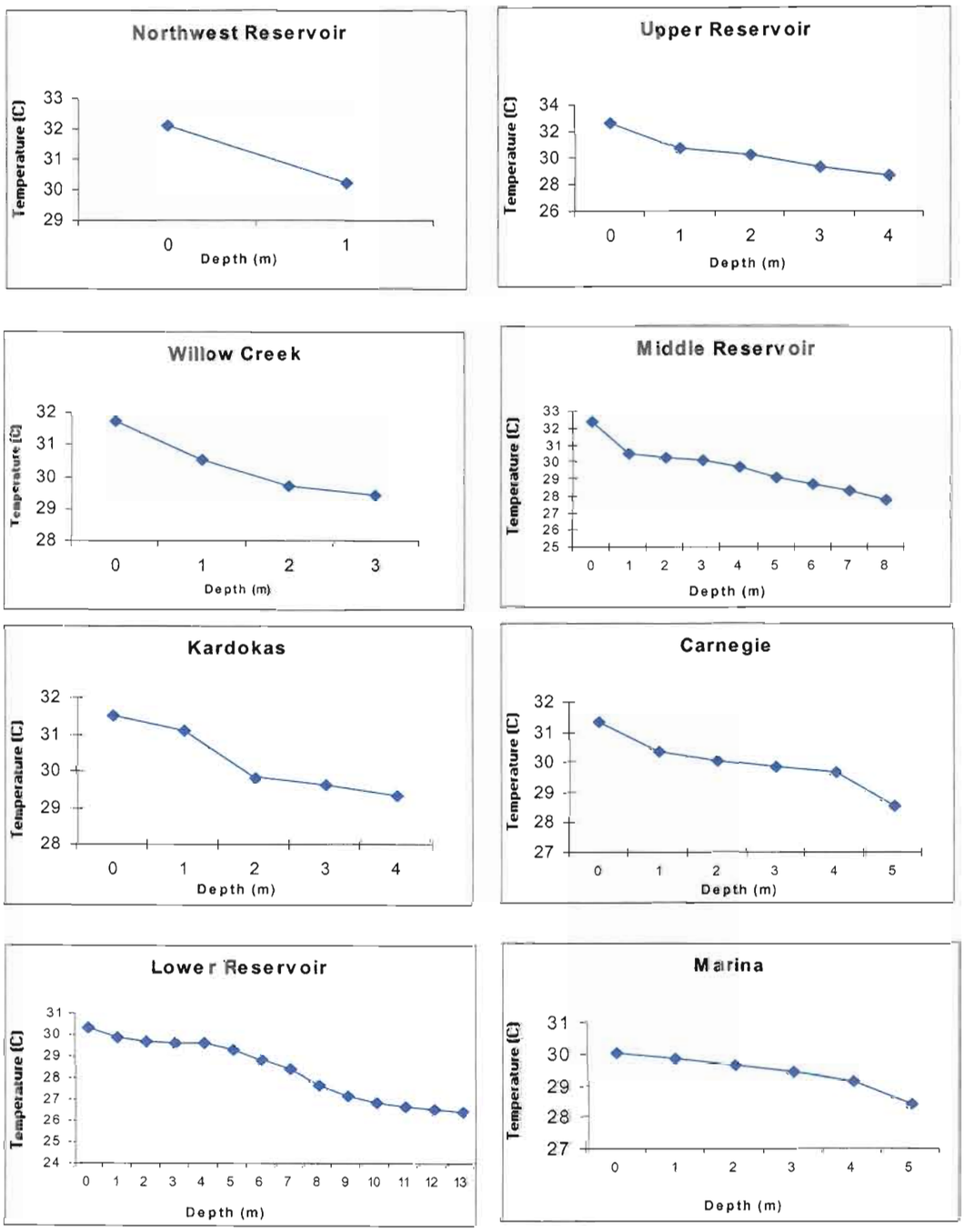


Figure 25. Temperature (C) profiles at eight locations on Fort Cobb Reservoir on 13 July 1998.

every station. Interestingly however, the dates for complete thermal mixing did not coincide at all stations. Wind and depth are undoubtedly important factors regulating the degree of thermal stratification in Fort Cobb Reservoir at all times of the year. In general, our data suggest that: (1) periods of weak thermal stratification occur during summer in deeper portions of the reservoir, probably following prolonged periods of calm; and, (2) wind-induced turbulence results in the

Table 10. Summary of temperature, conductivity and dissolved oxygen profiles at eight limnological sampling stations in Fort Cobb Reservoir.

	Depth (m)	Temperature (°C)		Conductivity (umhos/cm)		Dissolved Oxygen (ppm or mg/L)	
Location	mean	mean	range	mean	range	mean	range
Northwest Sector	2.0 6.5[1]	0.5	0 - 1.5	17	0 - 84	0.8	0.1 - 3.9
Upper Reservoir	4.4 14.5[1]	0.4	0 - 1.2	5	0 - 13	1.2	0.1 - 4.0
Willow Creek Arm	4.0 13.0[1]	0.5	0 - 1.3	3	0 - 10	1.0	0 - 2.7
Middle Reservoir	8.8 29.0[1]	0.5	0 - 1.5	6*	1 - 19	1.9	0.3 - 5.2
Kardokas Slough	4.6 15.0[1]	0.5	0.1 - 1.1	2	0 - 5	0.7	0.1 - 1.8
Carnegie Cove	5.2 17.0[1]	0.5	0 - 1.1	2*	0 - 7	0.8	0 - 2.2
Marina Cove	5.1 16.5[1]	0.8	0.1 - 1.5	5*	1 - 14	1.0	0.3 - 2.8
Lower Reservoir	14.1 46.5[1]	0.8	0 - 2.2	12*	0 - 71	2.6	0.1 - 6.5

Values represent the surface to bottom gradient at each station for all twelve months except for the July, 1998 sampling trip when the reservoir was most stratified.

[1] Units are in feet * Excludes 10/21/98 and 7/13/98

formation of only slight thermal gradients, or nearly complete thermal homogeneity, in the more shallow areas year-around.

The effects of even a weakly defined thermal gradient on the chemical environment of Fort Cobb Reservoir can be illustrated by considering the conductivity and dissolved oxygen (DO) profiles that were taken concurrently with temperature. Conductivity increased with depth at all eight stations on July 13, 1998 (Figure 26), indicating that some degree of chemical stratification accompanied the thermal layering previously noted. Of particular significance is the marked increase in conductivity that occurred below nine meters at the Lower Reservoir station. This profile clearly shows that the ionic strength of the water below this depth in the reservoir had been altered (*i.e.* increased) markedly. An examination of the DO profiles taken on this same date (Figure 27) reveals a corresponding pattern. D.O. decreased markedly with depth at all eight stations with essentially anoxic conditions prevailing in the reservoir below eight meters (see Lower Reservoir station). Taken together, these profiles show that prior to July 13, 1998, respiration in Fort Cobb

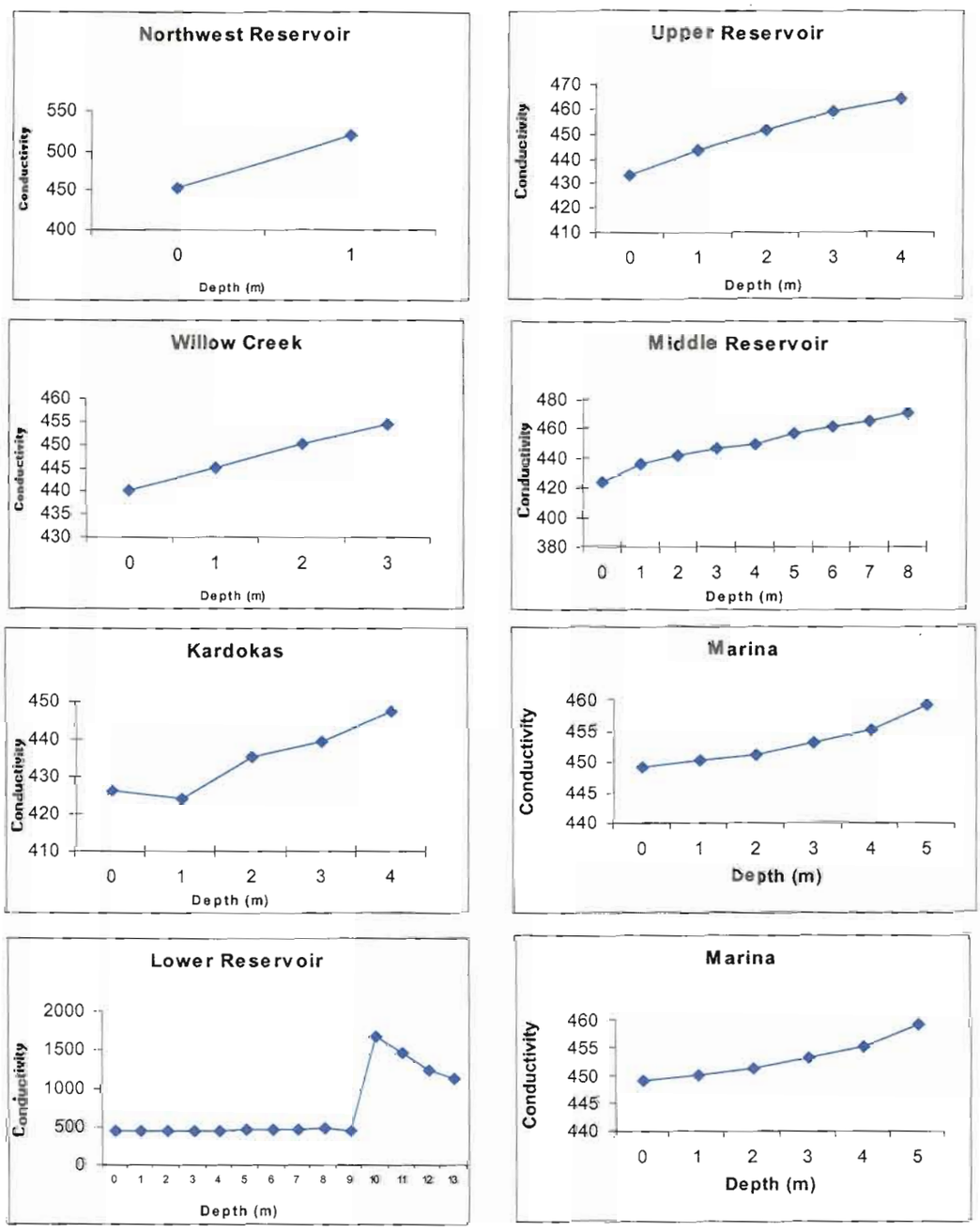


Figure 26. Conductivity (micromhos/cm) profiles at eight locations on Fort Cobb Reservoir on 13 July 1998.

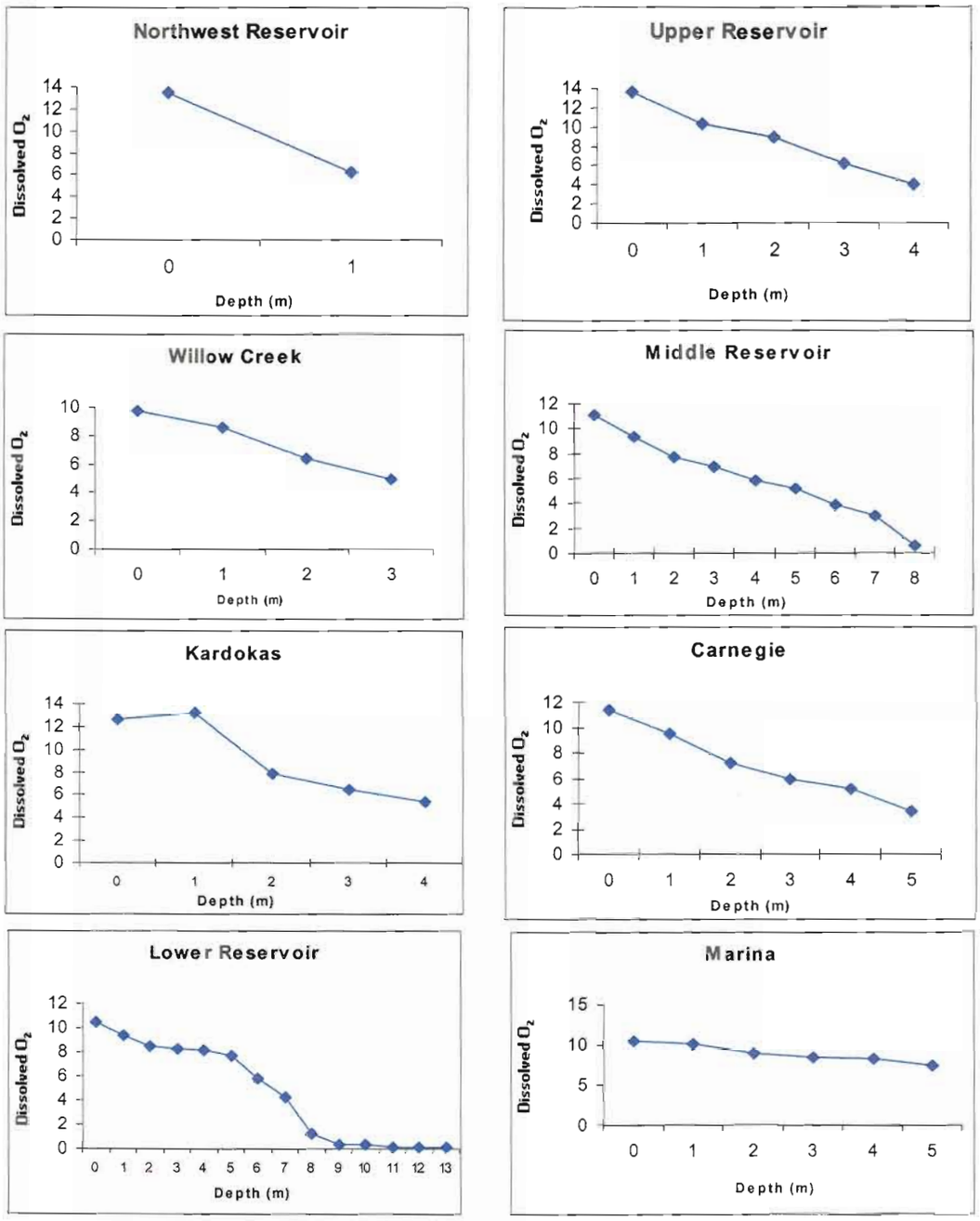


Figure 27. Dissolved Oxygen(mg/L) profiles at eight locations on Fort Cobb Reservoir on 13 July 1998.

reservoir and it's sediments had removed oxygen from the deep water layers faster than it could be replenished by mixing from the surface layers. This process continued, until by the time of the July 13 profiles, DO had been completely removed up to a depth of about eight to nine meters. In this highly reduced, anoxic condition, various ions were released from the sediments into the overlying water, resulting in greatly increased conductivities in the anoxic zone. It is not known how long this process continued after the July 13 profiles were taken, but the effects of the summer stagnation were still apparent at the next quarterly sampling on October 21, 1998. On this date, the density layer had risen to the four meter depth, and had spread throughout the lower half of the reservoir (Figure 28). When the July and October, 1998 profiles are excluded, Table 10 shows that very little chemical stratification was found at any of the reservoir stations on any of the remaining sampling dates. Mean conductivity gradients were less than ten micromhos/cm at all stations except the Northwest Sector and the Lower Reservoir stations. One other instance of complete oxygen depletion in the deeper layers of Fort Cobb Reservoir was encountered on August 16, 1999. On this date, DO was absent below the eleven meter depth at the Lower Reservoir station. Except for the July 1998 sampling date, the mean DO gradient averaged about one to two ppm throughout the reservoir (Table 10). In regard to chemical stratification in Fort Cobb Reservoir, these data suggest that: (1) Complete oxygen depletion probably occurs at lower depths in the water column every summer during periods of calm; (2) when the water overlying the sediments goes anaerobic, various ions (including nutrients) are released into the water column; and (3) following these periods of summer stagnation, water from the anoxic zone is mixed into the upper layers, resulting in a fresh supply of nutrients to the surface layers and the replenishment of oxygen to the deeper layers.

Solar radiation is vital to the metabolism of all freshwater ecosystems. Solar energy is converted into organic matter via photosynthesis in the upper layers of Fort Cobb Reservoir and is subsequently transported throughout the system in various forms. All light impinging on the surface of the reservoir however, does not penetrate. A significant portion is reflected and backscattered. Light that does penetrate the water is rapidly attenuated with depth by both absorption and scattering. Absorption and scattering are influenced by the molecular structure of the water and various dissolved constituents, as well as by particulate matter. In this study, we determined an extinction coefficient for solar radiation that includes both the light reflected at the surface and that which is attenuated in the water. In essence, ours is a measurement of the total visible light that is available to photosynthetic organisms inhabiting the water column.

By definition, the *euphotic zone* of a water body is the layer of surface water where light is of sufficient intensity to support photosynthesis. By convention, the lower limit of the euphotic zone is often estimated to be that depth where incident light at the surface is reduced to one per cent. As expected, the penetration of light into Fort Cobb Reservoir gradually increased from the headwaters to the dam (Figure 29). The 95% Confidence Interval for the 1% light depth ranged between 0.81 and 1.18 meters at the Northwest Sector and from 2.42 to 2.74 meters at the Lower Reservoir. In other words, there was nearly a three-fold increase in light penetration (and the average depth of the euphotic zone) between the upper and lower ends of the reservoir. This is important when one considers that the phytoplankton in Fort Cobb Reservoir are almost continually being mixed vertically, from the surface to the bottom as shown by the Water A chlorophyll data (Appendix B-5) and the temperature profiles. Further significance of light penetration and its effect on phytoplankton productivity will be discussed in the following paragraphs.

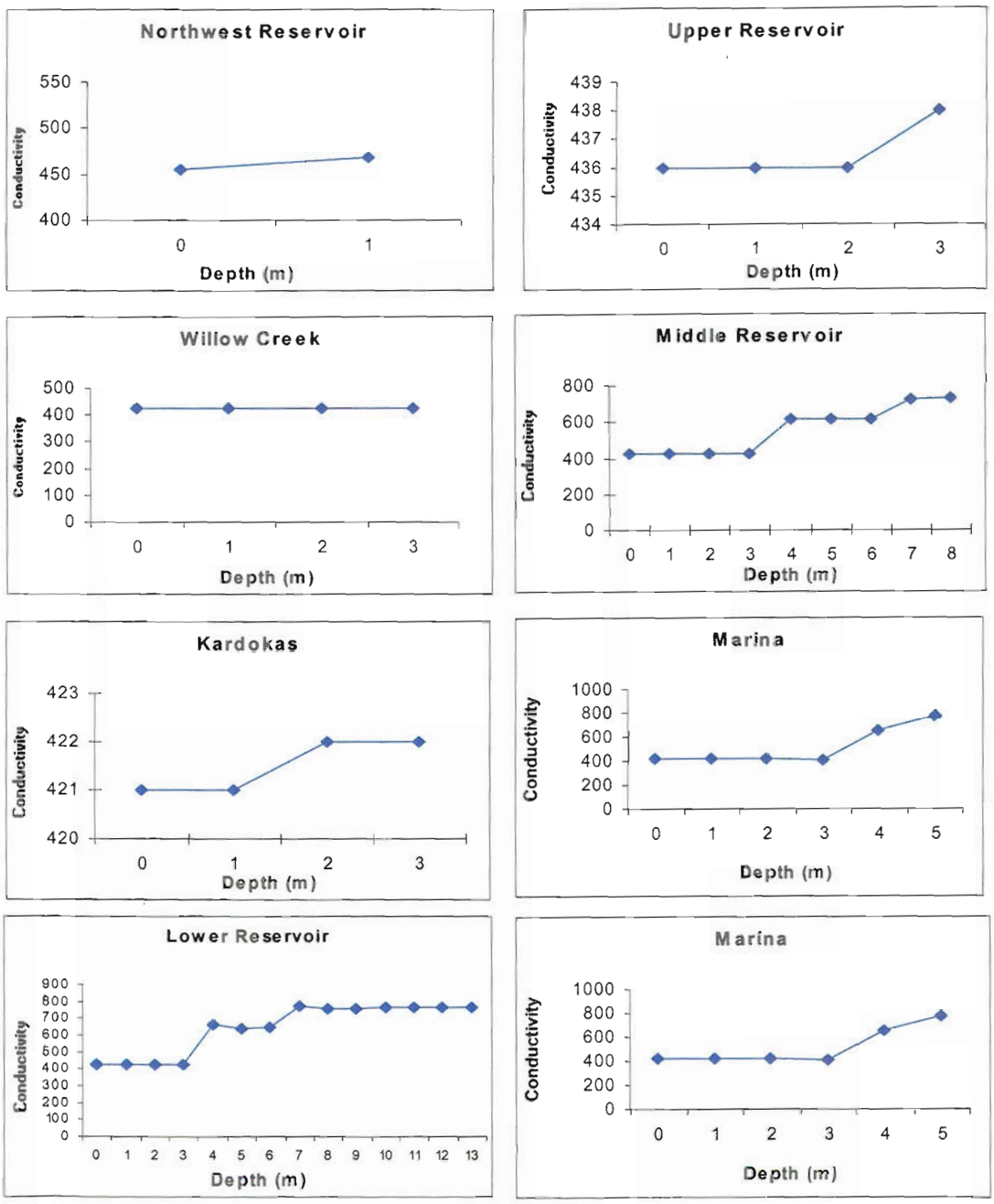


Figure 28. Conductivity (micromhos/cm) profiles at eight locations on Fort Cobb Reservoir on 21 October 1998.

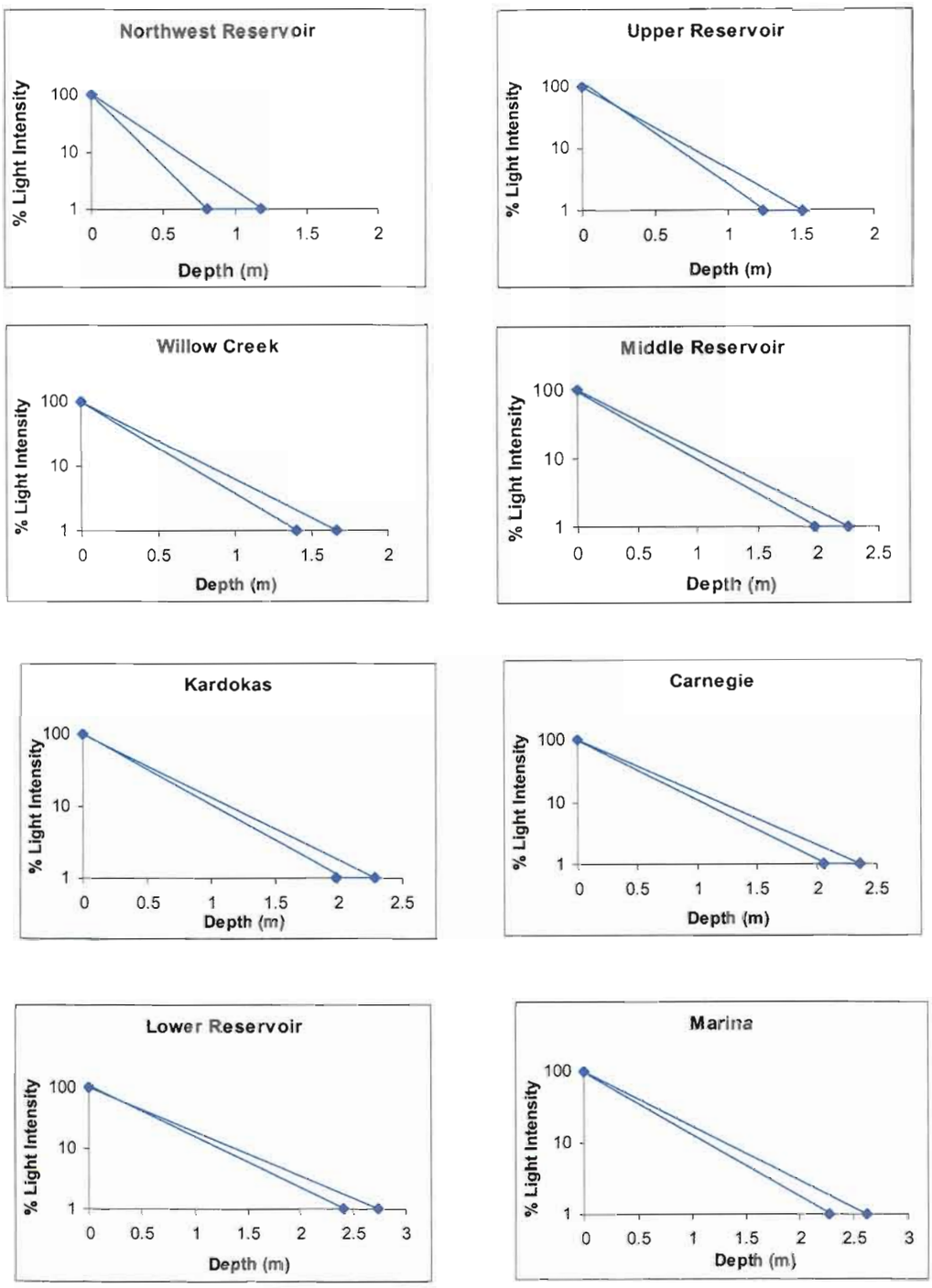


Figure 29. Profiles of visible light penetration at eight locations on Fort Cobb Reservoir. Lines represent 95 % confidence intervals for the entire study period.

Since there are very few aquatic macrophytes and negligible quantities of periphyton present in Fort Cobb Reservoir, phytoplankton is the foundation of primary productivity for this entire system. Due to the time consuming nature of phytoplankton productivity measurements using the light and dark bottle technique, only four of the eight limnological stations (Upper Reservoir, Willow Creek Arm, Middle Reservoir and Lower Reservoir) could be included on each sampling trip. These four stations were however, sufficient to provide a clear picture of the vertical and horizontal characteristics of primary production in the reservoir.

As was seen in the results of the Water A sampling, chlorophyll concentrations for the limnological cruises were consistently highest in the upper reaches of the reservoir, and decreased significantly downstream (Table 11). Seasonal variation was quite high, with concentrations spanning an order of magnitude at each station during the course of the study. Concentrations <10 ppb occurred at every station during one or more of the winter months, while highs ranging between 78 ppb at the Lower Reservoir and 110 ppb in the Upper Reservoir were found during mid to late summer.

Table 11. Phytoplankton metabolic characteristics in Fort Cobb Reservoir.

Characteristics	Upper Reservoir			Willow Creek Arm			Middle Reservoir			Lower Reservoir		
	mean	c.v.	range	mean	c.v.	range	mean	c.v.	range	mean	c.v.	range
Chlorophyll[1]	52	67%	8.2 - 110	37	65%	9.0 - 83	39	83%	4.4 - 90	29	88%	4.2 - 78
Maximum Daily Gross (MGP)[2]	5.61	76%	0.16-13.58	5.57	78%	0.42 - 12.8	4.63	87%	0.22 - 10.9	3.71	104%	0.22-10.06
Respiration (R)[2]	0.85	81%	0.08 - 2.30	0.86	79%	0.20 - 2.2	0.78	79%	0.12 - 1.7	0.55	89%	0.08 - 1.3
MGP/Chl[3]	97	45%	16 - 170	145	65%	47 - 376	113	54%	38 - 262	108	60%	22 - 249
R/Chl[3]	16	36%	8 - 27	24	47%	10 - 52	23	47%	12 - 51	20	42%	6.0 - 34
Compensation Depth[4]	1.4	30%	0.9 - 2.1	1.4	18%	1.0 - 1.8	1.8	30%	1.0 - 2.8	2.3	28%	1.4 - 3.5
Net Daily Productivity[5]	2.71	72%	0.00 - 5.42	2.91	82%	0.16 - 7.10	3.08	82%	0.06 - 6.83	2.98	98%	0.04 - 7.75

[1] mg /m^3 [2] g O_2 / m^3/day [3] mg O_2 / mg Chl /day [4] m [5] g O_2 / m^2 /day

One of the important metabolic parameters that is determined with each light/dark bottle profile is the maximum daily rate of gross photosynthesis (MGP) in the water column. This variable, whose units are in g O_2/m^3/day is also referred to as the photosynthetic rate at light saturation, and usually occurs at depth, since near the surface, photosynthesis is often inhibited by excessive sunlight. MGP was slightly more variable than chlorophyll at each station, and like chlorophyll decreased significantly from the upper to lower reservoir stations (Table 11). Wintertime lows were in the vicinity of 0.20-0.40 g O_2/m^3/day, while mid to late summertime highs ranged from 10.06 to 13.58 g O_2/m^3/day at the Lower Reservoir and Upper Reservoir stations, respectively.

Another important variable that is measured during the light/dark bottle incubations is the daily rate of community respiration (R). This parameter has the same units of measurement as

MGP except that MGP refers to oxygen produced by the phytoplankton community while R represents oxygen consumed. Like chlorophyll and MGP, R also decreased progressively from the upstream to downstream portions of the reservoir (Table 11) and was about as variable at each station. Minimum R values ranged from about 0.10 to 0.20 g O_2/m^3/day in winter while mid/late summer maxima ranged from 0.86 to 1.34 g O_2/m^3/day at the Lower Reservoir and Willow Creek Arm stations, respectively.

One might presume that chlorophyll (Chl) concentrations would be quantitatively related to phytoplankton metabolism, and could thus be used to predict such variables as MGP and R. To test this assumption, correlations between Chl *vs* MGP and Chl *vs* R were determined by combining data from all the light/dark bottle experiments (n=45). Significant ($p<0.01$) correlation coefficients of 0.89 and 0.88 were determined for MGP and R, respectively. In other words, between 75 and 80 per cent of the variation in either MGP or R at any location on Fort Cobb Reservoir, on any date, could be accounted for by the concentration of chlorophyll in the surface water. Again using the entire data set, it can be further shown that 1 mg/m^3 chlorophyll will produce an average of 115 mg O_2/m^3/day (95% C.I. = 94-135) MGP while consuming an average of 21 mg O_2/m^3/day (95% C.I. = 18-23) R. When the ratios MGP/Chl and R/Chl are considered, much of the seasonal variation is reduced at each station, and there is no significant difference from the upper to the lower portions of the reservoir (Table 11).

Thus far, we have seen how the different variables describing phytoplankton standing crop and community metabolism on a volumetric basis vary significantly from the upper to the lower end of Fort Cobb Reservoir. In short, the upper end supports a higher standing crop of phytoplankton with resultant higher community metabolic rates on a volumetric basis. The final variable to be considered is the depth of the euphotic zone, as measured by the light/dark bottle profiles, and how light penetration affects overall primary productivity within the reservoir. As predicted by measurements of visible light penetration (Figure 27), actual compensation depth increased from an average of 1.4 meters in the upper part of the reservoir to 2.3 meters in the lower portion (Table 11). Compensation depths at each station were more constant throughout the study, with Coefficients of Variation ranging from only 18 to 30 per cent. Thus, in the upper part of the reservoir, large standing crops of phytoplankton are circulated into (and out of) a relatively narrow band of light near the surface, while in the lower portions, smaller standing crops of phytoplankton spend more time photosynthesizing due to greater light penetration. The net outcome of these variables, working in combination, can be determined from the light/dark bottle profiles. Table 11 shows that on an average, net primary productivity on an areal basis (*i.e.* mgO_2/m^2/day), was nearly the same throughout the reservoir. Although seasonal variation was still apparent at all stations (with lows in winter and highs in mid to late summer), the 95% Confidence Intervals were similar and statistically there were no significant differences.

At least 72 individual phytoplankton taxa were identified from the samples taken during the light/dark bottle experiments (Table 12). Several of these taxa could not be identified to species, but were nonetheless morphologically distinct enough to be recognized separately. One-quarter (18) of the total taxa occurred year-round. These ubiquitous taxa included six blue-green algae (Cyanophyta), six green algae (Chlorophyta), two diatoms (Bacillariophyta), one euglenoid (Euglenophyta) and three cryptomonads (Pyrrophyta). In contrast, one-third (24) of the taxa were very limited in their occurrence, being confined to only one of the four seasons. Winter was the period of lowest taxonomic abundance. In addition to the year-round residents, only seven other

taxa were encountered in samples taken during December, January and February. Spring and summer were the periods of maximum numbers of taxa, with 49 and 50, respectively. During March, April and May, green algae attained their highest number of taxa, while the number of blue-green taxa peaked during June, July and August. Fall was a transition period between the summer maximum and winter minimum.

Table 12. Seasonal occurrence of phytoplankton in Fort Cobb Reservoir.

		Winter 12/1/2	Spring 3/4/5	Summer 6/7/8	Fall 9/10/11
Cyanophyta					
	Anabaena circinalis		+	+	+
	Anabaena sp. (a)	+		+	+
	Anabaena sp. (b)	+		+	+
	Anacystis (Microcystis?) sp.			+	+
	Anacystis sp. (a)			+	+
	Anacystis sp. (b)			+	
	Aphanizomenon flos-aquae	+	+	+	+
	Aphanocapsa sp.			+	
	Aphanothece sp.			+	
	Chroococcus limneticus			+	
	Chroococcus sp. (a)	+	+	+	+
	Chroococcus sp. (b)				
	Chroococcus dispersus				+
	Coelosphaerium sp.		+	+	
	Dactylococcopsis sp.	+	+	+	+
	Gomphosphaeria sp.			+	+
	Lyngbya contorta	+	+	+	+
	Lyngbya sp.			+	+
	Merismopedia glauca				+
	Merismopedia sp.		+		
	Merismopedia tenuissima		+	+	+
	Microcystis sp.			+	+
	Oscillatoria sp. (a)		+		
	Oscillatoria sp. (b)	+	+	+	+
	Oscillatoria subbrevis	+	+	+	+
	Raphidiopsis curvata			+	+
	Raphidiopsis mediterranea		+	+	+
Bacillariophyta					
	Aulacoseira distans		+	+	
	Aulacoseira granulata	+	+	+	+
	Fragilaria nanana		+		
	Melosira varians	+	+	+	
	Navicula sp.		+	+	
	Nitzschia sp.				+
	Stephanodiscus sp.	+	+	+	+
	Synedra sp.	+	+	+	
	Synedra ulna			+	
Chlorophyta					
	Actinastrum hantzschii		+	+	+
	Ankistrodesmus falcatus	+	+	+	+
	Botryococcus sp.	+			
	Cartena sp.		+	+	+
	Chlamydomonas sp. (a)	+	+	+	+
	Chlamydomonas sp. (b)	+	+	+	+
	Closterium sp.		+	+	
	Coelastrum sp.	+	+	+	+

Table 12. (cont.)		Winter 12/1/2	Spring 3/4/5	Summer 6/7/8	Fall 9/10/11
	Coelastrum sphaericum		+		
	Coleastrum microporum		+		
	Cosmarium sp.				+
	Crucigenia sp.		+	+	
	Dictyosphaerium sp.		+	+	+
	Gloeocystis sp. (a)		+		
	Gloeocystis sp. (b)				+
	Gloeotaenium sp.		+		
	Golenkinia sp.	+			
	Kirchneriella sp.		+		
	Lagerheimia sp.			+	
	Nephrocytium sp.		+		
	Oocystis spp.	+	+	+	+
	Pediastrum duplex		+		
	Scenedesmus dimorphus			+	
	Scenedesmus quadricauda		+		+
	Scenedesmus spp.		+	+	+
	Schroederia setigera	+	+	+	+
	Sphaerocystis sp.		+		
	Staurastrum sp.		+		+
Euglenophyta					
	Euglena sp.		+	+	+
	Phacus longicauda	+	+		
	Phacus sp.		+	+	
	Trachelomonas sp. (a)		+	+	
	Trachelomonas sp. (b)	+	+	+	+
Pyrrophyta					
	Chroomonas sp.	+	+	+	+
	Cryptomonas aspera	+	+	+	+
	Cryptomonas ovata	+	+	+	+

It is practically impossible to find a meaningful and/or unbiased method of measuring and expressing phytoplankton standing crop on an individual taxonomic basis. Perhaps the most common is to estimate the volume of each taxon present in a sample by measuring the dimensions of each structural unit (e.g. cell, colony or trichome) and multiplying these measurements by various geometric formulae. In addition to being extremely tedious and time-consuming, the resulting estimates of cell volume (or in some cases surface area) are often not quantitatively related to other estimates of standing crop, such as chlorophyll or total organic matter. In Fort Cobb Reservoir, it was readily apparent which group of taxa were most prominent in terms of standing crop or biomass. Blue-green algae were numerically more abundant than all other taxa throughout most of the year, and because they are much larger in comparison with other taxa, their dominance in terms of standing crop was overwhelming. Within the blue-green community, the filamentous forms were most prominent. Colonies of filamentous blue-greens often became visible to the naked eye in the surface waters, and during periods of calm, formed a greenish scum on the surface of the reservoir. *Oscillatoria subbrevis* and *Anabaena circinalis* were the most common members of these large "blooms" which began in early summer and lasted well into autumn. *Raphidiopsis mediterranea, Aphanizomenon flos-aquae* and *Lyngbya contorta* were also important. Among the free-floating colonies of unicellular blue-greens, *Merismopedia tenuissima, Anacystis sp.* and *Microsystis sp.* were common. One reason for the success of blue-green algae in Fort Cobb Reservoir, may be their ability to use low light intensities effectively. They can also control their buoyancy, and hence their position in the water column, via gas vacuoles. These factors may allow them to utilize the shallow euphotic zone depths in Fort Cobb Reservoir more

effectively than other groups of phytoplankton. Some planktonic blue-greens also have the ability to satisfy their nitrogen requirements by fixing atmospheric nitrogen. Thus, when nitrate and ammonium levels are low, but where phosphate is present, these blue-greens will thrive.

Massive blooms of blue-green algae in highly eutrophic drinking water reservoirs may become a nuisance since they can add an objectionable taste and odor to the water. More importantly however, is the fact that certain strains of such common species as *Aphanizomenon flos-aquae, Anabaena flos-aquae* and *Microcystis aeruginosa* produce potent toxins. If wild or domestic animals, not to mention humans, drink water containing a toxic bloom, they develop difficulties in breathing, severe diarrhoea, and may die. *Anabaena flos-aquae* and *Aphanizomenon flos-aquae* produce the potent neuromuscular poisons anatoxin and saxitoxin, respectively. *Microcystis aeruginosa* produces a cyclic polypeptide that causes necrosis and hemorrhage of the liver.

Significant pulses of diatoms were produced within the phytoplankton community during early spring and late fall. These preceded and followed the blue-green "blooms" but never began to approach the latter in terms of biomass development. Two centrate forms, *Aulacoseira granulata* and *Stephanodiscus sp.* completely dominated the diatom flora. Diatoms are known to flourish in temperate waters during periods of optimum nutrient availability, and the two dominant taxa in this study are typical of nutrient-rich conditions.

Standing crops of all the green algae, if combined, would not begin to approach that of even one of the most common blue-green taxa, and would be considerably less than that of the more common diatoms. The same holds true for the euglenoids and cryptomonads as well. However, one must be careful not to use standing crop and importance synonymously. After all, standing crop is the net result of production minus predation. It is possible, even probable that the smaller greens, euglenoids and cryptomonads are heavily grazed by zooplankton and that their rates of primary productivity per unit cell volume may be many times that of the larger blue-greens. Importance in terms of the overall reservoir ecosystem varies with each taxon, and for specific purposes within the ecosystem will not necessarily be proportional to that taxon's rank in terms of standing crop.

5. Bioassays

The bioassays in this study were designed to identify the potential limiting effect of one physical variable (light) and two nutrients (nitrogen and phosphorus), either singly or in combination, on phytoplankton productivity in Fort Cobb Reservoir. These bioassays are based on the simple premise that if one of these factors is limiting growth in the phytoplankton community at a given point in time, then any enhancement or enrichment of that constituent in the community will stimulate growth up to the point where another factor becomes limiting. For example, if a nutrient such as phosphorus is limiting, then the addition of phosphorus will stimulate growth until some other nutrient, say nitrogen, is exhausted. Numerous authors (*e.g.* Hansen *et al*, 1997; Phlips *et al*, 1997: Vanni and Temte, 1990) have noted that light and nutrient limitation are seasonal in nature and usually shift in importance during the course of a year. Therefore, the results of experiments in this study were grouped according to season.

Phytoplankton standing crops, and attendant nutrient concentrations, in the surface water varied at the beginning of each bioassay (Table 13). Chlorophyll ranged from 5.8 ppb in June, 1998 to 58 ppb in October, 1999. Total dissolved nitrogen, which includes ammonia-N, nitrite-N and nitrate-N, and is thus available for phytoplankton growth, ranged from 262 to 1902 ppb. SRP, which is the phosphorus fraction available to phytoplankton, ranged between < 10 and 102 ppb. A comparison of these values with results from the Water A sampling (Appendix B) shows that bioassay conditions were representative of seasonal conditions in the lower portion of Fort Cobb Reservoir.

One method of evaluating the response of the phytoplankton community to both light and nutrients was to calculate the growth rate (r) of the phytoplankton in each treatment based on changes in chlorophyll concentration that occurred over the four-day incubation period using the expression $\ln Chl_4 - \ln Chl_0 = 4r$, where Chl_4 and Chl_0 are chlorophyll concentrations on day 4 and day 0, respectively. Table 14 shows that positive growth rates occurred in the controls in over half of the experiments and at least once during every season of the year. One can only conclude that on these specific occasions, the community was not nutrient limited, since growth was enhanced by simply incubating the phytoplankton in a more favorable light environment. A clear

Table 13. Summary of Lower Reservoir conditions at initiation of nutrient enrichment bioassays.

Date	Temperature (Celsius)	Chlorophyll (ppb)	Turbidity (NTU)	Dissolved Nitrogen (ppb)	Soluble Reactive Phosphorus (ppb)
Winter					
12/4/98	14	42	15	1326	56
1/16/00	10	38	10	1088	<10
Spring					
3/15/99	11	6.9	8.1	751	76
4/9/00	16	24	9.9	1902	25
Summer					
6/7/98	25	5.8	6.6	938	62
7/18/99	29	30	8.9	262	102
8/6/00	30	48	10	584	<10
Autumn					
9/13/98	27	34	9.1	1452	72
10/4/99	22	58	24	275	39

case of nitrogen limitation is illustrated by the chlorophyll data in July, 1999. On this date, there was no growth in the controls, minimal growth in the phosphorus treatment, and substantial growth in the nitrogen and nitrogen plus phosphorus treatments. These results occurred on the same date that total dissolved nitrogen was at its lowest concentration (Table 13). One could speculate that on this date, the dissolved nitrogen was primarily organic, and hence unavailable to phytoplankton. The same general pattern of nitrogen limitation in the bioassays combined with low available nitrogen in the environment was also suggested in the October, 1999 experiment, however the

effects of nitrogen enrichment were not nearly as pronounced. Phosphorus was never clearly shown to be a single limiting factor in any of the experiments, even though growth was enhanced somewhat in the phosphorus treatment in August, 2000. Table 13 shows that there was very little phosphorus available for phytoplankton growth on this date, and yet there was some growth in the nitrogen treatment alone.

Beyond the stage of looking for one limiting factor in the results of the bioassays, lies the next step of looking for the possible combined effects of light and nutrients. For example, if one considers the June, 1998 experiment, it is apparent that light was an important factor limiting the productivity of the phytoplankton community. However, the results further show that when light is held constant (*i.e.* when all samples are incubated at optimal light conditions), the addition of phosphorus markedly enhances the growth of primary producers. A similar situation can be seen to a lesser degree in April, 2000. In September, 1998 and March, 1999, nitrogen additions combined with enhanced light conditions led to an increase in phytoplankton growth.

A second method of evaluating the response of the phytoplankton community to nutrient additions alone was to measure the rate of gross photosynthesis in each of the treatments on day-4 of the experiment and express the results as treatment/control ratios (Table 14). In about half of the cases, there was good agreement between this method and the chlorophyll growth rates. In particular, both methods showed little evidence for nutrient limitation in the wintertime experiments; and both indicated that when the effects of light were removed, phosphorus was the limiting nutrient in June, 1998 and April, 2000. In the remaining experiments, the two methods showed mixed (sometimes contradictory) results due to errors in estimates of gross photosynthetic rates. These errors resulted from supersaturation of photosynthetic oxygen, and the subsequent formation of O_2 bubbles, in the light bottles during the 24-hour incubation period. Since the Winkler technique, used in the light/dark bottle method, measures only dissolved oxygen, gross photosynthetic rates are underestimated any time O_2 bubbles are formed. For this reason, the chlorophyll measurements are considered to be the more reliable method of evaluating results in these bioassay experiments.

Changes in nitrogen and phosphorus concentrations, combined with changes in chlorophyll, allow for estimates of nutrient uptake per unit of chlorophyll synthesized during the four-day bioassay incubations. Before extrapolating the results of these calculations to the "real world" however, one must consider some of the other variables operating during these experiments. At least two factors directly affect the chlorophyll concentrations. First, the phytoplankton cultures were not allowed to circulate vertically in the water column, but were incubated continuously at near-optimum light conditions. Second, zooplankton were not removed from the cultures prior to incubation. With regard to nutrient concentrations, it should be noted that nutrient regeneration always occurs simultaneously with uptake in each of the cultures. In fact, dissolved nitrogen concentrations increased in just over one-fourth of the treatments during incubation, resulting in "negative" uptake estimates. This phenomenon can be ascribed to zooplankton grazing and/or bacterial decomposition of organic matter. With some of these precautionary notes in mind, one can estimate from these experiments, that on average, about three milligrams of phosphorus were taken up for every milligram of increase in chlorophyll; and similarly, about 30 milligrams of nitrogen were assimilated for each milligram of chlorophyll produced. These estimates (actually 2.7:1-P and 28:1-N) result in a predicted N:P uptake ratio of 10:1. This is very similar to the 11:1 N:P ratio recommended by Miller *et al* (1978) as optimum for *Selenastrum capricornutum* in their

Table 14. Response of phytoplankton community to nutrient enrichment

Growth rate is based on change in chlorophyll, Day-0 to Day-4

Gross O_2 productivity measured on Day-4

	Growth Rate					Ratio Treatment / Control			
Date	Control	P	N	P + N	Date	Control	P	N	P + N
Winter					Winter				
12/4/98	0.09	0.10	0.10	0.09	12/4/98	1.00	1.10	0.90	1.10
1/16/00	0.00	0.01	0.00	-0.01	1/16/00	1.00	1.00	1.10	1.10
Spring					Spring				
3/15/99	0.08	0.09	0.12	0.14	3/15/99	1.00	1.20	1.10	1.20
4/9/00	0.13	0.16	0.13	0.16	4/9/00	1.00	1.60	1.00	1.70
Summer					Summer				
6/7/98	0.36	0.54	0.38	0.62	6/7/98	1.00	1.80	1.00	3.30
7/18/99	0.00	0.03	0.21	0.21	7/18/99	1.00	1.80	0.50	1.10
8/6/00	-0.03	0.12	0.10	0.14	8/6/00	1.00	1.70	0.90	0.60
Autumn					Autumn				
9/13/98	0.21	0.23	0.34	0.24	9/13/98	1.00	1.30	0.90	0.10
10/4/99	-0.05	-0.06	0.02	0.07	10/4/99	1.00	2.50	4.50	5.50

laboratory assays. In fact, these authors go so far as to state that natural waters containing N:P ratios greater than 11:1 may be considered phosphorus limited, while those containing N:P ratios less than 11:1 can be considered nitrogen limited for algal growth. It appears that the 10:1 N:P ratio may be a useful guideline for estimating the response of Fort Cobb Reservoir phytoplankton to nutrient enrichment.

V. SUMMARY AND CONCLUSIONS

The first objective of this study was to provide a baseline for surface water quality in tributaries to Fort Cobb Reservoir. Six stations on the three primary streams entering the reservoir (Cobb, Willow and Lake Creeks), and four additional sites on relatively minor streams (Eakly, Crooked, Camp and Noname Creeks), were sampled over a period of about 2½ years at base flow conditions. Water quality constituents were divided into two groups, each having its own sampling schedule. Samples for the general constituents (temperature, pH, conductivity, turbidity, chlorophyll, chemical oxygen demand, total alkalinity, chloride, sulfate, total phosphorus, soluble reactive phosphorus, total nitrogen, nitrate-nitrogen, ammonia-nitrogen, and nitrite-nitrogen) were taken on 12 dates, ostensively at quarterly intervals, but on a schedule that included every month of the calendar year during the study period. Samples for major cations and trace elements were taken on 4 dates, at intervals designed to include all four seasons of the year.

Water temperatures during the course of this study followed a typical annual cycle with

lows near 1°C in January and highs exceeding 30°C in August. Short-term, spatial and temporal water temperature variations are greatly influenced by air temperature and solar radiation, due to the broad, shallow morphometry of the tributary streams. Overall, tributary pH ranged from 7.0 to 8.7, with station means ranging from 7.7 to 8.0 (except for Noname Creek which averaged 7.3). Depending on the date, there seemed to be a tendency for all stations to exhibit either "high" or "low" pH. Turbidity values ranged across three orders of magnitude during the study, from 2.1 to >2000 NTU. Values greater than 100 NTU were uncommon (occurring in less than 10%of the samples), and are probably always indicative of surface runoff. Water clarity was quite good (<10 NTU) in just over one-third of the samples taken. Throughout the course of the study, values for chemical oxygen demand (COD) were somewhat randomly distributed in the tributaries, ranging from <1 ppm at several of the sampling stations to a high of 40 ppm on one occasion in upper Lake Creek. The two small, spring-fed, perennial streams, Crooked and Camp Creeks, appeared to be consistently the lowest in organic matter content (COD). Chlorophyll a was relatively low in all of the tributaries, averaging less than 10 ppb at all of the stations except Lake Creek. Lake Creek, which is much more sluggish than the other tributaries, is probably more conducive to year-round phytoplankton growth. Conductivity, which is a good indicator of the total dissolved inorganic constituents in a water sample, ranged from 267 to 842 micromhos/cm in all samples. There was very little seasonal variation in conductivity at any of the stations, with Coefficients of Variation ranging from just 3 to 15 per cent. This indicates that each tributary is relatively stable year-round with respect to it's major ionic composition. Cobb Creek had a markedly higher average conductivity than either Willow or Lake Creeks, indicating a higher concentration of total dissolved ions.

All tributaries exhibited the same basic composition with respect to the major cations, *i.e.* calcium> magnesium> sodium>potassium. Based on milliequivalents per liter (meq/L), calcium comprised from 46% to 72% of the total cations, magnesium 15% to 33%, sodium 11% to 19% and potassium <1% to 2%. Cobb Creek was consistently highest in calcium, magnesium and sodium, a condition that was reflected in the conductivity measurements previously mentioned. In any water, the sum of the cations must equal the sum of the anions (in meq/L). Total alkalinity was the predominant anion in each of the Fort Cobb tributaries, comprising from 54% to 84% of the total. Total alkalinity in these waters is primarily the sum of carbonate and bicarbonate ions, and at the pH values that exist in these tributaries, bicarbonate would be the most common ionic form. Sulfate was the second most abundant anion at all locations, ranging between 10% and 42% of the total, while relative concentrations of chloride ranged between 2% and 16%. The most marked differences among the tributaries with respect to major anions, were the consistently high sulfate concentrations in Cobb Creek and unusually high chloride values for Noname Creek.

Since the availability of nitrogen and phosphorus has the potential to regulate or limit the productivity of organisms in any freshwater ecosystem, the concentrations and proportions of these elements in the tributaries to Fort Cobb Reservoir are of special interest. Nitrate-N, an important plant nutrient, was the most abundant form of inorganic nitrogen at all locations, ranging from 200 to 3800 ppb. Of the three principle tributaries, Cobb Creek had the highest nitrate concentrations, followed by Lake and Willow Creeks. Ammonia-N, which is also readily available for plant growth, was the second most abundant form of inorganic nitrogen, and ranged from <10 to 340 ppb. Lake Creek had the highest concentrations of ammonia, followed by Willow and Cobb Creeks. Nitrite, which is often the least abundant form of inorganic nitrogen in natural waters,

ranged from <1 to 103 ppb and was about evenly distributed among the three primary tributaries. On average, inorganic nitrogen (nitrate+ammonia+nitrite) comprised between 39 and 68 per cent of the total nitrogen at each tributary station. Soluble reactive phosphorus (SRP), which is comprised largely of the orthophosphate ion, and is hence available for plant uptake, ranged from <10 to 290 ppb. Cobb Creek had the highest concentrations of SRP, followed closely by Lake, then Willow Creeks. Using average values from each station, SRP made up 44 to 61 per cent of the total phosphorus in the tributaries. In short, ample supplies of both nitrogen and phosphorus are available for plant growth in Fort Cobb tributaries on an annual basis. The average ratios of inorganic nitrogen to SRP (N:P) in the three primary tributaries to Fort Cobb Reservoir were 8:1, 7:1 and 6:1 for Cobb, Willow and Lake Creeks, respectively. Based on the optimal N:P ratio of 11:1, reported for algal growth by Miller *et al.*, 1978, water flowing into Fort Cobb Reservoir from all three of its tributaries would appear to have an excess of phosphorus, and therefore be nitrogen limited for phytoplankton growth.

Baseline conditions for about 20 trace elements were determined not only in water, but in tributary sediment and watershed soil as well. In the water samples, no significant difference between concentrations of total and dissolved As, B, Ba, Cr, Mn, Ni, Se, Si, Sr and V could be demonstrated, while significant differences were shown for Ag, Al, Co, Cu, Fe, Pb, Sb and Zn. All samples for total and dissolved Cd, Hg and Mo were below the detection limits of the methods used. While not all of the trace elements analyzed in this study are included in the Oklahoma Water Quality Standards, concentrations of Ag, As, Ba, Cd, Cr, Cu, Hg, Ni, Pb, Se and Zn in the tributaries to Fort Cobb Reservoir appear to be well below the most conservative criteria listed in the standards. The first step in analyzing the sediment trace element data was to establish the relationship between bulk concentration (*i.e.* ppm dry weight) and the texture and/or organic matter content of the sample. In the Willow and Lake Creek drainages, significant correlations ($p<0.01$) were obtained between every element and the surrogate for fine-grained particles (aluminum). In the Cobb Creek drainage, every element except calcium, cadmium, sulfur and selenium was significantly correlated with aluminum. Once the relationship between the various elements and the fine-grained fraction of the sediment is verified, the second step in analyzing the data is to geochemically normalize the elemental concentrations using concentrations of aluminum (de Groot, 1995). Normalized soil and sediment data indicated that 10 elements (Cd, Cr, Fe, K, N, P, Pb, Se, V and Zn) were more concentrated in the soil than in sediment, suggesting that somehow these elements are depleted in the benthic environment, perhaps either by uptake or solution. Concentrations of five elements (As, Co, Cu, Mn and Ni) were unchanged between soil and sediment, indicating that once these elements are moved physically from the watershed into the stream, they are neither depleted nor enriched. Concentrations of only seven elements (B, Ba, Be, Ca, Mg, S and Sr) appeared to be geochemically enriched in the sediment. Normalized concentrations also indicated that with the exception of Cu, sediments in Willow and Lake Creeks and their deltas were similar, whereas concentrations in the Cobb Creek system were signigicantly higher than the other two tributaries with respect to over half of the elements analyzed (Ca, Cr, Fe, K, Mg, Mn, Ni, P, Pb, Sr, V and Zn).

A simple test for hydrogen sulfide-producing bacteria, performed on tributary water samples, indicated the presence of these organisms at every station on every sampling date. Hydrogen sulfide bacteria have been shown to be associated with fecal contamination and total coliform bacteria. Potential sources of these organisms in the Fort Cobb watershed include

municipal sewage wastewater, manure from domestic livestock, and fecal material from wild animals. Although the actual taxonomic nature and source of bacteria are unknown, and may vary with season and locale, the best advice would be *don't drink the water.*

The second objective of this study was to evaluate the present status of water quality in Fort Cobb Reservoir and examine potential changes that may occur as a result of future development within the watershed. To this end, eight sampling stations were established on the reservoir, four along the main longitudinal axis from the headwaters to the dam, and four in the largest embayments. General chemical constituents (see para.1, this section) were analyzed from samples taken at surface and bottom depths on approximately the same schedule as the tributary sampling. Twelve synoptic, limnological surveys, consisting of vertical profiles of temperature, conductivity, dissolved oxygen, ambient light penetration, phytoplankton standing crop and primary productivity were conducted at quarterly intervals. Sediment was taken once at each station and analyzed for the same constituents previously described for tributaries. Nutrient enrichment bioassays were conducted on nine occasions in the lower reservoir, and three species of fish were collected on one occasion from all parts of the reservoir and analyzed for trace elements.

Temperature data indicate that: (1) periods of weak thermal stratification occur in deeper portions of the reservoir during summer, probably following periods of calm winds; and (2) wind-induced turbulence results in the formation of only slight thermal gradients, or nearly complete vertical, thermal homogeneity, in the more shallow areas year-round. Dissolved oxygen data show that: (1) surface waters are near saturation nearly all of the time due to wind mixing and high rates of photosynthesis; and (2) during mid-summer periods of thermal stagnation, dissolved oxygen is completely depleted at lower depths in the deeper portions of the reservoir and anaerobic conditions result.

Conductivity is a good indicator of the major ionic strength in a water sample, and hence is a reliable means of identifying the movement and distribution of various water masses within a system. Overall, conductivity in Fort Cobb Reservoir was consistently less than that in the tributary streams at base flow conditions, and decreased significantly between the upper reservoir and the dam. This leads to the conclusion that either groundwater and/or stormwater runoff is an important component of reservoir water, since it is apparent that normal tributary flows are being diluted. Based on conductivity profiles, there is evidence of some vertical stratification of water masses in the reservoir, specifically during the periods of mid-summer calm weather and thermal stagnation. During these periods, when water overlying the sediment goes anaerobic, various ions (including nutrients) are released from the sediment into the water column. Following these periods of summer stagnation, water from the anoxic zone is mixed into the upper layers, resulting in a fresh supply of nutrients to the surface layers and the replenishment of oxygen to the deeper layers.

The penetration of visible light into the surface layer of the reservoir increased nearly three-fold from the headwaters to the dam. The depth at which ambient light was reduced to 1% varied from means of 0.96 m at the former to 2.57 m at the latter. Turbidity, which was less variable in the reservoir than in the tributaries, also decreased significantly between the upper reservoir stations and the lower portion of the reservoir. Part of the difference in water clarity was due to the presence of wind-induced, resuspended, bottom sediment in the shallower, more exposed, upper

reaches of the reservoir, and part was due to the presence of more phytoplankton in the headwaters area.

Chlorophyll is an indicator of phytoplankton standing crop in a body of water. Chlorophyll concentrations increased markedly once water entered the reservoir from the tributaries, then decreased gradually downstream towards the dam. Except for the Lower Reservoir station, there was no significant difference between chlorophyll concentrations in the surface and bottom samples. Looking at the distribution of chlorophyll in the reservoir, one would conclude: (a) nutrient-rich water, relatively devoid of phytoplankton, enters the upper reservoir via the three main tributaries; (b) following a rapid "bloom" of intense growth in the upper reservoir, phytoplankton standing crop declines gradually as water moves towards the dam; and, (c) in general, vertical mixing keeps the phytoplankton homogeneously distributed throughout the water column, except at the deepest locations. Concentrations of nitrogen and phosphorus seem to support this generalized picture. In the upper portions of the reservoir, organic nitrogen increases from around 50% of the total in the tributaries, to about 70% to 80%, then gradually decreases downstream with a concurrent increase in ammonia-N which is the first degradation product of organic nitrogen. By the time the water reaches the dam, the organic:inorganic nitrogen ratio is approximately the same as in the tributary streams. Nitrate-N concentrations in the reservoir are also greatly reduced in comparison to the tributaries. Phosphorus follows a similar pattern. Organic phosphorus increases from about 40% to 50% in the tributaries to over 70% in the upper portions of the reservoir, with a gradual decline downstream.

Several systems of classifying the trophic status of lakes and reservoirs are in use today. The Oklahoma Water Resources Board (OWRB) uses the method described by Carlson (1977) to classify 201 lentic waterbodies in the state, including Fort Cobb Reservoir (Oklahoma Department of Environmental Quality, 1998). Carlson's Trophic State Indices (TSI) can be calculated using either chlorophyll or total phosphorus data. Using the average chlorophyll and total phosphorus concentrations for Fort Cobb Reservoir, the calculated TSIs are 65 and 75, respectively. OWRB uses the following scale to assign trophic state classifications:

Oligotrophic	TSI <40
Mesotrophic	TSI 41-50
Eutrophic	TSI 51-60
Hypereutrophic	TSI >60

The Tulsa District, U.S. Army Corps of Engineers (USACE) uses Reckhow and Chapra (1983) to classify reservoirs in Oklahoma according to their chlorophyll concentrations (USACE, 1993):

Oligotrophic	<4 ppb
Mesotrophic	4-10 ppb
Eutrophic	10-25 ppb
Hypereutrophic	>25 ppb

The average chlorophyll concentration in Fort Cobb Reservoir was 35 ppb. Wetzel (1975) proposed the following general relationship of lake productivity to average total phosphorus concentration:

Ultra-oligotrophic	<5 ppb
Oligo-mesotrophic	5-10 ppb
Meso-eutrophic	10-30 ppb
Eutrophic	30-100 ppb

Hypereutrophic >100 ppb

The average total phosphorus concentration in Fort Cobb Reservoir was 139 ppb. Regardless of which classification scheme one chooses, the outcome is the same. Fort Cobb Reservoir is clearly a hypereutrophic water body.

Although a total of 72 individual phytoplankton taxa were identified from the reservoir, blue-green algae dominated in terms of numbers and biomass. Within the blue-green community, the filamentous forms were most prominent. Colonies of filamentous blue-greens often became visible to the naked eye in the surface waters, and during periods of calm, formed a greenish scum on the surface of the reservoir. One reason for the success of blue-green algae may be their ability to utilize low light intensities effectively. Also, they can control their buoyancy, and hence their position in the water column, via gas vacuoles. These factors may allow them to utilize the shallow photosynthetic zone in Fort Cobb Reservoir more effectively than other groups of phytoplankton. Chlorophyll data show that phytoplankton are circulated vertically from top to bottom in the water column via wind-induced turbulence, while the light/dark bottle experiments showed that net photosynthesis was restricted to the upper 1 to 2 meters. Some planktonic blue-greens also have the ability to satisy their nitrogen requirements by fixing atmospheric nitrogen. It has been suggested previously that the N:P ratios in the tributary waters may indicate a nitrogen-limited chemical environment for algal growth. Thus, it appears that the basic chemical/physical environment in Fort Cobb Reservoir is favorable to the development of blue-green algal "blooms", and these conditions can only persist or become more pronounced with time.

The bioassay experiments conducted in this study were designed to identify the potential limiting effect of one physical variable (light) and two nutrients (nitrogen and phosphorus) on phytoplankton productivity. Using the rate of chlorophyll synthesis as a means of evaluating the response of the community to both light enhancement and nutrient enrichment, it was discovered that in over half of the experiments, light was the limiting factor. Nitrogen appeared to be limiting in some of the other experiments, whereas phosphorus limitation alone was never clearly shown. Estimates of nutrient uptake per unit of chlorophyll synthesized in these experiments indicated that about 3 mg of phosphorus and 30 mg of nitrogen were assimilated for each milligram of chlorophyll produced. This N:P ratio of about 10:1 is very similar to the 11:1 ratio suggested by Miller *et al* (1978) as optimum for algal growth, and supports the notion that N:P ratios in the Fort Cobb tributaries favor the nitrogen-fixing blue-green algae.

When elemental concentrations in reservoir sediment were geochemically normalized, they were found to be very similar to those from the tributary samples. A comparison of bulk elemental concentrations, with suggested standards for the protection of benthic aquatic organisms found in the literature, suggested that sediments in Fort Cobb Reservoir are not particularly hazardous to benthic aquatic life in general, but may pose a slight threat to the most sensitive species. Sediments are however, a major source for recirculation of nitrogen and phosphorus back into the water column during certain times of the year. Overall, the whole-body fish data from this study yielded no evidence of elemental contaminant problems in Fort Cobb Reservoir. Concentrations of individual elements ranged in the vicinity of values shown by other authors to be normal or below suggested dietary threshold concentrations for food-chain organisms.

Under present conditions, Fort Cobb Reservoir exhibits several of the undesirable

characteristics of hypereuptophic reservoirs: high rates of primary productivity, massive "blooms" of blue-green algae, and oxygen deficits in the lower depths. Under current or increased levels of nutrient loading, the situation may become progressively worse, until eventually, a plateau in the annual production rate is reached. At this point, annual total productivity is completely light limited. There is some evidence from this study that this condition already exists since light was shown to be the primary limiting factor in over half of the bioassay experiments. For this reason, any measures to control nutrient input at the present time may have limited success and must be weighed before expensive options for protection and/or restoration are implemented.

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APPENDIXES

Appendix A - 1.
Water Analysis of duplicate samples.

		Laboratory Duplicates				Field Duplicates	
Constituent	**N**	**Mean Difference[a]**	**Mean RPD[b]**	**N[c]**	**Mean Difference[a]**	**Mean RPD[b]**	**Range**
Aggregate Properties							
Temperature (C)	*	*	*	15	0.1	1	1.2 - 32.6
Conductivity (micromhos)	24	1	<1	34	2	<1	379 - 839
Turbidity (NTU)	23	0.72	3	34	1.4	7	4.9 - 84
pH	*	*	*	34	0.06	*	7.2 - 8.2
Chlorophyll (ppb)	10	2	6	33	1.6	10	2.2 - 114
Chemical Oxygen Demand (ppm)	21	1	20	34	1	10	<1 - 29
Major Cations & Anions (ppm)							
Calcium	13	1.3	2	T=7 / S=7	T=2 / S=2	T=2/S=2	T= 41-120 / S= 41 -116
Magnesium	13	0.34	1	T=7 / S=7	T= 0.4 / S= 0	T=2/S=0	T= 10-26 / S= 10-25
Sodium	13	1	2	T=7 / S=7	T= 1/ S= 1	T=4/S=3	T= 19-27 / S= 18-27
Potassium	13	2.6	2	T=7 / S=7	T= 0.1/ S= 0.1	T=4/S=4	T= 1.7- 5.2 / S= 1.7-5.1
Alkalinity (as $CaCO_3$)	24	2	2	34	4.1	3	86 - 282
Sulfate	21	5.2	5	32	7.4	11	18 - 184
Chloride	20	0.3	3	34	0.45	5	5.75 - 29.75
Nutrients (ppb)							
Total Nitrogen	24	260	18	33	330	18	700 - 3,200
Ammonia Nitrogen	24	11	19	34	16	22	<10 - 820
Nitrite Nitrogen	23	<1	5	32	8	31	1 - 64
Nitrate Nitrogen							
Low Range	12	16	11	18	38	17	20 - 580
High Range	12	92	7	16	94	9	200 - 2,600
Total Phosphorus	16	44	46	23	34	32	<10 - 361
Soluble Reactive Phosphorus	21	22	22	29	37	25	<10 - 382
Major Trace Elements (ppm)							
Iron	13	0.01	17	T=7 / S=7	T=0.14 / S= <0.01	T= 25 / S= 14	T <0.02 - 1.6 / S <0.02
Manganese	14	<0.01	2	T=7 / S=7	T= 0.04 / S= <0.01	T= 18 / S= 7	T<0.001 - 0.282/ S <0.001 - 0.222
Aluminum	14	0.01	3	T=7 / S=7	T= 0.18 / S= 0	T= 32 / S= 7	T <0.05-1.90 / S <0.05
Barium	13	<0.01	2	T=7 / S=7	T= <0.01 / S= <0.01	T= 3 / S= 3	T= 0.117 - 0.296 / S = 0.112 - 0.294
Strontium	14	0.01	1	T=7 / S=7	T= 0.02 / S= 0.03	T= 2/ S= 2	T= 0.24 - 3.2 / S= 0.24 - 3.2
Sulfur	13	0.24	1	T=7 / S=7	T= 0.8 / S= 0.3	T= 2/ S= 1	T= 13 - 71 / S= 13 - 71
Silica	9	0.08	1	T=5 / S=5	T= 0.4 / S= 0.2	T= 4/ S=2	T= 1.2 - 14 / S= 1.1 - 12
Minor Trace Elements (ppb)							
Arsenic	13	0.3	13	T=7 / S=7	T= 0.68 / S= 0.87	T= 15 / S= 31	T= 0.60 - 13 / S= 1.2 - 13
Copper	14	0.52	4	T=7 / S=7	T= 0.15 / S= 0 .13	T= 12/ S= 23	T= 0.32 - 1.6 / S= 0.32 - 1.0

Appendix A - 1. (Cont.)							
Zinc	14	0.8	9	T=7 / S=7	T= 2.1 / S= 1.1	T= 26/ S= 39	T= 1.0 - 30 / S< 0.20 - 4.0
Selenium	13	0.04	8	T=7 / S=7	T= 0.11 / S= 0 .06	T= 25/ S= 10	T= 0.12 - 2.5 / S= 0.10 - 2.8
Nickel	14	0.31	6	T=7 / S=7	T= 0.32 / S= 0.27	T= 21/ S= 23	T< 0.50 - 2.6 / S< 0.50 - 1.3
Lead	14	0.01	8	T=7 / S=7	T= 0.21 / S= 0	T= 46/ S= 0	T= 0.14 - 1.1 / S< 0.05
Chromium	14	0.04	2	T=7 / S=7	T= 0.21 / S= 0 .04	T= 21/ S= 2	T< 1.0 - 1.6 / S< 1.0 - 2.0
Boron	14	4.5	6	T=7 / S=7	T= 3 / S= 3	T= 5 / S= 7	T= 24 - 84 / S= 20 - 76
Vanadium	14	0.19	2	T=7 / S=7	T= 0.3 / S= 0 .1	T= 6 / S= 2	T= 2.4 - 9.7 / S= 2.0 - 8.7
Cadmium	14	<0.01	3	T=7 / S=7	T <0.01 / S= 0	T= 14 / S= 0	T< 0.05 / S< 0.05
Molybdemum	14	0.07	9	T=7 / S=7	T= 0.05 / S= 0 .01	T= 3 / S= 1	T< 1.0 - 2.6 / S< 1.0
Mercury	13	0.006	2	T=7 / S=7	T= 0.002 / S= 0	T= 16/ S= 0	T< 0.005 - 0.01 / S< 0.005
Cobalt	10	0.06	9	T=6 / S=6	T= 0.16 / S= 0	T= 22 / S= 0	T= 0.07 - 0.93 / S= 0.06 - 0.40
Silver	8	<0.01	5	T=3 / S=3	T= 0.04 / S= 0	T= 61 / S= 0	T< 0.05 / S< 0.05
Antimony	8	0.03	14	T=3 / S=3	T= 0.07 / S= 0	T= 23/ S= 0	T= 0.11 - 0.30 / S< 0.05 - 0.25

[a]Mean difference between sample pairs

[b]Mean difference between sample pairs expressed as percent of pair mean

[c]T=Total Recoverable;
S=Soluble

Appendix A - 2. Water. Analysis of field blanks and standards

	Field Blanks			Standards			
		Mean Concentration			Percent Recovery		
Constituent	Detection Limit	Initial	Terminal	N	Mean	95% C.I.	Certified Values
Aggregate Properties							
Temperature (C)	0.1	*	*	*	*	*	*
Conductivity (micromhos)	1	6	6	48	101	100 - 102	445 - 720
Turbidity (NTU)	0.1	0.14	0.14	120	100	98 - 102	5.3 - 422
pH	*	*	*	72	101	100 - 102	4.0 - 10.0
Chlorophyll (ppb)	0.2	<0.20	0.2	*	*	*	*
Chemical Oxygen Demand (ppm)	1	1	1	36	95	89 - 101	10 - 30
Major Cations & Anions (ppm)							
Calcium	0.50	<0.50	<0.50	11	101	98 - 104	6.0 - 31
Magnesium	0.10	<0.10	<0.10	11	98	96 - 100	1.6 - 8.0
Sodium	2	<2	<2	11	105	96 - 114	2.3 - 29
Potassium	0.10	<0.10	<0.10	11	101	100 - 102	0.70 - 2.4
Alkalinity (as $CaCO_3$)	2.5	5	4	*	*	*	*
Sulfate	1	<1.0	<1.0	63	94	84 - 104	25 - 200
Chloride	0.25	0.7	0.65	57	106	105 - 107	6.0 - 50
Nutrients (ppb)							
Total Nitrogen	100	200	200	43	110	100 - 120	1.0 - 10
Ammonia Nitrogen	10	10	10	40	102	98 - 106	25 - 50
Nitrite Nitrogen	1	1	<1	22	85	82 - 88	50
Nitrate Nitrogen				24	83	78 - 88	500 - 1000
Low Range	10	<10	<10				
High Range	100	<100	<100				
Total Phosphorus	10	13	14	29	100	96 - 104	250 - 1000
Soluble Reactive Phosphorus	10	<10	<10	44	105	101 - 109	62 - 1000
Major Trace Elements (ppm)							
Iron	0.02	<0.02	<0.02	11	100	92 - 108	0.03 - 0.10
Manganese	0.001	<0.001	<0.001	18	100	96 - 104	0.003 - 0.12
Aluminum	0.05	<0.05	<0.05	16	101	99 - 103	0.03 - 0.13
Barium	0.002	<0.002	<0.002	16	104	101 - 107	0.01 - 0.51
Strontium	0.002	<0.002	<0.002	13	100	97 - 103	0.03 - 0.29
Sulfur	1	<1.0	<1.0	*	*	*	*
Silica	0.1	<0.10	<0.10	3	107	105 - 109	4.7
Minor Trace Elements (ppb)							
Arsenic	0.05	0.24	0.58	13	97	93 - 101	0.72 - 56
Copper	0.2	<0.20	<0.20	18	105	102 - 108	1.2 - 85
Zinc	0.2	0.65	0.3	18	106	102 - 110	0.93 - 72
Selenium	0.05	<0.05	0.08	11	104	95 - 113	11 - 22
Nickel	0.5	<0.50	<0.50	18	100	98 - 102	0.67 - 58
Lead	0.05	<0.05	<0.05	18	104	100 - 108	0.07 - 28
Chromium	1	<1.0	<1.0	18	99	97 - 101	0.30 - 39
Boron	20	<20	<20	9	105	103 - 107	145 - 301
Vanadium	0.5	<0.50	<0.50	10	100	95 - 105	0.30 - 35
Cadmium	0.05	<0.05	<0.05	18	102	100 - 104	0.01 - 23
Molybdemum	1	<1.0	<1.0	18	103	101 - 105	0.19 - 113
Mercury	0.005	<0.005	<0.005	2	100	*	0.002
Cobalt	0.05	<0.05	<0.05	13	101	99 - 103	.03 - 20
Silver	0.05	<0.05	<0.05	7	100	96 - 104	1.3 - 7.6
Antimony	0.05	<0.05	<0.05	10	107	103 - 111	0.23 - 54

Appendix A-3. Sediment Analysis of laboratory duplicates and standards

Constituent (ppm)	Laboratory Duplicates (N=5)			Standards (n=5)		
	Detection Limit	Mean RPD[a]	Range	Mean	95% C.I.	Certified Values
Aluminum	0.50	2	2190 - 7200	*	*	*
Arsenic	0.40	2	.74 - 10.3	89	76 - 103	21
Boron	0.40	20	.51 - 8.5	*	*	*
Barium	0.20	4	10.3 - 287	*	*	*
Beryllium	0.10	6	.11 - 2.0	41	37 - 45	2.3
Calcium	4.0	5	256 - 33800	*	*	*
Cadmium	0.01	21	.05 - .25	102	87 - 116	0.24
Cobalt	0.40	4	.70 - 8.6	90	88 - 93	14
Chromium	0.30	1	3.9 - 34	31	26 - 35	106
Copper	0.50	3	1.4 - 21	93	89 - 97	39
Iron	2.0	1	3140 - 31400	*	*	*
Potassium	5.0	2	442 - 4740	*	*	*
Mercury	0.01	1	<.01 - .01	94	84 - 105	0.09
Magnesium	2.0	1	444 - 7570	*	*	*
Manganese	0.50	2	38 - 1160	87	83 - 91	365
Molybdenum	0.20	35	.25 - .39	82	77 - 86	2.8
Nitrogen	50	4	135 - 3660	91	89 - 92	22500 - 27600
Sodium	50	7	<50 - 238	*	*	*
Nickel	0.30	2	2.1 - 26	86	78 - 94	49
Phosphorus	10	2	55 - 823	*	*	*
Lead	0.50	1	1.7 - 20	81	76 - 86	22
Sulphur	20	4	24 - 4690	*	*	*
Selenium	0.001	4	.02 - .06	91	88 - 94	0.72
Strontium	0.02	1	1.6 - 320	51	48 - 54	125
Titanium	0.50	4	68 - 165	*	*	*
Vanadium	0.20	4	5.3 - 59	28	24 - 32	252
Zinc	1.0	7	6.4 - 74	82	78 - 86	172
TOC (%)	0.01	13	.10 - 2.9	102	101 - 104	9 - 17%
Clay (%)	0.02	0	< .02	*	*	*
Silt (%)	0.02	4	8.4 - 93	*	*	*
Sand (%)	---	4	6.8 - 100	*	*	*

[a]Mean difference between sample pairs expressed as percent of pair mean

Appendix A-4. Fish. Analysis of laboratory duplicates and standards.

Constituent (ppm)	Laboratory Duplicates (N=5)			Standards (n=5)	
	Detection Limit	Mean RPD[a]	Range	Mean	Certified Values
Aluminum	0.5	5	16 - 22	102	11
Arsenic	0.5	-		79	18
Boron	0.5	-		-	
Barium	0.2	5	0.55 - 3.7	-	
Beryllium	0.1	-		-	
Cadmium	0.2	-		105	0.04
Cobalt	0.5	-		0.18	270
Chromium	0.3	-		35	79
Copper	0.5	4	2 - 3	2.3	105
Iron	3.0	3.8	37 - 144	140	95
Mercury	0.1	11	0.15 - 0.43	4.6	98
Magnesium	2.0	3	750 - 1100	-	-
Manganese	0.5	3.6	1 - 5.3	3.7	95
Molybdenum	0.3	-		-	-
Nickel	0.3	12	0.56	19	80
Phosphorus	10.0	3.6	0.75	-	
Lead	0.2	70	7400 - 11000	0.07	180
Sulfur	20.0	0.46	7100 - 8000	-	
Selenium	1.0	1.9	0.3 - 1.3	1.4	89
Strontium	0.02	9.6	17 - 69	-	
Titanium	0.5	8.4	0.7 - 0.96	-	
Vanadium	0.3	-		-	
Zinc	1.0	1.5	19 -230	26	83

[a]Mean difference between sample pairs expressed as percent of pair mean

Appendix B-1: Temperature (C)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	8.1	8.3	15.5	27.7	16.4	*	14.8	20.7	21.9	10	18.3	22.4
LWC	10	9.2	20	28.6	19	2.4	22.5	23.6	23.5	9.4	17.8	27.8
ULC	6.7	7.2	17.5	32.7	16.5	1.6	17.9	23.1	23	8.1	17	24.9
LLC	8.3	8.3	19.7	28.6	17.8	2	22.4	24.1	24.1	8.7	18.2	25.5
UCC	8.9	8.6	16.9	27.9	17	1.2	17.5	23.7	22.5	8.8	16.3	23.6
LCC	9	9	18.2	27.7	17.2	1.3	20.1	23.7	23.1	9.3	17.1	24.4
EC	8.8	8.3	18.8	Dry	Dry	1.9	19.3	23.6	22.8	8.8	16.3	24.9
CrC	9.8	9.3	17.1	25.4	17	2.8	18.4	22.1	22.6	10.1	17	23.8
CaC	8.8	8.6	16.2	25.6	16.8	1.4	19	21.8	22	9.4	17.7	24.2
NNC	10.4	8.5	18.7	Dry	Dry	4.8	22.4	21.8	Dry	9.7	*	25.2
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	14.1	8.1	19.5	29.2	19.1	5.8	16.1	27.4	27	11.9	13.7	25.1
OC	14.2	8.4	18.1	30.1	19.2	5.6	17.8	27.2	27.4	*	14.7	25.6
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	9.4	10.9	23.1	26.8	15.5	5.7	17.6	30.4	22.9	9.9	15.3	26.7
UR-S	9.7	10	23	28	18.1	4.3	17.2	30.1	23.2	11.9	15.2	26.6
UR-B	*	*	*	*	*	*	*	*	*	*	*	*
WCA-S	10	10	21.4	28.5	18.2	3.6	17.4	30.7	23.4	11.9	15.3	26.4
WCA-B	*	*	*	*	*	*	*	*	*	*	*	*
MR-S	10.8	9.1	21.4	28.1	18.8	3.5	16.1	29.6	24	12.9	14.5	26.6
MR-B	*	*	*	*	*	*	*	*	*	*	*	*
KS-S	10.9	8.7	21.8	28.3	18.7	4.6	16.1	30.1	23.3	12.6	14.3	26.2
CC-S	10.9	8.6	20.4	27.8	18.7	4.8	16.1	29.3	23.4	12.6	14.4	26.7
MC-S	11.1	8.2	21.7	28.1	18.9	5.1	15.5	29.3	23.6	12.9	13.9	26.5
LR-S	11.4	8.6	20.4	28	19.2	3.2	15.3	28.9	24	13.3	14.1	26.5
LR-B	*	*	*	*	*	*	*	*	*	*	*	*

Appendix B-2: Conductivity (micromhos/cm)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	459	464	494	339	447	467	472	460	267	453	454	438
LWC	553	549	569	422	513	570	574	561	461	508	587	540
ULC	591	595	614	535	506	625	578	586	478	395	591	590
LLC	612	607	623	488	482	622	584	578	482	402	606	566
UCC	834	823	840	746	835	836	799	770	723	702	788	721
LCC	842	818	840	764	818	828	795	761	755	708	789	738
EC	674	612	604	Dry	Dry	698	618	617	491	647	639	686
CrC	671	638	648	606	656	670	638	606	641	611	638	628
CaC	680	642	685	692	711	699	677	558	652	606	668	628
NNC	448	379	390	Dry	Dry	545	486	477	Dry	477	*	433
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	451	489	485	418	423	459	504	496	447	458	495	453
OC	451	490	496	497	422	460	501	536	453	*	494	450
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	500	642	501	426	496	505	607	499	448	438	520	505
UR-S	480	536	493	409	429	471	546	489	452	475	506	468
UR-B	488	539	497	410	428	471	546	489	452	475	505	467
WCA-S	468	515	494	404	419	475	532	467	447	456	498	466
WCA-B	469	508	493	404	418	473	532	477	447	455	497	465
MR-S	458	498	491	413	419	461	517	486	446	472	487	465
MR-B	458	523	490	413	430	463	517	495	446	475	489	463
KS-S	457	488	486	409	414	456	514	481	447	469	484	463
CC-S	453	491	483	416	415	460	514	483	446	469	487	464
MC-S	453	484	485	423	415	453	510	480	448	464	482	462
LR-S	454	489	486	422	413	453	508	486	448	465	482	464
LR-B	454	492	492	442	422	453	508	493	448	465	485	464

Appendix B-3: Chemical Oxygen Demand (ppm)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	*	3	2	3	2	< 1	< 1	17	*	2	4	3
LWC	*	6	7	5	2	3	4	4	22	9	6	9
ULC	*	6	6	40	4	2	5	6	15	14	7	12
LLC	*	7	9	9	< 1	5	8	10	21	17	8	13
UCC	*	6	6	7	4	3	4	14	11	14	7	11
LCC	*	6	7	5	4	2	4	14	10	11	6	12
EC	*	7	6	Dry	Dry	3	6	7	25	6	7	8
CrC	*	1	1	3	< 1	< 1	< 1	5	5	5	3	6
CaC	*	3	2	4	< 1	<1	2	3	20	6	4	5
NNC	*	6	8	Dry	Dry	8	13	11	Dry	13	*	17
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	*	9	10	15	3	13	11	7	18	15	23	10
OC	*	10	11	32	3	17	19	12	17	*	12	9
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	11	9	10	26	10	9	11	13	20	29	13	14
UR-S	11	9	10	19	10	11	7	< 1	19	15	10	17
UR-B	11	9	10	19	10	12	9	< 1	18	15	11	12
WCA-S	11	9	9	18	11	10	10	2	18	15	10	10
WCA-B	11	9	9	18	11	10	9	< 1	18	15	12	7
MR-S	11	10	10	17	13	12	10	5	18	13	10	10
MR-B	12	10	9	20	12	10	8	2	18	13	11	8
KS-S	11	10	9	18	12	11	8	5	17	11	13	8
CC-S	11	10	10	17	12	13	8	3	18	13	10	8
MC-S	10	10	11	14	12	11	8	3	18	12	11	7
LR-S	15	9	10	14	11	11	8	4	16	12	9	10
LR-B	11	9	11	14	11	11	9	< 1	16	11	10	9

Appendix B-4: Turbidity (NTU)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	6	11	13	5.9	8.2	3.8	6.1	17	>2000	18	9.4	16
LWC	12	17	25	17	14	15	9.5	34	159	46	14	38
ULC	21	25	32	33	13	10	17	23	132	318	18	224
LLC	14	29	34	12	9.8	5.9	21	20	84	295	12	223
UCC	7	22	29	22	14	12	8.8	94	43	50	21	57
LCC	9.2	20	31	14	13	14	12	116	28	57	20	65
EC	8	11	13	Dry	Dry	4.3	5.7	24	155	8.8	5.8	7.2
CrC	7.3	14	6.4	5.2	2.2	5.4	3.7	28	7	56	3.1	14
CaC	6.8	13	5.8	4.6	3.1	2.4	2.1	70	40	61	2.1	29
NNC	2.7	8.1	7.4	Dry	Dry	4.5	6.8	3.5	Dry	4.8	*	8.6
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	7.4	4.7	10	13	15	12	17	12	15	17	109	15
OC	7.2	5.5	2.2	7.5	11	11	7.8	7	8.5	*	9.7	10
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	12	28	26	90	55	16	35	84	42	143	40	64
UR-S	11	13	13	24	35	12	14	38	35	30	22	41
UR-B	11	12	13	32	34	12	16	62	38	30	23	24
WCA-S	8.4	11	12	30	27	7.8	19	21	31	48	22	31
WCA-B	8.7	10	14	31	28	9.7	19	21	35	49	23	27
MR-S	7.3	5.7	5.2	22	20	9	7.4	12	27	14	12	20
MR-B	7.3	13	12	23	36	9.6	7.5	25	25	17	14	20
KS-S	5.7	4.6	5.5	22	17	9.9	6.2	13	22	12	8.3	14
CC-S	5	5.3	7	16	16	10	6.1	11	25	14	10	15
MC-S	4.8	3.4	5.4	9.2	16	9.9	7.1	9.1	21	11	10	9.9
LR-S	6.1	6.6	5.5	9.2	16	8.6	6.8	7.2	22	13	8.2	11
LR-B	9.5	7.2	17	15	23	9.7	11	7.3	27	15	17	25

Appendix B-5: Chlorophyll (ppb)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	0.79	2.6	3.1	7.5	3.9	2.4	5.5	7.9	*	7.1	5.5	2.8
LWC	2	5.5	6.5	14	11	4.9	9	23	*	2.8	11	7.5
ULC	4.7	10	17	26	8.1	3.9	20	13	33	7.9	18	5.9
LLC	3.5	18	13	8.5	6.9	6.5	14	11	15	6.3	14	8.3
UCC	3.5	8.9	14	17	5.3	5.1	9.4	20	9.4	5.9	11	9
LCC	2.4	8.1	13	12	5.3	3.7	13	20	11	5.9	9.4	7.9
EC	0.39	5.1	11	Dry	Dry	2.6	3.5	5.1	24	0.39	15	2.4
CrC	2.4	2	4.7	7.3	3.1	1.6	5.9	8.7	3.1	1.6	2.8	3.9
CaC	1.6	5.3	5.7	3.1	2.4	1.8	8.3	5.5	9.4	0.79	7.9	3.1
NNC	1.2	3.5	3.3	Dry	Dry	2.6	2.4	0.8	Dry	< .20	*	0.39
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	15	4.3	2.8	74	38	19	42	10	56	40	*	13
OC	16	5.5	0.79	9.6	42	19	49	31	44	*	15	17
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	14	79	62	151	70	11	44	112	64	41	61	72
UR-S	15	26	30	98	73	19	15	70	65	51	38	136
UR-B	14	27	12	103	72	19	13	62	66	55	37	18
WCA-S	12	21	7.1	90	75	18	13	59	60	49	32	13
WCA-B	11	8.3	4.1	86	79	16	11	45	57	51	34	11
MR-S	10	16	4.3	86	60	20	9.8	40	55	38	14	47
MR-B	10	7.1	3.1	81	53	21	11	16	57	43	16	5.1
KS-S	11	13	5.9	83	66	22	13	38	58	36	13	30
CC-S	10	8.9	3.9	76	61	21	9	37	54	38	15	22
MC-S	11	8.1	9.6	54	52	20	14	30	50	28	14	28
LR-S	11	9.6	3.7	45	49	24	16	31	47	32	12	24
LR-B	10	3.1	3.5	28	42	20	11	8.3	50	29	16	8.3

Appendix B-6: pH

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	8.2	7.8	8.2	8.3	8.3	7.5	8.1	8.1	7.4	7.6	7.7	7.7
LWC	8.3	8.2	8.2	7.8	8.4	7.7	7.9	8.2	7.7	7.3	8.4	7.8
ULC	8.3	8	8.2	8.2	8.3	7.4	8.1	8.2	7.9	7.3	7.8	8
LLC	8.4	8.2	8.2	8	8.3	7.6	8	8	7.9	7.4	8.4	7.8
UCC	8.2	8	8.1	7.9	8.4	7.4	7.9	7.9	7.7	7.3	8.2	8.1
LCC	8.6	8.5	8.6	8.3	8.7	7.8	8.4	7.9	8.1	7.7	8.3	8
EC	8.1	7.9	8	Dry	Dry	7.3	7.8	7.6	7.9	7.1	7.8	7.9
CrC	8.1	7.9	8	7.8	8.2	7.5	7.8	7.8	7.7	7	8.3	7.9
CaC	8.1	7.9	8	7.9	8.2	7.3	7.7	7.9	7.6	7.2	8.4	7.9
NNC	7.7	7.6	7.7	Dry	Dry	7	7.3	7.5	Dry	7	*	7.5
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	8.8	8.7	8.3	8.2	8.5	7.7	8.2	8.5	7.9	7.9	8.2	7.8
OC	9	8.9	8.2	7.6	8.8	8	8.7	7.9	8.1	*	8.3	8.1
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	8.6	8.6	7.9	8.1	7.9	8.4	8.3	8.7	8.7	7.8	8.6	8.1
UR-S	8.7	8.5	8.1	8.5	7.8	8.4	8.2	8.8	8.8	8.4	7.5	7.6
UR-B	*	*	*	*	*	*	*	*	*	*	*	*
WCA-S	8.7	8.5	8	8.4	8	8.4	8.1	8.6	8.7	8.4	7.4	8
WCA-B	*	*	*	*	*	*	*	*	*	*	*	*
MR-S	8.6	8.6	8.1	8.5	7.8	8.3	8.1	8.8	8.7	8.4	7.2	8.1
MR-B	*	*	*	*	*	*	*	*	*	*	*	*
KS-S	8.6	8.6	8.1	8.7	8	8.3	8.3	8.8	8.7	8.3	7.3	8.1
CC-S	8.6	8.5	8.1	8.5	7.8	8.3	8.2	8.8	8.7	8.4	7.9	8.1
MC-S	8.6	8.6	8.1	8.2	7.9	8.4	8.2	8.8	8.6	8.4	7.3	8.2
LR-S	8.6	8.6	8.1	8.3	7.8	8.4	8.1	8.7	8.4	8.4	7.8	8.1
LR-B	*	*	*	*	*	*	*	*	*	*	*	*

Appendix B-7: Alkalinity (ppm as calcium carbonate)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	205	200	205	175	180	180	180	195	118	195	170	192
LWC	235	235	230	160	180	210	225	175	160	205	235	222
ULC	275	275	270	170	218	255	245	240	170	170	250	265
LLC	280	280	275	175	195	260	250	230	175	175	260	252
UCC	245	245	230	200	215	220	235	155	200	210	235	220
LCC	250	245	235	205	215	225	225	125	210	*	240	222
EC	315	290	275	Dry	Dry	295	285	275	180	295	280	325
CrC	200	195	195	175	195	175	235	155	195	190	185	200
CaC	225	220	230	212	225	215	205	170	200	195	210	225
NNC	155	135	150	Dry	Dry	140	180	175	Dry	180	*	200
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	120	135	130	85	90	95	120	120	90	110	115	125
OC	120	140	130	130	90	100	125	130	100	*	115	125
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	140	200	125	80	105	130	170	140	105	112	135	125
UR-S	135	155	130	80	85	115	150	130	95	112	130	122
UR-B	135	150	135	80	85	110	140	125	98	100	130	130
WCA-S	130	155	135	80	85	115	135	115	95	118	135	130
WCA-B	130	145	130	80	85	115	135	120	95	105	135	125
MR-S	125	140	130	85	85	110	125	120	95	110	135	125
MR-B	120	155	130	85	85	105	125	125	92	115	120	130
KS-S	120	140	132	80	85	100	125	130	95	110	120	128
CC-S	120	140	130	90	85	100	120	140	90	115	125	130
MC-S	120	135	130	95	88	105	125	135	100	110	120	130
LR-S	120	140	130	90	85	105	115	130	100	105	115	125
LR-B	115	140	135	105	100	105	115	125	95	110	115	125

Appendix B-8: Sulfate (ppm)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	31	42	36	34	42	44	50	40	*	36	43	39
LWC	54	56	52	45	67	84	75	68	60	60	67	62
ULC	35	47	46	72	44	56	58	51	52	39	52	54
LLC	41	49	43	54	48	62	60	54	*	44	54	58
UCC	190	178	178	164	156	168	168	190	137	102	158	155
LCC	190	178	180	175	156	190	171	176	156	157	159	159
EC	22	23	22	Dry	Dry	42	36	*	44	41	28	32
CrC	168	149	138	122	130	146	138	136	118	76	138	139
CaC	155	131	127	146	120	151	131	101	120	76	142	116
NNC	18	19	16	Dry	Dry	84	38	32	Dry	27	*	10
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	119	104	43	101	54	104	94	99	74	76	90	82
OC	114	105	44	97	50	118	104	93	64	*	96	105
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	122	139	86	117	144	94	31	94	92	104	105	98
UR-S	120	121	78	105	123	84	50	76	76	104	100	90
UR-B	126	117	83	107	122	85	27	81	105	97	100	94
WCA-S	119	116	84	98	115	80	20	81	87	116	93	93
WCA-B	112	111	76	98	118	79	24	75	88	96	104	105
MR-S	115	112	76	99	115	76	45	82	76	102	96	94
MR-B	117	119	70	96	117	76	25	82	77	103	102	87
KS-S	110	110	69	94	87	76	25	70	71	107	96	87
CC-S	119	115	67	91	98	82	25	81	86	101	93	87
MC-S	115	108	64	90	102	74	26	82	73	107	97	88
LR-S	117	111	58	85	104	76	15	86	70	104	97	102
LR-B	115	109	55	85	83	72	24	63	61	77	99	97

Appendix B-9: Chloride (ppm)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	6.25	6.75	7.25	6.75	6.5	6	5	5.5	4.25	7.75	6	5.75
LWC	11.5	13	11.75	10	13	12	11.25	10.75	11.75	11.5	14	11.25
ULC	13	14	13.5	30.25	14.75	13.25	14.5	12.5	17.25	8.75	13	7
LLC	13	13.75	12.5	18	13	12.75	12.75	12.5	17.25	9	13.25	12.25
UCC	11.75	12.5	10.75	11	12.5	8	10.75	9.75	10	10.5	11	9.5
LCC	11.75	12.5	10.75	11.25	12.25	10.25	11.5	9.75	11.25	10	11.5	10.25
EC	17.5	15.75	13.75	Dry	Dry	20.5	16	13.25	14.75	16.25	9.25	15.75
CrC	5.75	7	6.25	5.25	5.25	5	6	4.5	5.5	6.5	5.75	7
CaC	9	10.5	8.5	8.5	8.5	8	7.75	7	9.5	11	8.25	8.5
NNC	34.5	22.5	18.25	Dry	Dry	31.75	25	24	Dry	30.5	*	21.5
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	9.5	9.75	9.5	10.25	12	11.25	11.25	10.75	12.25	12	12	10.5
OC	10	11	9.25	8.75	11	11.25	10.75	11.25	11.25	*	12	10.75
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	10.5	8	10.25	11.25	11.75	11.5	11.25	11.5	10.75	12.75	12.5	10.25
UR-S	10	10.5	9.5	10.75	11.75	11	11	9.5	11.5	11.75	11.75	10.5
UR-B	10.5	10.75	9.25	10.25	11.75	10.75	10.5	11	11.5	11.5	11.75	10.5
WCA-S	10	10.75	9.5	10	11.75	11.25	10	11.25	10.75	11.25	11.75	10
WCA-B	10.5	10.25	10.25	10.5	11.75	10.75	10.5	10.75	10.75	11.5	11.75	10.75
MR-S	10	10.5	9.75	10.25	12	11.25	10.25	10.25	11.5	12.75	11.5	10.5
MR-B	10	10.5	9.25	10.5	12.25	10.75	10.75	11	11.25	11.75	11	11
KS-S	10	10.25	9.75	10.75	11	11	11.25	11	11.25	11.5	11.75	10
CC-S	10.5	8.75	9	9.75	11.25	10.25	11	10	11	12	10.75	11
MC-S	10.25	9.5	10	10.25	11	11	11.5	10.25	10.25	12.5	9.5	10.75
LR-S	9.75	10	9.75	10.75	10.75	11	10.75	10.75	11	12.75	11	10.75
LR-B	10.25	10.5	9	10.5	10.75	10.75	10.75	10.75	11	12	11	10.5

Appendix B-10: Nitrate - N (ppm)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	1.9	1.7	1.6	0.7	1.1	1.4	1	0.9	1.4	1.3	1	1.1
LWC	0.9	0.8	1.1	0.3	0.5	0.8	0.4	0.6	0.5	0.9	0.5	0.8
ULC	1.3	1	1.1	0.3	0.8	1.3	0.9	0.7	0.6	0.9	0.7	1.2
LLC	1.1	0.9	1.2	0.2	0.3	0.7	0.7	0.7	0.3	0.8	0.5	1.4
UCC	1.4	1.3	1.5	1.4	1.1	1.2	0.9	0.5	1.1	0.9	1	1
LCC	1.5	1.3	1.6	1.1	1.1	1.3	1	0.7	1	0.9	1	1
EC	3.8	2.3	2.2	Dry	Dry	2.4	0.7	1.7	2.3	2.1	1.7	2.4
CrC	2.5	2.3	2	2	1.6	1.9	1.3	1.5	1.4	1.8	1.4	1.6
CaC	1.9	1.6	2.2	1.9	1.4	1.7	1.1	1.3	1.3	1.7	1.2	1.7
NNC	0.8	1.3	1.1	Dry	Dry	1.4	0.4	0.8	Dry	0.9	*	0.8
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	0.3	0.3	0.65	< 0.1	0.5	0.3	0.6	0.3	0.2	0.3	0.4	0.8
OC	0.3	0.29	0.43	0.7	0.5	0.3	0.5	0.3	0.2	*	0.3	0.7
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	0.19	*	0.4	0.05	0.23	0.43	0.47	0.05	0.01	0.29	0.28	0.31
UR-S	0.17	0.54	0.54	0.02	0.22	0.41	0.44	0.05	0.01	0.14	0.17	0.35
UR-B	0.18	0.49	0.6	0.02	0.22	0.41	0.43	0.05	0.02	0.14	0.2	0.49
WCA-S	0.15	0.45	0.93	0.04	0.2	0.4	0.42	0.03	0.01	0.14	0.18	0.48
WCA-B	0.15	0.42	0.91	0.01	0.17	0.37	0.43	0.04	0.03	0.18	0.22	0.46
MR-S	0.16	0.38	0.89	0.02	0.35	0.38	0.44	0.05	0.02	0.12	0.17	0.37
MR-B	0.22	0.47	0.98	0.02	0.34	0.39	0.42	0.27	0.03	0.13	0.2	0.3
KS-S	0.15	0.44	0.8	0.01	0.34	0.41	0.41	0.03	0.03	0.13	0.2	0.32
CC-S	0.16	0.3	0.92	0.03	0.4	0.4	0.42	0.02	0.08	0.15	0.23	0.38
MC-S	0.16	0.37	0.75	0.22	0.27	0.42	0.41	0.01	0.03	0.14	0.22	0.21
LR-S	0.23	0.3	0.88	0.11	0.21	0.42	0.42	0	0.02	0.14	0.2	0.26
LR-B	0.2	0.26	0.6	*	0.26	0.4	0.41	0.26	0.02	0.17	0.2	0.42

Appendix B-11: Ammonia - N (ppm)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	0.02	0.03	0.1	0.03	< 0.01	0.06	0.07	0.01	0.34	0.05	0.05	0.03
LWC	< 0.01	0.09	0.15	0.05	< 0.01	0.1	0.05	0.05	0.02	0.09	0.07	0.03
ULC	0.02	0.07	0.18	0.04	< 0.01	0.07	0.08	0.06	0.09	0.11	0.04	0.2
LLC	0.03	0.1	0.15	0.02	0.01	0.07	0.12	0.06	0.02	0.13	0.06	0.31
UCC	0.03	0.06	0.07	0.03	0.01	0.05	0.05	0.03	< 0.01	0.05	0.06	0.02
LCC	0.03	0.07	0.07	0.03	< 0.01	0.08	0.02	0.05	0.05	0.07	0.06	0.02
EC	0.01	0.02	0.08	Dry	Dry	0.05	0.05	0.2	0.03	0.07	0.08	0.02
CrC	0.01	0.04	0.06	0.02	< 0.01	0.02	< 0.01	0.11	< 0.01	0.04	0.01	0.04
CaC	0.01	0.05	0.13	0.03	< 0.01	0.1	0.03	0.15	0.08	0.08	0.03	0.11
NNC	0.01	0.05	0.05	Dry	Dry	0.04	0.09	0.07	Dry	0.02	*	0.04
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	0.03	0.47	0.47	0.03	0.26	0.23	0.49	0.05	0.08	0.44	0.35	< 0.01
OC	< 0.01	0.48	0.63	> 0.80	0.18	0.23	0.35	> 0.80	0.13	*	0.37	< 0.01
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	0.06	0.11	0.06	0.07	< 0.01	0.16	0.14	0.04	< 0.01	0.1	0.11	0.12
UR-S	0.05	0.37	0.13	< 0.01	< 0.01	0.2	0.41	0.04	< 0.01	0.1	0.2	0.15
UR-B	0.07	0.37	0.32	0.02	< 0.01	0.21	0.47	0.05	< 0.01	0.07	0.23	0.2
WCA-S	0.07	0.43	0.36	0.01	< 0.01	0.19	0.49	0.05	< 0.01	0.1	0.23	0.19
WCA-B	0.07	0.46	0.48	0.01	0.01	0.2	0.47	0.05	0.01	0.07	0.25	0.21
MR-S	0.07	0.42	0.36	0.02	0.15	0.27	0.54	0.03	0.01	0.29	0.45	0.12
MR-B	0.05	0.49	0.45	0.01	0.15	0.26	0.59	< 0.01	< 0.01	0.26	0.46	0.18
KS-S	0.09	0.44	0.31	< 0.01	0.08	0.27	0.58	0.04	< 0.01	0.29	0.47	0.11
CC-S	0.07	0.46	0.4	< 0.01	0.19	0.25	0.53	0.04	< 0.01	0.3	0.46	0.13
MC-S	0.06	0.45	0.29	0.07	0.33	0.25	0.59	0.03	< 0.01	0.51	0.56	0.03
LR-S	0.05	0.47	0.38	0.09	0.43	0.25	0.66	0.01	< 0.01	0.49	0.5	0.08
LR-B	0.06	0.58	0.8	> 0.80	0.31	0.23	0.73	0.03	< 0.01	0.44	0.53	0.31

Appendix B-12: Nitrite - N (ppm)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	0.032	0.013	0.04	0.008	0.03	0.009	0.051	0.024	0.094	0.018	0.029	0.025
LWC	0.017	0.019	0.049	0.003	0.012	0.009	0.032	0.021	0.02	0.016	0.025	0.026
ULC	0.021	0.023	0.081	0.017	0.03	0.018	0.067	0.024	0.048	0.025	0.032	0.052
LLC	0.018	0.026	0.08	0.001	0.012	0.013	0.049	0.058	0.008	0.026	0.026	0.078
UCC	0.02	0.024	0.043	0.021	0.013	0.011	0.031	0.014	0.031	0.017	0.034	0.022
LCC	0.022	0.026	0.043	0.027	0.012	0.014	0.023	0.064	0.031	0.018	0.033	0.024
EC	0.033	0.028	0.09	Dry	Dry	0.031	0.057	0.063	0.103	0.038	0.059	0.042
CrC	0.018	0.017	0.049	0.008	0.012	0.008	0.023	0.044	0.026	0.022	0.029	0.031
CaC	0.024	0.02	0.055	0.023	0.02	0.013	0.031	0.038	0.079	0.03	0.029	0.048
NNC	0.01	0.015	0.021	Dry	Dry	0.016	0.15	0.098	Dry	0.011	*	0.014
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	0.009	0.007	0.023	< .001	0.028	0.004	0.032	0.003	0.035	0.01	0.022	0.004
OC	0.007	0.007	0.037	0.019	0.031	0.004	0.021	0.009	0.009	*	0.015	0.003
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	0.009	0.029	0.015	0.007	0.024	*	0.021	0.005	0.002	0.025	0.052	0.033
UR-S	0.008	0.033	0.127	0.002	0.052	*	0.016	0.003	0.002	0.012	0.014	0.039
UR-B	0.007	0.019	0.072	0.002	0.056	*	0.016	0.002	0.002	0.013	0.025	0.041
WCA-S	0.006	0.024	0.103	0.002	0.052	*	0.016	0.001	0.001	0.013	0.031	0.037
WCA-B	0.007	0.013	0.072	0.001	0.043	*	0.018	0.004	0.001	0.033	0.047	0.039
MR-S	0.006	0.019	0.137	0.002	0.005	*	0.013	0.001	0.001	0.011	0.009	0.037
MR-B	0.008	0.029	0.14	0.001	0.051	*	0.013	0.002	0.001	0.011	0.011	0.027
KS-S	0.005	0.021	0.121	0.002	0.095	*	0.013	0	0.001	0.009	0.008	0.04
CC-S	0.005	0.009	0.101	0.001	0.039	*	0.013	0.001	0.031	0.02	0.027	0.035
MC-S	0.005	0.023	0.112	0.096	0.05	*	0.012	0.001	0.001	0.008	0.015	0.024
LR-S	0.008	0.006	0.144	0.027	0.018	*	0.013	0.001	0.001	0.008	0.009	0.032
LR-B	0.006	0.004	0.025	> 0.35	0.048	*	0.013	0.001	0.001	0.021	0.01	0.026

Appendix B-13: Total N (ppm)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	2.2	2.7	3.2	1	3.2	1.7	1.8	0.6	19	2.5	2	2.1
LWC	1.3	1.6	3	0.45	0.5	1.5	1.2	< .100	2.4	2.1	1.7	1.7
ULC	1.6	2.1	2.6	2.1	1.3	2.2	2.1	0.25	2.1	4.7	2.1	3.8
LLC	1.8	2.4	3	0.65	0.7	0.7	1.4	< .100	1.7	3.8	2.1	3.5
UCC	2.1	2.4	2.5	2.3	2	1.7	2	0.65	2.5	2.3	2.8	2.4
LCC	1.9	2.6	3	2.3	1.4	1.5	2	1.3	2.4	2.5	2.3	2.7
EC	4.3	4	3.6	Dry	Dry	3.2	1.4	2.8	6.7	4.6	3.4	4.4
CrC	2.9	3.6	3.1	2.4	1.9	2.3	2	1.6	3.4	4.1	3	2.5
CaC	2.5	3.2	9.9	2	2.1	2	1.8	1.6	3	*	2.2	3.9
NNC	1.5	2.2	1.9	Dry	Dry	2	1.3	< .100	Dry	1.9	*	1.4
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	0.75	0.65	1.6	0.6	1.1	0.9	2.2	< .100	1.5	1.9	3.8	1.2
OC	0.7	0.5	1.4	6.8	1.5	0.75	1.8	2.3	1.3	*	2.4	1.2
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	0.78	1.1	1	2.7	2.2	1.8	1.6	1.8	1.2	2.2	2.1	1.9
UR-S	0.82	0.8	1.1	1.6	2.3	1.4	1.5	0.9	1.6	1.1	1.6	1.7
UR-B	0.73	*	1.3	1.6	2.5	1.8	1.7	1.2	1.8	1.2	1.8	*
WCA-S	0.67	0.8	1.2	1.7	1.9	2.4	1.6	0.8	1.1	2	1.6	*
WCA-B	0.72	0.75	1.4	1.8	2	2.4	1.7	0.8	1.2	1.3	3	3.6
MR-S	0.83	0.55	1.6	1.4	2	2.1	1.5	0.7	1.3	2.2	1.7	*
MR-B	0.83	0.95	1.6	1.4	1.8	1.5	1.3	1.1	1.4	1.5	1.7	1
KS-S	0.93	0.75	1.8	1.2	1.7	1.6	1.8	0.75	1.9	1.2	1.8	0.8
CC-S	0.9	0.5	1.1	1.1	2.3	2.6	1.4	0.8	1.2	2.3	1.6	*
MC-S	0.75	0.45	1.5	1.5	2.2	1.7	1.7	0.5	1.4	2.1	1.8	0.7
LR-S	0.62	0.8	1.1	1.1	2.1	1.9	1.6	0.8	1.1	1.3	1.9	0.7
LR-B	0.75	0.65	1.6	2.2	2	1.6	1.7	0.6	1.2	1.4	3.6	0.5

Appendix B-14: Total P (ppb)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	102	137	206	59	220	112	225	137	1830	88	248	133
LWC	182	132	248	130	302	106	216	142	257	132	320	183
ULC	119	142	326	95	358	77	308	470	313	339	320	388
LLC	176	158	308	112	294	86	266	102	288	276	300	356
UCC	139	126	362	146	208	209	245	103	236	173	440	228
LCC	124	149	284	141	286	85	211	480	338	168	440	259
EC	148	111	198	Dry	Dry	85	157	202	185	96	232	106
CrC	118	104	133	96	303	86	173	155	286	135	108	124
CaC	177	153	386	171	419	106	198	204	315	197	200	251
NNC	124	90	214	Dry	Dry	88	175	291	Dry	57	*	150
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	26	51	65	<10	110	74	171	218	23	108	940	108
OC	245	83	133	538	99	61	146	225	72	*	208	83
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	62	162	126	178	202	157	194	342	175	261	412	180
UR-S	55	108	288	72	211	160	108	268	171	124	372	169
UR-B	59	122	94	11	50	141	120	347	203	136	292	102
WCA-S	52	108	106	40	214	130	178	293	270	135	264	108
WCA-B	46	106	94	45	106	160	122	211	752	150	280	104
MR-S	52	88	88	<10	56	142	110	108	207	110	196	94
MR-B	52	96	79	<10	176	146	156	245	85	100	216	111
KS-S	52	90	94	<10	112	195	104	203	128	87	156	92
CC-S	46	94	117	<10	70	120	76	175	234	92	176	92
MC-S	49	54	74	10	86	147	93	162	310	90	180	77
LR-S	49	76	54	52	58	228	79	256	210	96	164	81
LR-B	59	92	119	189	86	78	115	216	77	115	308	137

Appendix B-15: Soluble Reactive Phosphorus (ppb)

LOCATION	11/3/1997	2/10/1998	5/2/1998	8/3/1998	10/29/1998	1/4/1999	4/20/1999	7/12/1999	9/11/1999	12/13/1999	3/15/2000	6/22/2000
UWC	94	103	164	< 10	126	67	121	88	232	42	120	90
LWC	94	121	227	58	119	94	161	67	25	51	122	86
ULC	77	131	190	86	76	65	121	132	142	61	110	77
LLC	80	153	290	99	220	79	184	70	241	61	116	73
UCC	101	120	284	88	167	65	141	140	198	57	204	100
LCC	66	99	241	94	167	76	189	208	164	62	238	125
EC	102	86	117	Dry	Dry	74	121	117	70	52	56	42
CrC	69	88	133	40	83	59	130	79	52	44	28	87
CaC	118	142	158	140	117	67	121	125	229	96	86	176
NNC	58	87	126	Dry	Dry	63	65	189	Dry	27	*	48
LOCATION	**11/3/1997**	**2/23/1998**	**5/13/1998**	**8/3/1998**	**10/29/1998**	**1/4/1999**	**4/20/1999**	**7/12/1999**	**9/11/1999**	**12/13/1999**	**3/15/2000**	**6/22/2000**
OA	12	48	48	< 10	44	65	20	53	< 10	25	86	55
OC	24	39	89	362	63	47	36	26	63	*	64	45
LOCATION	**11/13/1997**	**2/23/1998**	**5/13/1998**	**8/11/1998**	**10/23/1998**	**1/11/1999**	**4/6/1999**	**7/23/1999**	**9/21/1999**	**12/6/1999**	**3/9/2000**	**6/15/2000**
NWS-S	26	50	16	43	54	83	168	180	74	39	34	40
UR-S	18	44	< 10	< 10	41	91	89	113	72	< 10	36	31
UR-B	19	64	26	< 10	25	69	117	135	25	< 10	38	36
WCA-S	18	47	42	13	< 10	99	67	45	32	< 10	34	38
WCA-B	16	55	32	< 10	11	60	105	155	< 10	< 10	32	39
MR-S	20	35	39	< 10	27	95	68	103	67	20	60	33
MR-B	22	63	40	< 10	38	85	84	171	< 10	17	50	52
KS-S	23	36	30	< 10	< 10	120	84	72	14	22	50	39
CC-S	20	31	35	< 10	61	70	68	137	40	25	62	36
MC-S	21	23	29	< 10	22	63	88	85	43	33	58	24
LR-S	21	37	37	< 10	41	86	54	68	22	34	58	37
LR-B	23	49	68	140	27	40	53	149	22	35	66	63

Appendix C-1: Calcium (ppm)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	74	74	34	34	73	71	69	69
LWC	81	81	49	51	82	86	74	74
ULC	84	82	27	27	74	72	74	74
LLC	82	84	38	37	73	74	66	66
UCC	127	127	117	115	117	113	107	107
LCC	133	131	110	110	123	117	106	105
EC	84	90	Dry	Dry	80	76	Dry	Dry
CrC	110	114	97	96	100	102	98	94
CaC	101	104	104	104	104	108	95	95
NNC	37	38	Dry	Dry	47	48	39	37
OUTA	54	55	44	46	56	54	40	41
OUTB	53	54	*	*	*	*	42	43
OUTC	53	56	41	42	55	55	41	41

Appendix C-2: Magnesium (ppm)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	10	10	6.4	6.5	9.9	9.9	9.3	9.2
LWC	16	16	12	12	15	16	13	13
ULC	22	21	14	14	19	19	18	18
LLC	22	23	17	17	21	21	19	19
UCC	25	25	23	23	24	24	25	26
LCC	25	26	22	22	24	24	26	25
EC	23	23	Dry	Dry	23	22	Dry	Dry
CrC	13	14	12	12	13	13	14	14
CaC	20	20	18	18	19	19	20	20
NNC	15	16	Dry	Dry	18	21	15	15
OUTA	16	17	16	16	18	18	19	19
OUTB	16	16	*	*	*	*	19	19
OUTC	16	17	16	16	18	18	19	19

Appendix C-3: Sodium (ppm)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	16.2	16.3	15.2	15.2	15.5	15.9	15.3	14.9
LWC	19.6	19.9	18.8	17.8	20	20.7	18.3	18.1
ULC	27	27.5	28.7	27.4	25.8	26.1	23.7	24.1
LLC	26.5	27.7	28.4	26.9	25.7	26.8	24.6	25
UCC	27.4	27.7	29.9	26.6	25.6	26.2	25.4	25.3
LCC	26.4	27.2	28.7	25.3	21.4	25.9	25.2	24.1
EC	25.2	25.9	Dry	Dry	28.3	27.5	Dry	Dry
CrC	20.3	20.6	20.9	19.8	19.8	19.7	20	20
CaC	19.8	20.3	18.5	17.8	17.8	16.7	17.9	18.3
NNC	16.3	17.3	Dry	Dry	19	21.8	17.5	17
OUTA	18.1	18.3	18.5	17.5	19.3	20.5	20.1	20.6
OUTB	18	18.4	*	*	*	*	19.9	22.3
OUTC	18.1	18.6	19.1	18	20.2	19.6	20.8	20.3

Appendix C-4: Potassium (ppm)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	1.53	1.44	1.39	1.29	1.44	1.66	1.53	1.51
LWC	2	1.88	1.66	1.76	1.36	1.31	1.86	1.87
ULC	2.47	2.1	2.15	2.12	2.12	2.03	2.45	2.45
LLC	2.42	2.25	2.41	2.28	1.93	1.81	2.85	2.87
UCC	2.41	2.28	2.01	1.98	2.24	2.17	2.63	2.67
LCC	2.5	2.37	2.05	1.98	2.22	1.91	2.67	2.62
EC	1.78	1.85	Dry	Dry	1.17	1.18	Dry	Dry
CrC	1.11	1.15	1.34	1.31	1.3	1.28	1.56	1.58
CaC	3.86	3.91	1.8	1.8	1.11	1.09	3.06	3.19
NNC	2.74	2.84	Dry	Dry	2.34	2.34	3.63	2.82
OUTA	4.69	4.75	5.06	4.89	4.79	4.86	5.09	5.11
OUTB	4.57	4.62	*	*	*	*	5	5.03
OUTC	4.67	5.07	5.04	5	4.77	4.69	5.19	5.1

Appendix C-5: Aluminum (ppm)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	0.488	< .05	0.147	< .05	0.085	< .05	0.255	< .05
LWC	0.506	< .05	0.38	< .05	0.183	< .05	0.267	< .05
ULC	2.24	< .05	0.061	< .05	0.426	< .05	0.347	< .05
LLC	1.47	< .05	0.077	< .05	0.509	< .05	0.15	< .05
UCC	0.307	< .05	0.086	< .05	0.21	< .05	0.102	< .05
LCC	0.592	< .05	0.169	< .05	0.727	< .05	0.132	< .05
EC	0.214	< .05	Dry	Dry	0.137	< .05	Dry	Dry
CrC	0.197	< .05	< .05	< .05	0.084	< .05	0.051	< .05
CaC	0.828	< .05	< .05	< .05	< .05	< .05	0.06	< .05
NNC	0.246	< .05	Dry	Dry	< .05	< .05	0.446	< .05
OUTA	0.073	< .05	< .05	< .05	0.28	< .05	0.096	< .05
OUTB	0.187	< .05	*	*	*	*	0.085	< .05
OUTC	0.097	< .05	0.074	< .05	0.135	< .05	0.099	< .05

Appendix C-6: Iron (ppm)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	0.484	< .02	0.132	<. 02	0.24	< .02	0.249	< .02
LWC	0.411	< .02	0.358	< .02	0.429	< .02	0.322	< .02
ULC	1.83	< .02	0.082	< .02	0.577	< .02	0.393	< .02
LLC	1.39	0.04	0.088	< .02	0.695	< .02	0.203	< .02
UCC	0.402	< .02	0.106	< .02	0.281	< .02	0.122	< .02
LCC	0.506	< .02	0.155	< .02	0.841	< .02	0.147	< .02
EC	0.363	< .02	Dry	Dry	0.224	< .02	Dry	Dry
CrC	0.155	< .02	0.053	< .02	0.09	< .02	0.06	< .02
CaC	0.572	< .02	0.058	< .02	0.09	< .02	0.119	0.02
NNC	0.862	0.111	Dry	Dry	0.977	0.114	2	0.05
OUTA	0.06	< .02	0.05	< .02	0.238	< .02	0.107	< .02
OUTB	0.128	< .02	*	*	*	*	0.09	< .02
OUTC	0.1	0.02	0.06	< .02	0.104	< .02	0.1	< .02

Appendix C-7: Manganese (ppm)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	0.197	0.18	0.038	0.012	0.115	0.11	0.099	0.084
LWC	0.187	0.498	0.076	0.021	0.226	0.193	0.101	0.08
ULC	0.309	0.235	0.059	0.023	0.181	0.117	0.089	0.05
LLC	0.362	0.331	0.054	0.009	0.303	0.183	0.052	0.038
UCC	0.141	0.118	0.081	0.043	0.115	0.069	0.05	0.04
LCC	0.172	0.157	0.073	0.037	0.312	0.084	0.052	0.041
EC	0.559	0.634	Dry	Dry	0.196	0.186	Dry	Dry
CrC	0.088	0.086	0.067	0.056	0.049	0.043	0.068	0.063
CaC	0.166	0.17	0.065	0.051	0.074	0.07	0.126	0.12
NNC	0.638	0.656	Dry	Dry	0.968	1.19	1.69	0.968
OUTA	0.021	0.004	0.082	0.007	0.089	0.015	0.066	0.004
OUTB	0.025	0.002	*	*	*	*	0.089	0.011
OUTC	0.012	0.004	0.045	0.003	0.022	0.002	0.069	0.001

Appendix C-8: Barium (ppm)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	0.231	0.232	0.108	0.097	0.203	0.192	0.207	0.209
LWC	0.184	0.188	0.136	0.134	0.173	0.169	0.192	0.19
ULC	0.198	0.176	0.082	0.08	0.162	0.15	0.16	0.156
LLC	0.193	0.176	0.123	0.11	0.156	0.14	0.153	0.151
UCC	0.173	0.169	0.143	0.138	0.154	0.146	0.153	0.154
LCC	0.167	0.167	0.14	0.126	0.171	0.137	0.156	0.156
EC	0.215	0.211	Dry	Dry	0.185	0.176	Dry	Dry
CrC	0.165	0.162	0.149	0.145	0.124	0.124	0.158	0.162
CaC	0.163	0.152	0.14	0.139	0.11	0.105	0.157	0.158
NNC	0.068	0.075	Dry	Dry	0.079	0.074	0.112	0.086
OUTA	0.118	0.124	0.096	0.097	0.12	0.113	0.115	0.114
OUTB	0.12	0.122	*	*	*	*	0.117	0.113
OUTC	0.117	0.122	0.093	0.092	0.112	0.112	0.116	0.113

Appendix C-9: Silica (ppm)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	9.9	9.6	11.4	11.3	*	*	11.1	10.7
LWC	11.5	10.9	11.9	11.1	*	*	11.9	11.3
ULC	14.9	10.7	10	9.6	*	*	11.2	10.6
LLC	13.6	11	9.1	10.5	*	*	10.1	9.7
UCC	9.8	9.2	12	11.6	*	*	11.6	11.5
LCC	10.6	9.8	12.5	11.8	*	*	12	11.5
EC	9.8	9.8	Dry	Dry	*	*	Dry	Dry
CrC	10	9.8	11.5	11.4	*	*	10.8	10.7
CaC	11.2	9.9	12.2	12.2	*	*	12	12.2
NNC	8.8	8.9	Dry	Dry	*	*	15.1	14.2
OUTA	1.4	1.3	2.5	2.1	*	*	1.2	1.1
OUTB	1.4	1.1	*	*	*	*	1.5	1.5
OUTC	1.3	1.2	0.72	0.43	*	*	1.2	1.1

Appendix C-10:Strontium (ppm)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	0.19	0.19	0.12	0.12	0.21	0.21	0.18	0.19
LWC	0.32	0.32	0.26	0.27	0.39	0.4	0.3	0.3
ULC	0.41	0.41	0.22	0.22	0.41	0.4	0.35	0.35
LLC	0.41	0.42	0.28	0.27	0.42	0.42	0.36	0.36
UCC	2.9	2.8	3.1	3.1	3.6	3.7	3.6	3.7
LCC	2.6	2.6	2.5	2.5	3.1	3.2	3.1	3.2
EC	0.45	0.47	Dry	Dry	0.56	0.57	Dry	Dry
CrC	0.21	0.22	0.2	0.2	0.23	0.23	0.22	0.23
CaC	1.1	1.1	0.74	0.74	0.82	0.84	0.79	0.8
NNC	0.17	0.18	Dry	Dry	0.26	0.26	0.19	0.17
OUTA	1	1.1	0.94	0.97	1.2	1.2	1	1
OUTB	1	1	*	*	*	*	0.99	0.99
OUTC	1	1.1	0.94	0.95	1.2	1.2	1	1

Appendix C-11: Mercury (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	< .005	< .005	< .005	< .005	< .005	< .005	< .005	< .005
LWC	< .005	< .005	< .005	< .005	< .005	< .005	< .005	< .005
ULC	< .005	< .005	< .005	< .005	< .005	< .005	< .005	< .005
LLC	< .005	< .005	< .005	< .005	< .005	< .005	< .005	< .005
UCC	< .005	< .005	< .005	< .005	< .005	< .005	< .005	< .005
LCC	< .005	< .005	< .005	< .005	< .005	< .005	< .005	< .005
EC	< .005	< .005	Dry	Dry	< .005	< .005	Dry	Dry
CrC	< .005	< .005	< .005	< .005	< .005	< .005	< .005	< .005
CaC	< .005	< .005	< .005	< .005	< .005	< .005	< .005	< .005
NNC	< .005	< .005	Dry	Dry	< .005	< .005	< .005	< .005
OUTA	< .005	< .005	< .005	< .005	< .005	< .005	< .005	< .005
OUTB	< .005	< .005	*	*	*	*	< .005	< .005
OUTC	< .005	< .005	< .005	< .005	< .005	< .005	< .005	< .005

Appendix C-12: Cadmium (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	< .05	< .05	< .05	< .05	< .05	< .05	< .05	< .05
LWC	< .05	< .05	< .05	< .05	< .05	< .05	< .05	< .05
ULC	< .05	< .05	< .05	< .05	< .05	< .05	< .05	< .05
LLC	< .05	< .05	< .05	< .05	< .05	< .05	< .05	< .05
UCC	< .05	< .05	< .05	< .05	< .05	< .05	< .05	< .05
LCC	< .05	< .05	< .05	< .05	< .05	< .05	< .05	< .05
EC	< .05	< .05	Dry	Dry	< .05	< .05	Dry	Dry
CrC	< .05	< .05	< .05	< .05	< .05	< .05	< .05	< .05
CaC	< .05	< .05	< .05	< .05	< .05	< .05	< .05	< .05
NNC	< .05	< .05	Dry	Dry	< .05	< .05	< .05	< .05
OUTA	< .05	< .05	< .05	< .05	< .05	< .05	< .05	< .05
OUTB	< .05	< .05	*	*	*	*	< .05	< .05
OUTC	< .05	< .05	< .05	< .05	< .05	< .05	< .05	< .05

Appendix C-13: Molybdenum (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	< 1	< 1	< 1	< 1	1	< 1	< 1	< 1
LWC	1.63	<1	< 1	< 1	< 1	< 1	< 1	< 1
ULC	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
LLC	< 1	< 1	< 1	< 1	1	< 1	< 1	< 1
UCC	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
LCC	< 1	< 1	< 1	3.15	< 1	< 1	1	< 1
EC	< 1	< 1	Dry	Dry	1	<1	Dry	Dry
CrC	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
CaC	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
NNC	< 1	< 1	Dry	Dry	< 1	< 1	< 1	< 1
OUTA	1.7	1.38	< 1	< 1	1	1	1	1
OUTB	1.1	< 1	*	*	*	*	1	1
OUTC	1.22	< 1	< 1	3.12	1	< 1	1	1

Appendix C-14: Lead (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	0.4	< .05	0.3	< .05	0.33	< .05	0.34	< .05
LWC	0.25	0.07	0.53	< .05	0.26	< .05	0.31	< .05
ULC	1.2	< .05	0.16	< .05	0.44	< .05	0.39	< .05
LLC	0.89	< .05	0.32	< .05	0.73	< .05	0.25	< .05
UCC	0.36	< .05	0.2	< .05	0.37	< .05	0.15	< .05
LCC	0.44	< .05	0.23	< .05	1.49	< .05	0.2	< .05
EC	0.21	< .05	Dry	Dry	3.01	< .05	Dry	Dry
CrC	0.17	< .05	0.09	<.05	0.1	< .05	0.06	0.21
CaC	0.4	< .05	0.06	< .05	< .05	< .05	0.09	< .05
NNC	0.23	< .05	Dry	Dry	< .05	< .05	0.72	< .05
OUTA	0.14	< .05	0.17	< .05	0.55	< .05	0.26	< .05
OUTB	0.16	< .05	*	*	*	*	0.19	< .05
OUTC	0.7	< .05	0.56	0.16	0.55	0.05	0.39	< .05

Appendix C-15: Silver (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	0.134	< .05	*	*	0.17	< .05	*	*
LWC	0.126	< .05	*	*	0.05	< .05	*	*
ULC	0.133	< .05	*	*	< .05	< .05	*	*
LLC	0.089	< .05	*	*	0.43	< .05	*	*
UCC	0.067	< .05	*	*	< .05	< .05	*	*
LCC	0.053	< .05	*	*	< .05	< .05	*	*
EC	< .05	< .05	*	*	< .05	< .05	*	*
CrC	< .05	< .05	*	*	< .05	< .05	*	*
CaC	< .05	< .05	*	*	< .05	< .05	*	*
NNC	< .05	< .05	*	*	0.11	< .05	*	*
OUTA	< .05	< .05	*	*	< .05	< .05	*	*
OUTB	< .05	< .05	*	*	*	*	*	*
OUTC	< .05	< .05	*	*	< .05	< .05	*	*

Appendix C-16: Antimony (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	0.447	< .05	*	*	*	*	0.05	< .05
LWC	0.62	0.09	*	*	*	*	0.07	0.06
ULC	0.395	< .05	*	*	*	*	0.08	0.06
LLC	0.32	< .05	*	*	*	*	0.1	0.08
UCC	0.286	< .05	*	*	*	*	0.11	0.06
LCC	0.274	< .05	*	*	*	*	0.11	0.06
EC	0.21	< .05	*	*	*	*	Dry	Dry
CrC	0.197	< .05	*	*	*	*	< .05	< .05
CaC	0.199	< .05	*	*	*	*	0.05	< .05
NNC	0.227	< .05	*	*	*	*	0.07	< .05
OUTA	0.398	0.087	*	*	*	*	0.28	0.27
OUTB	0.403	0.068	*	*	*	*	0.25	0.24
OUTC	0.375	< .05	*	*	*	*	0.28	0.25

Appendix C-17: Chromium (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	1.07	< 1	< 1	< 1	< 1	< 1	1.8	1.9
LWC	< 1	< 1	< 1	< 1	< 1	< 1	1.5	1.3
ULC	1.97	< 1	< 1	< 1	< 1	< 1	2	1.8
LLC	1.37	< 1	< 1	< 1	< 1	< 1	1.6	1.4
UCC	< 1	< 1	< 1	< 1	< 1	< 1	1.4	2
LCC	< 1	< 1	< 1	< 1	1.1	< 1	1.3	2.1
EC	< 1	< 1	Dry	Dry	< 1	< 1	Dry	Dry
CrC	1.27	< 1	< 1	< 1	< 1	< 1	1.9	2
CaC	2.26	1.51	< 1	< 1	< 1	< 1	1.4	1.7
NNC	< 1	< 1	Dry	Dry	< 1	< 1	1.3	1.1
OUTA	2.1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
OUTB	< 1	< 1	*	*	*	*	< 1	< 1
OUTC	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1

Appendix C-18: Copper (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	0.92	0.5	0.78	0.58	0.6	0.4	0.8	0.4
LWC	0.8	0.68	1.03	0.6	0.8	0.6	0.7	0.4
ULC	1.77	0.67	1.01	0.92	0.9	3	1	0.7
LLC	1.4	0.69	0.95	0.8	1.1	0.5	0.6	0.4
UCC	1.02	0.81	0.99	0.95	0.9	0.7	0.8	0.6
LCC	1.16	0.8	1.03	1	1.5	0.7	0.8	0.6
EC	0.81	0.75	Dry	Dry	0.6	0.5	Dry	Dry
CrC	0.72	0.6	0.68	0.69	0.7	0.6	0.6	0.7
CaC	1.1	0.75	0.64	0.59	0.5	0.5	0.6	0.4
NNC	0.74	< 0.2	Dry	Dry	0.4	0.4	0.9	< 0.2
OUTA	1.51	1.08	0.81	0.76	1.4	1.1	0.7	0.5
OUTB	0.98	0.35	*	*	*	*	0.5	0.4
OUTC	1.08	0.65	1.3	0.88	1.4	1.1	1.2	0.8

Appendix C-19: Zinc (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	1.86	0.63	< .2	< .2	0.6	< .2	0.8	0.3
LWC	1.63	0.97	1.01	< .2	0.9	0.3	1	0.2
ULC	5.1	0.93	0.62	0.31	1.3	0.2	1	0.2
LLC	3.63	0.89	< .2	< .2	1.9	0.3	0.7	0.3
UCC	2.12	1.19	1.07	1.6	1.1	0.5	0.9	0.5
LCC	2.58	1.18	0.72	0.89	4.2	0.6	1	1
EC	1.65	1.04	Dry	Dry	0.6	0.2	Dry	Dry
CrC	1.56	0.88	0.21	0.55	0.6	0.4	0.8	1.2
CaC	2.44	1.02	0.23	0.25	0.5	0.4	0.9	0.7
NNC	1.2	0.62	Dry	Dry	0.5	0.3	3.2	1.6
OUTA	8.23	5.78	36.4	25.4	35.7	24.4	15.3	8.9
OUTB	1.26	0.62	*	*	*	*	0.9	0.4
OUTC	18.2	12.7	6.9	3.94	9.7	5.2	7.8	4.7

Appendix C-20: Cobalt (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	*	*	0.36	0.18	0.33	0.26	0.32	0.15
LWC	*	*	0.4	0.18	0.36	0.27	0.27	0.18
ULC	*	*	0.36	0.3	0.46	0.27	0.35	0.22
LLC	*	*	0.36	0.27	0.62	0.32	0.27	0.18
UCC	*	*	0.4	0.17	0.38	0.23	0.25	0.19
LCC	*	*	0.33	0.19	1.37	0.23	0.27	0.4
EC	*	*	Dry	Dry	0.47	0.4	Dry	Dry
CrC	*	*	0.23	0.16	0.23	0.19	0.21	0.18
CaC	*	*	0.2	0.16	0.2	0.16	0.24	0.19
NNC	*	*	Dry	Dry	0.79	0.86	1.71	0.78
OUTA	*	*	0.1	0.08	0.2	0.12	0.12	0.08
OUTB	*	*	*	*	*	*	0.13	0.09
OUTC	*	*	0.12	0.08	0.16	0.12	0.14	0.08

Appendix C-21: Boron (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	27	24	47	41	47	36	29	25
LWC	32	30	58	51	59	51	35	30
ULC	36	38	78	70	61	52	45	42
LLC	33	47	78	68	65	53	49	44
UCC	84	75	90	83	88	79	75	68
LCC	74	67	87	78	82	73	73	70
EC	26	26	Dry	Dry	59	53	Dry	Dry
CrC	31	28	50	44	54	47	39	34
CaC	53	51	76	69	78	70	64	59
NNC	22	< 20	Dry	Dry	40	36	25	<20
OUTA	47	77	60	54	73	65	56	50
OUTB	44	42	*	*	*	*	56	50
OUTC	54	59	61	52	70	64	56	51

Appendix C-22: Vanadium (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	*	*	18.1	17.3	7.5	6.3	8.1	7.7
LWC	*	*	9.8	8.8	4.6	3.6	5.2	4.8
ULC	*	*	12.8	12.4	5	3.8	4.9	4.4
LLC	*	*	8.7	8.2	5.5	3.6	4.2	4.1
UCC	*	*	8.1	7.6	5.1	4.5	4.5	4.7
LCC	*	*	8.8	8.2	6.8	4.5	4.4	4.8
EC	*	*	Dry	Dry	2.7	2.2	Dry	Dry
CrC	*	*	7.4	7.1	5.6	5.2	5.2	5.6
CaC	*	*	6	5.7	3.8	3.6	3.6	3.9
NNC	*	*	Dry	Dry	0.6	< .5	1.1	< .5
OUTA	*	*	4.8	4.6	2.7	2	2.5	2.3
OUTB	*	*	*	*	*	*	2.3	2.3
OUTC	*	*	5.6	5.2	2.5	2.2	2.3	2.2

Appendix C-23: Nickel (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	1.57	1.2	< .5	0.62	0.6	< .5	< .5	< .5
LWC	1.33	1.49	1.81	0.72	0.9	0.5	0.6	< .5
ULC	2.87	1.44	1.94	1.71	1.3	0.7	0.7	< .5
LLC	2.33	1.56	0.6	< .5	1.5	0.8	0.7	0.5
UCC	1.7	1.67	2.64	2.45	1.1	0.6	< .5	< .5
LCC	1.89	1.69	2.01	1.92	2.1	0.7	< .5	< .5
EC	1.62	1.75	Dry	Dry	1.5	1.3	Dry	Dry
CrC	1.09	1.15	1.48	1.37	0.6	< .5	< .5	< .5
CaC	1.49	1.2	1.72	1.51	< .5	< .5	< .5	< .5
NNC	0.79	0.63	Dry	Dry	1.2	1.1	1.3	0.5
OUTA	1.8	1.03	1.61	1.81	1.5	1	0.7	< .5
OUTB	1.05	0.86	*	*	*	*	0.7	< .5
OUTC	0.99	0.96	< .5	< .5	0.9	0.7	0.7	< .5

Appendix C-24: Selenium (ppb)

	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	0.62	0.6	0.37	0.4	0.49	0.49	0.35	0.39
LWC	0.19	0.28	0.23	0.33	0.21	0.18	0.21	0.26
ULC	0.27	0.21	0.14	0.24	< .05	0.16	0.15	0.19
LLC	0.21	0.17	0.17	0.21	0.12	0.09	0.15	0.16
UCC	0.61	0.46	0.46	0.54	0.58	0.52	0.45	0.47
LCC	0.52	0.48	0.3	0.38	< .05	0.35	0.42	0.42
EC	0.21	0.2	Dry	Dry	0.16	0.1	Dry	Dry
CrC	0.33	0.32	0.13	0.23	0.29	0.23	0.19	0.2
CaC	0.5	0.43	0.19	0.26	0.25	0.25	0.25	0.24
NNC	0.08	0.09	Dry	Dry	0.14	0.12	0.16	0.14
OUTA	0.14	0.15	0.16	0.16	0.12	0.1	0.14	0.14
OUTB	0.18	0.12	*	*	*	*	0.14	0.16
OUTC	0.19	0.1	0.15	0.18	0.05	0.1	0.14	0.15

Appendix C-25: Arsenic (ppb)								
	1/15/1998		7/21/1998		4/20/1999		10/19/1999	
LOCATION	Total	Dissolved	Total	Dissolved	Total	Dissolved	Total	Dissolved
UWC	3.53	3.34	12.8	12.9	4.37	3.39	5.2	4.71
LWC	2.94	3.08	13.5	13.3	6.7	5.21	3.99	3.58
ULC	5.5	3.96	25.2	3.48	6.73	5.3	2.65	4.72
LLC	5.6	4.62	18.6	21.9	7.59	5.36	4.24	3.87
UCC	2.85	2.82	10.6	1.38	3.72	3.32	2.76	3.01
LCC	2.8	2.48	7.34	17.1	4.48	3.35	2.6	2.53
EC	5.26	4.7	Dry	Dry	7.18	6.08	Dry	Dry
CrC	1.71	1.37	2.86	3.01	1.91	1.76	1.67	1.69
CaC	1.9	1.55	6.36	3.58	1.87	1.82	2.21	1.84
NNC	3.19	2	Dry	Dry	2.31	1.78	3.11	1.28
OUTA	2.76	2.54	8.65	8.72	1.41	1.08	1.72	1.52
OUTB	2.55	2.18	*	*	*	*	2.2	1.51
OUTC	2.56	2.31	8.1	11.2	1.07	0.51	2.15	1.9

Appendix D-1. Concentration of elements in fish (ppm dry weight), CC- channel catfish; C- common carp; W - walleye.

Species	Length (cm)	Weight (g)	Moisture (%)	Al	As	B	Ba	Be	Cd	Co	Cr	Cu	Fe
CC	54	1560	73.3	1410	< 0.5	1.17	14	< 0.1	< 0.2	< 0.5	1.36	2.32	894
CC	52	1362	69.8	485	< 0.5	1.07	32.1	< 0.1	< 0.2	< 0.5	1.92	5.24	527
CC	42	681	76.7	843	< 0.5	2.21	8.65	< 0.1	< 0.2	< 0.5	1.31	3.5	714
CC	43	766	76.9	1330	< 0.5	4.18	12.5	< 0.1	< 0.2	< 0.5	2.13	3.6	998
CC	54	1532	78.2	1050	< 0.5	3.47	10.7	< 0.1	< 0.2	< 0.5	1.9	5.94	741
CC	39	568	77.2	1280	< 0.5	3.18	14	< 0.1	< 0.2	< 0.5	2.02	2.86	966
C	61	3377	68.3	93.2	< 0.5	0.94	5.41	< 0.1	< 0.2	< 0.5	2.65	1.87	206
C	65	3689	74.2	12.3	< 0.5	< 0.5	2.89	< 0.1	< 0.2	< 0.5	2.48	2.92	116
C	65	3547	75.6	19.9	< 0.5	< 0.5	3.44	< 0.1	< 0.2	2.06	2.46	2.97	142
C	68	3887	75.5	2.7	< 0.5	4.76	5.18	< 0.1	< 0.2	< 0.5	2.85	3.6	280
C	58	2469	75.6	453	< 0.5	0.74	16.4	< 0.1	< 0.2	< 0.5	5.85	3.04	714
C	57	2724	66.9	286	< 0.5	< 0.5	6.23	< 0.1	< 0.2	< 0.5	3.47	1.82	370
W	41	738	69.6	10.2	< 0.5	< 0.5	0.397	< 0.1	< 0.2	< 0.5	< 0.3	1.3	5305
W	52	1561	64.4	9.32	< 0.5	< 0.5	1.08	< 0.1	< 0.2	< 0.5	< 0.3	1.28	41
W	42	823	73.1	8.34	< 0.5	< 0.5	0.469	< 0.1	< 0.2	< 0.5	< 0.3	1.23	31.8
W	42	908	76	7.02	< 0.5	< 0.5	2.76	< 0.1	< 0.2	< 0.5	0.55	1.86	58.8
W	38	624	67.5	4.76	< 0.5	< 0.5	0.37	< 0.1	< 0.2	< 0.5	0.401	1.01	28.6
W	39	624	68.5	7.95	< 0.5	< 0.5	0.694	< 0.1	< 0.2	< 0.5	1.02	0.962	46.5
Species	Hg	Mg	Mn	Mo	Ni	P	Pb	S	Se	Sr	Ti	V	Zn
CC	0.145	1070	53.1	< 0.3	1.48	8630	< 0.2	5910	< 1.0	71.5	29.6	2.46	47
CC	0.152	946	163	< 0.3	14	11700	< 0.2	5380	< 1.0	117	12.2	0.962	50.5
CC	0.109	1160	25.3	< 0.3	4.78	9600	< 0.2	7540	< 1.0	69.9	20.2	1.37	48.2
CC	0.131	1100	33.1	< 0.3	3.97	8150	0.81	6520	< 1.0	68.8	30	2.05	46.5
CC	0.266	1140	39.5	< 0.3	7.19	8900	1.39	7150	< 1.0	52.7	20.8	1.81	45.9
CC	0.131	1150	40.5	< 0.3	3.49	7670	0.516	7050	1	61.2	29.2	2.13	51.5
C	0.332	1010	12.8	< 0.3	2.1	12400	0.284	6540	< 1.0	100	2.99	< 0.3	178
C	0.594	1050	4.25	< 0.3	0.506	11100	< 0.2	7580	1.6	59.4	0.517	< 0.3	227
C	0.434	1050	5.1	< 0.3	0.601	11200	0.407	8030	1.3	65.6	0.96	< 0.3	228
C	0.425	1090	9.34	< 0.3	2.6	11000	0.227	8180	1.3	62.2	5.27	0.453	270
C	0.536	1450	34.4	< 0.3	17.4	18800	0.42	7570	1.2	146	12.8	1.7	448
C	0.177	805	66	< 0.3	10.5	8580	0.222	4710	< 1.0	58.8	8.33	0.331	156
W	0.168	833	1.14	< 0.3	0.48	7350	< 0.2	7410	< 1.0	11.3	< 0.5	< 0.3	18.1
W	0.258	835	1.2	< 0.3	< 0.3	8940	< 0.2	6740	1.2	25.5	0.917	< 0.3	25.3
W	0.147	778	0.863	< 0.3	0.368	7480	< 0.2	6950	< 1.0	17.5	0.533	< 0.3	19.2
W	0.818	1630	3.52	< 0.3	1.27	16500	< 0.2	10500	1.2	47.5	< 0.5	< 0.3	59.8
W	0.142	655	0.717	< 0.3	0.584	6570	< 0.2	6380	< 1.0	11.9	1.51	< 0.3	21.6
W	0.171	735	0.987	< 0.3	0.539	7120	< 0.2	7000	< 1.0	15.6	1.19	< 0.3	25.3