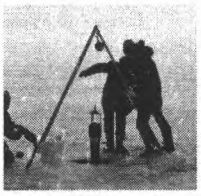
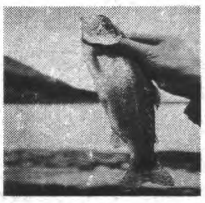
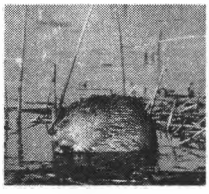
Canada Alberta Northwest Territories

Northern River Basins Study



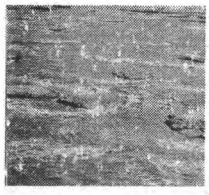


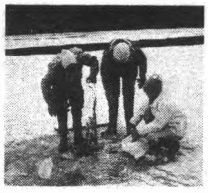
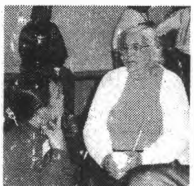





NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 131

LIMNOLOGICAL INVESTIGATIONS IN THE WEST BASIN OF GREAT SLAVE LAKE, MARCH 1994



Prepared for the
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by

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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of particular work conducted as part of the Northern River Basins Study. As such, the work was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

NORTHERN RIVER BASINS STUDY
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Whereas the above publication is the result of a project conducted under the Northern River Basins Study and the terms of reference for that project are deemed to be fulfilled,
IT IS THEREFORE REQUESTED BY THE STUDY OFFICE THAT;
this publication be subjected to proper and responsible review and be considered for release to the public.

F. J. Wrona — 14 May 96
(Dr. Fred J. Wrona, Science Director) (Date)

Whereas it is an explicit term of reference of the Science Advisory Committee "to review, for scientific content, material for publication by the Board",
IT IS HERE ADVISED BY THE SCIENCE ADVISORY COMMITTEE THAT;
this publication has been reviewed for scientific content and that the scientific practices represented in the report are acceptable given the specific purposes of the project and subject to the field conditions encountered.
SUPPLEMENTAL COMMENTARY HAS BEEN ADDED TO THIS PUBLICATION: [ ] Yes [ ] No

P. A. Larkin — 24 May/96
(Dr. P. A. Larkin, Ph.D., Chair) (Date)

Whereas the Study Board is satisfied that this publication has been reviewed for scientific content and for immediate health implications,
IT IS HERE APPROVED BY THE BOARD OF DIRECTORS THAT;
this publication be released to the public, and that this publication be designated for: **[ ] STANDARD AVAILABILITY [ ] EXPANDED AVAILABILITY**

Lucille Partington — May 29/96
(Lucille Partington, Co-chair) (Date)

Robert McLeod — May 21/96
(Robert McLeod, Co-chair) (Date)

LIMNOLOGICAL INVESTIGATIONS IN THE WEST BASIN OF GREAT SLAVE LAKE, MARCH, 1994

STUDY PERSPECTIVE

Important to our understanding of cumulative effects is appreciation of how natural systems have changed over time. The Board of the Northern River Basins Study was interested in understanding how the Peace, Athabasca and Slave rivers had changed and were likely to change with additional development within their basins. Considerable interest was expressed in what changes had occurred to water chemistry. Sediments and their deposition in rivers offers one potential means for beginning to understand possible physical-chemical-biological changes. But the dynamic nature of these systems makes it very difficult to locate sites where material is deposited chronologically in an undisturbed state. Standing waters like lakes located on these river systems offer investigators the opportunity to gather undisturbed material. As layer by layer of the sediment is separated and subjected to a variety of analyses, investigators can begin to determine changes in the composition of material, the aquatic life that was associated with it as well as the chemicals that might bond to the sediment.

Related Study Questions

13a) *What predictive tools are required to determine the cumulative effects of man made discharges on the water and aquatic environment?*

14) *What long term monitoring programs and predictive models are required to provide an ongoing assessment of the state of the aquatic ecosystems. These programs must ensure that all stake holders hove the opportunity for input.*

Limnology is the study of the physical, chemical and biological characteristics of fresh waters and also involves understanding the influences of meteorological events. As part of an investigation to gather and analyse sediments deposited in Great Slave Lake, limnological sampling was done concurrent with sediment coring work. Information from this initiative complements the coring work by allowing investigators to understand the current relationship between deposited sediment and a measure of how things may have changed over time.

Limnological investigations from this project confirmed that nutrient concentrations were low in Great Slave Lake but the Slave River appeared to be a major contributor of phosphorus and nitrogen with little of the material escaping via the outflow of the Mackenzie River. The limited extent of investigations undertaken by this project precluded substantiation of any major trends but the work did underscore the need for follow-up work. The author concluded that this follow-up work should be directed at better understanding the influence of the Slave River on the West Basin of Great Slave Lake, particularly as the water quality of the Slave River may change and subsequently influence the lake.

Complementary work is reported in Northern River Basins Study Project Reports No. 99 (*Depositional History of Sediment in Great Slave Lake: Spatial and Temporal Patterns in Geochronology, Bulk Parameters PAHs, and Chlorinated Contaminants*).

REPORT SUMMARY

This report presents the results of limnological sampling conducted in March 1994 and concurrent with sediment coring studies in the West Basin of Great Slave Lake. Of particular interest were gradients in limnological parameters relative to increasing distance from the Slave River outflow.

Conductivity, a potential tracer of Slave River water, varied little over the West Basin although values tended to be slightly lower offshore of the Slave River. Turbidity values were low, including those areas offshore of the Slave River. The upper 30-m of the lake was isothermal with warmer water at greater depths. The water column was well-oxygenated with percent saturation decreasing with depth. This decrease probably was associated with the decomposition of organic matter in the water column and, more importantly, at the sediment-water interface. pH of surface waters varied little over the study area although the lowest values were offshore of the Slave River. pH tended to increase with depth although some sites exhibited an decrease in pH near the lake floor.

Nutrient concentrations were low and showed only a weak trend to increase near the lake floor: this increase occurred only at the deeper sites. Slightly higher total phosphorus concentrations were observed in surface waters at two stations offshore of the Slave River: this suggests that the Slave River may provide an enriched source of phosphorus to the West Basin of Great Slave Lake during March. Higher phosphorus concentrations also were observed at Site 12, offshore of Hay River. The reasons for these elevated concentrations are unclear but may be related to a Hay River influence. Calculations based on the Slave River inflow rate and phosphorus and nitrogen concentrations in its delta channels suggest that the river is a major source of phosphorus and nitrogen to West Basin. Most of the phosphorus and nitrogen enters the lake during the spring-summer high-flow period. Much of the phosphorus may enter the lake from riverbank erosion associated with ice break-up. It is estimated that <5% of the total phosphorus and <23% of the total nitrogen entering Great Slave Lake with Slave River inflow is exported from the lake via Mackenzie River outflow.

Phytoplankton biomass was low. Diatoms dominated the algal community at sites close to the Slave River mouth. Because diatoms require a turbulent environment in order to remain in the upper, well-lit regions of the water column, they may have entered Great Slave Lake via Slave River inflow. At other study sites, highly motile species (Pyrrophyta, Cryptophyta, and Chrysophyta) were the taxonomic dominants (biomass basis). Algal biomass was greatest at Sites 20 and 21 (offshore of the Slave River mouth) and at Site 12 (which may have been affected by a Hay River influence).

This study provides baseline information on the limnology of the West Basin during an extended period (ca. 2 months) of ice cover. Because the lake probably remained ice-covered for another two months, deep-water oxygen concentrations would have continued to decline while nutrient concentrations would have increased. Moreover, with increasing day length and the gradual loss of snow from the clear lake ice, phytoplankton biomass may have increased.

ACKNOWLEDGMENTS

Field and analytical costs for the March 1994 limnological sampling were supported by the Northern River Basins Study (NRBS). The National Hydrology Research Centre, Saskatoon (NHRC) also provided financial support for some aspects of this research. The March 1994 sampling was conducted with Aero Arctic Helicopter Services, Yellowknife. The service of Seiji Susuki in piloting the aircraft and assisting with the sampling is very much appreciated. This study was conducted as part of an NRBS-supported study designed to collect sediment cores for dating and organic contaminant studies. Dr. Richard Bourbonniere and Earl Walker (National Water Research Institute, Burlington) were team-members in the sediment sampling and contributed to the success of the limnological sampling. Eric Marles and Nancy Glozier (NHRC) provided useful advice for the winter sampling and assisted in the preparation of the equipment required for this study. Dr. Chris Earle (Concordia College, Edmonton) performed the phytoplankton enumeration and identifications. Nutrient analyses were performed by the Water Quality Laboratory (NHRC). Special appreciation is extended to Julie Knox (NHRC) for her participation in the limnological and sediment studies. Her dedicated efforts and cheerful spirits enabled much to be accomplished in what can now be remembered as fun-filled days.

Fisheries and Oceans staff, Hay River, provided much support for the study. Sampling equipment was shipped to their facilities and space was provided for use as a daily staging area. As the scientific party encountered some difficulties in the field sampling, Fisheries and Oceans staff provided advice and equipment to help overcome these problems. The assistance of Dale Archibald, Dan DeChief, and George Lowe on this and earlier trips is very much appreciated. Pat Bobinski provided the scientific party with laboratory facilities for processing the limnological samples. His support of this and other research also is appreciated.

Reviewers of an earlier version of this report include: Dr. Peter Larkin and Michael Healey, with the Science Advisory Committee, and Richard Chabaylo, Component Coordinator, NRBS. Their scientific comments were helpful in revising and improving this report. Ashleen Downes prepared the figures and tables and then integrated this information into the text of the report. Her careful work, close attention to detail, in addition to her and Carol Casey's constructive editorial comments are very much appreciated.

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1.0 INTRODUCTION

Great Slave Lake has a surface area of 28,600 km^2, a total volume of 2,088 km^3, and a mean depth of 73 m (Herdendorf, 1982): it is Canada's fourth largest lake in terms of volume. Its drainage basin is large, extending over 983,000 km^2 (Rawson, 1950) with the Slave River contributing some 87% of the total (135 km^3) water inflow into the lake. The Slave River, in turn, receives most of its water from the confluence of the Peace and Athabasca Rivers. Great Slave Lake forms the headwaters of the Mackenzie River. Great Slave Lake can be divided into two major regions - the West Basin and the East Arm (Figure 1). The East Arm, in turn, can be divided into McLeod and Christie Bays.

The Slave River has a major influence on the chemistry and productivity of Great Slave Lake waters. Rawson (1950) reported that total dissolved solid (TDS) concentration in the West Basin average 150 mg/L while TDS concentration (summer data) near the Slave River mouth ranged from 160-174 mg/L. The East Arm is located in the Precambrian Shield where waters draining this ancient bedrock tend to be very low in TDS concentration. Thus, McLeod Bay had a TDS concentration of only 22 mg/L while Christie Bay has a TDS of 110 mg/L (Rawson, 1950). The higher TDS concentration in Christie versus McLeod Bay waters is due to the stronger intrusion of West Basin water (including Slave River water) into the East Arm (Evans and Headley, 1993; Evans unpublished data): McLeod Bay is relatively isolated from West Basin water inflow by the narrow channel at Taltheilei Narrows.

Although climate (low temperatures, short growing season) is the major factor affecting the productivity of Great Slave Lake, two factors affect regional variations in biomass and, by inference, productivity. Depth is of primary importance with plankton and benthic biomass greater in the relatively shallow waters of the West Basin (mean depth = 41 m) than the deeper waters of McLeod (mean depth = 120 m) and Christie (mean depth = 249 m) Bays. Watershed influences also are important with a greater invertebrate biomass in the relatively deep waters of Christie Bay than in the shallower, soft-waters of McLeod Bay (Rawson, 1953, 1955, 1956). This suggests that Slave River inflow into the East Arm may enhance the productivity of Christie Bay. Slave River inflow may also be the primary factor affecting the greater abundance of benthos in its delta region than at similar depths in the main part of the West Basin (Rawson, 1956).

Great Slave Lake, located in subarctic Canada, has a mean plankton biomass and fish yield similar to several large (and deep) southern lakes - Lakes Huron, Michigan and Ontario (Rawson, 1955). Despite low primary production rates, Great Slave Lake has relatively high fish yields (Fee et al., 1985). The reason for this is uncertain, but it suggests that the Slave River may be enhancing the productivity of the lake. There is some evidence that the Slave River may contribute significant amounts of dissolved nutrients to the lake which, in turn, could enhance production. The Mackenzie River Basin Commission (1981) reported that total dissolved phosphorus concentrations in the Slave River delta channels ranged from 20 - 350 µg/L (and averaged 140 µg/L); total dissolved nitrogen concentrations ranged from 460 - 1,020 µg/L (and averaged 600 µg/L); and soluble reactive silica concentrations ranged from 0.36 - 3.70 mg/L (and averaged 1.83 mg/L). The Slave River may also provide significant amounts of organic particulates (detritus, plankton) to the West Basin.

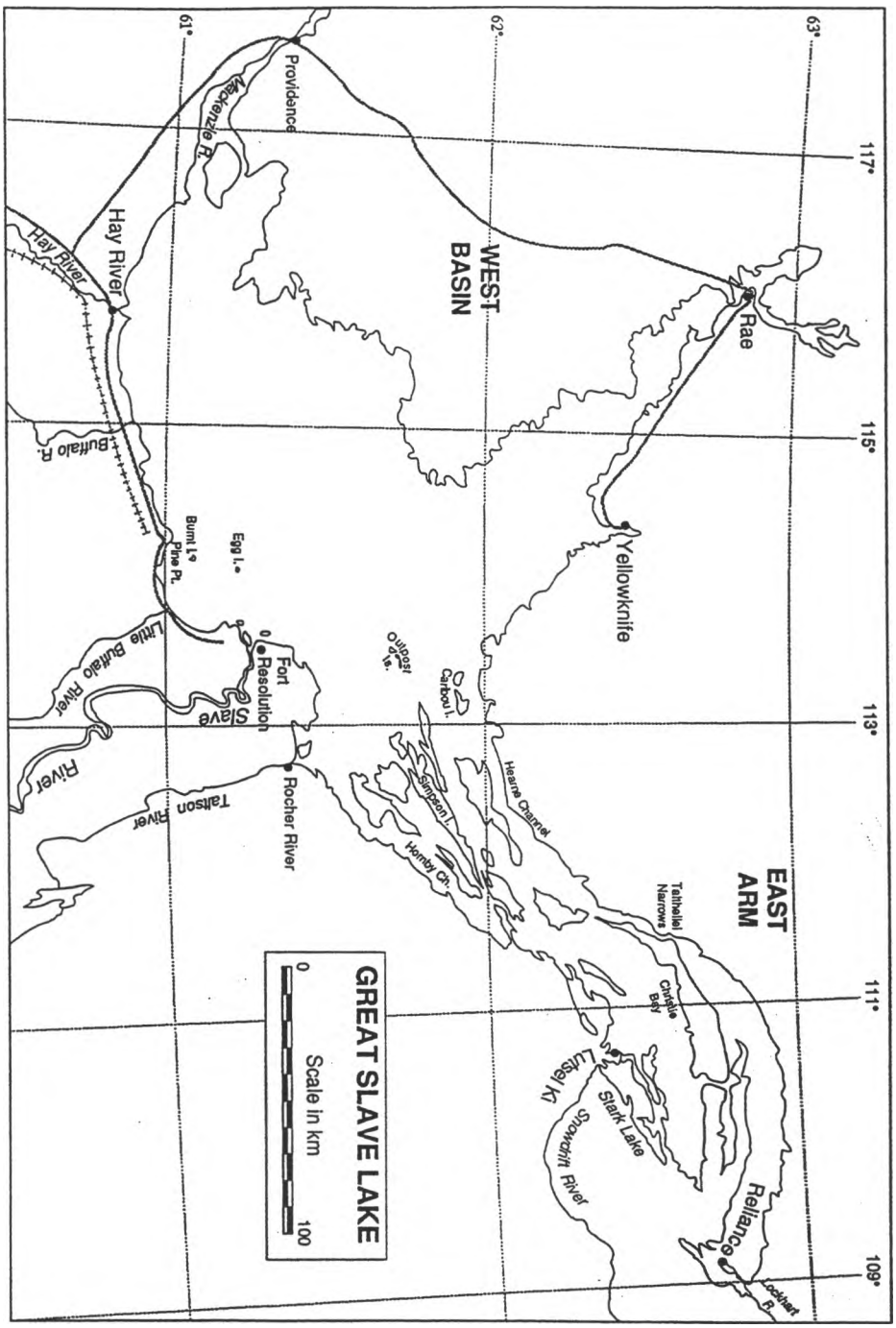

Figure 1. Map of Great Slave Lake showing major geographic features, towns, communities, highways and the railway line.

Although Great Slave Lake is a relatively pristine ecosystem with documented anthropogenic pollution limited primarily to the Yellowknife area (Moore, 1978, 1979; Moore et al., 1978), long-range transport does affect the lake. Long-range atmospheric transport is contributing to the organic contaminant loading of Great Slave Lake (Mudroch et al., 1992). River inputs, especially via the Slave River, also are a major source of organic contaminants to Great Slave Lake (Evans et al., 1996, Evans, unpublished data). Thus, there is concern that increasing development in the southern regions of the Peace and Athabasca River watersheds will result in the increased pollution of Great Slave Lake. Moreover, there is concern that the Slave River will be the primary transport route for many of these pollutants, given the fact that it is the major source of water to the lake.

Although the most recent environmental concerns for Great Slave Lake have focused on the presence of persistent organic contaminants in lake sediments (Mudroch et al., 1992: Evans and Headley, 1993; Evans et al., 1996), there also is the potential for nutrient loading to Great Slave Lake to increase. There is some evidence that this has already occurred. Paleolimnological studies conducted by Stoermer et al. (1990) suggested that the algal community of McLeod Bay has been affected by a recent increase in nutrient loading, possibly from atmospheric sources. In addition, coring studies conducted in the West Basin have documented an increase in total organic carbon (TOC) and total organic nitrogen (TON) concentrations in the sediments since the turn of the century (Evans et al., 1996). The increases in TOC and TON concentrations have been most pronounced since the 1950s. These data suggest that Great Slave Lake has become more productive in recent years, possibly because of increased nutrient inputs. Evans et al. (1996) hypothesized that this increased productivity was related to anthropogenic activities occurring in the Slave River watershed, particularly in the Peace and Athabasca River watersheds. Increased land-clearing during the early 1900s and industrial development in the 1950s (oil refineries, pulp and paper mills) may have been important factors affecting an increase in nutrient loading to Great Slave Lake. Agricultural runoff and sewage discharge from local communities also may have been important sources of nutrients to Great Slave Lake.

Relatively little is known about the factors affecting the productivity of Great Slave Lake, especially nutrient dynamics. Rawson's (1950) early physical limnology research focused on temperature and oxygen determinations over a wide area of the lake during the summer. Later studies focused on benthos and plankton standing stocks and species composition (Rawson, 1955, 1956). Moore conducted a number of seasonal studies of nutrients, benthos, and plankton dynamics in Yellowknife Bay, a region impacted by localized pollution from sewage and mining discharges (Moore et al., 1978; Moore, 1978, 1979, 1980). Fee et al. (1985) conducted a study of nutrients, chlorophyll, phytoplankton biomass, and primary productivity in surface waters over a broad region of Great Slave Lake from June to August 1983. However, this study did not expressly focus on the influence of the Slave River on the productivity of Great Slave Lake. Evans and Headley (1993) measured temperature, oxygen, nutrient, and chlorophyll profiles at two sites in the West Basin and two sites offshore of Lutsel K'e (East Arm) in March 1992: no collections were made in the immediate vicinity of the Slave River. In August 1993, Evans (unpublished data) investigated temperature, oxygen, pH, turbidity, nutrients, and chlorophyll concentrations with depth at ten stations in the Slave River delta region: sediments also were sampled for organic contaminants during this cruise (Evans et al., 1996). In August 1995, Evans (unpublished data) conducted limited limnological sampling in the East Arm.

This report is based on a series of limnological collections made in the West Basin of Great Slave Lake in March 1994. The primary goal of the field sampling was to collect a series of cores for organic contaminant studies (Evans et al., 1996). However, this field trip provided an excellent opportunity to obtain new information on the general limnology of the West Basin during a period of extended ice cover. Thus, the sediment coring studies were broadened to include limnological collections. The study components and objectives of these investigations are described below.

2.0 STUDY COMPONENTS

The overall goal of the water column sampling was to assess the influence of the Slave River on the limnology on the West Basin of Great Slave Lake. Various aspects of influence were investigated. Conductivity (salinity) is a relatively conservative property of water and its measurement provides useful information on water movements. Although conductivity has been used more commonly to identify water masses and to investigate their movement in marine waters (Sverdrup et al., 1942), it has potential as a useful tracer of the Slave River influence in Great Slave Lake: this is because of the known marked variations in conductivity between West Basin and East Arm waters.

Turbidity also is a potentially useful tracer of the Slave River inflow because of the large mass of suspended sediments (26.4 - 67.2 x 10^9 kg/y: Evans et al., 1996) which are transported into the lake each year. These sediments create a highly-turbulent river plume which, in some summers, is visible more than 60 km north of the Slave River mouth (Rawson, 1956). Turbidity may be a less useful tracer of Slave River inflow during winter when flow rates are lower and suspended sediment concentrations are reduced (Mackenzie River Basin Committee, 1981).

Temperature measurements provide useful information on water column stratification and, in some instances, water sources. Isothermal conditions indicate that the water column is physically well-mixed. Stratified water indicates that wind mixing has been sufficiently intense to mix the water column down to a certain depth: below that depth, the water column is relatively quiescent. Regions of markedly different water temperatures in the vicinity of a river mouth can provide an additional tracer of river influence. In spring, for example, inflowing river water is substantially warmer than lake water while, in autumn, the converse is observed.

Dissolved oxygen concentrations provide useful information on the trophic status of a lake. In highly productive lakes, it is not uncommon for dissolved oxygen concentrations and percent saturation to decline to very low values and, in some instances, to near zero (Wetzel, 1975). Low oxygen concentrations typically occur during thermal stratification in the hypolimnion and/or during winter ice cover. Great Slave Lake waters are well-oxygenated during summer (Rawson, 1950) and presumably remain well-oxygenated during winter. Nevertheless, because Great Slave Lake experiences a period of extended ice cover, it is possible that oxygen concentrations decline to low levels in deep, stratified waters. Such declines would be associated with the sediments because it is the decomposition of organic matter in the sediments which consumes most of the oxygen from the water column.

pH also provides useful information on lake metabolism: pH values tend to be lower in regions where significant amounts of carbon dioxide are produced through decomposition and respiration. Higher pH values are associated with the loss of carbon dioxide from the water column due to photosynthesis. Dissolved oxygen concentrations (and percent saturation) also tended to be high in environments where photosynthetic rates are high. pH also is related to the buffering capacity of the water. Lakes with high concentrations of carbonates tend to have a higher pH than lakes with lower concentrations of carbonates.

Nutrients (phosphorus, nitrogen) provide information on the trophic status of a lake. Relatively high concentrations deep in the water column are indicative of a significant regeneration of nutrients from lake sediments. Relatively high concentrations at a river mouth provide evidence that the river is a significant source of nutrients to the lake. Particulate concentrations (organic carbon, organic nitrogen) provide for an assessment of the amount of organic matter in the water column although such measurements do not distinguish between detritus, bacteria and phytoplankton. Dissolved organic carbon (DOC) can be a food resource to the microbial community. Vertical variations in DOC concentration may provide insight into metabolic processes occurring in the water column while horizontal gradients may provide information on localized sources, such as a river.

Finally, information on algal standing stocks (chlorophyll concentration, biomass) and composition provide for an assessment of the trophic status of a lake. Algal biomass increases as total phosphorus concentration increases: algal species composition changes with increasing trophy and with zooplankton grazing pressure (Wetzel, 1975). Algal biomass data also are useful in interpreting spatial patterns in nutrient concentrations because low nutrient concentrations alone are not indicative of unproductive systems. Intense demand by the phytoplankton community can result in nutrient-depleted waters but relatively high concentrations of algal biomass.

The March 1994 study incorporated a wide variety of limnological sampling. Collection costs (Appendix A) were supported by the Northern River Basins Study (NRBS). The study was designed to investigate several aspects of the influence of the Slave River on the limnology of the West Basin. Specifically, it was designed to:

1. Investigate spatial variations in conductivity and turbidity with increasing distance from the Slave River mouth.

2. Investigate spatial variations in temperature and determine whether the water column was thermally stratified.

3. Investigate spatial variations in dissolved oxygen (concentration and percent oxygen saturation) and pH profiles. The study also investigated whether these profiles differed at sites close to the Slave River than at sites farther away.

4. Investigate spatial variations in nutrient (phosphorus, nitrogen), particulate (organic carbon, organic nitrogen, and phosphorus) and dissolved organic carbon concentrations. The study investigated whether concentrations were elevated with increasing proximity to the Slave River which would suggest that the river was a significant source of nutrients to the lake. The study also

investigated whether nutrient concentrations increased near the lake floor providing evidence of nutrient representation at the sediment/water interface.

5. Determine chlorophyll concentrations, phytoplankton biomass and species composition at selected depths in the water column. The study also investigated whether algal standing stocks and composition differed at sites located close to the Slave River outflow than at sites further away.

3.0 METHODS

3.1 FIELD SAMPLING

In March 1994, a sampling grid was designed to obtain a series of cores in various regions of the West Basin (Evans et al., 1996; Figure 2). The goal of the study was to obtain a broad coverage of information on sedimentation rates in the West Basin. Of particular interest were variations in sedimentation rate with increasing distance from the Slave River plume. A sampling grid was initially designed and then modified as it became apparent that shallow-water sites (<30 m) did not provide good cores. Stations also were eliminated as extremely cold weather (<-20°C) limited what could be accomplished in a day. Limnological data were collected during the course of this study to provide background data on the West Basin. In some instances, stations were sampled only to obtain limnological data.

A 6-passenger Bell 206L-1 helicopter was used to transport the scientific party and equipment to and from the sampling sites (Figure 2). Given the size of the helicopter and constraints on the volume and weight of equipment which could be carried, only limited limnological sampling study could be conducted. Thus, it was not possible to conduct zooplankton studies and the number of water samples which could be collected at a site was limited.

A 8-inch (20.3cm) diameter hole was drilled through the ice. Limnological sampling was conducted before the hole was used for coring studies. A Hydrolab Surveyor 3 was used to determine temperature, conductivity, dissolved oxygen, percent oxygen saturation, and pH at 1 - 5 m depth intervals. Data for a given depth were entered on field sheets: data were also stored electronically and later down-loaded. For stations shallower than 50-m, the probe was lowered until the base touched the lake floor and then the cable was raised 0.5 m for the final reading. The maximum depth to which the water column could be sampled with the available cable length was ca. 50 m.

The Hydrolab Surveyor 3 has an accuracy of ±0.15 °C for temperature, ±0.2 units for pH, and ±0.2 mg/L for dissolved oxygen (Hydrolab Corporation, 1993). The accuracy of specific conductance is ± 1% of the range (0.15 - 1.5 mS/cm) or 0.01 mS/cm. The Hydrolab Surveyor 3 has a precision (resolution) of 0.01 °C for temperature, 0.0001 mS/cm for conductivity (for ranges used), 0.01 for pH, and 0.01 mg/L for dissolved oxygen. These specifications apply over an operating range of 5 °C to 50 °C. Air temperatures ranged from -20 °C to -15 °C during most of our sampling. Thus accuracy (and precision) may have been slightly lower than the manufacturer's specifications. To minimize this problem the display logger was stored in a cooler with heat packs to keep it relatively warm. This procedure also allowed us to read the LCD despite the very cold temperatures.

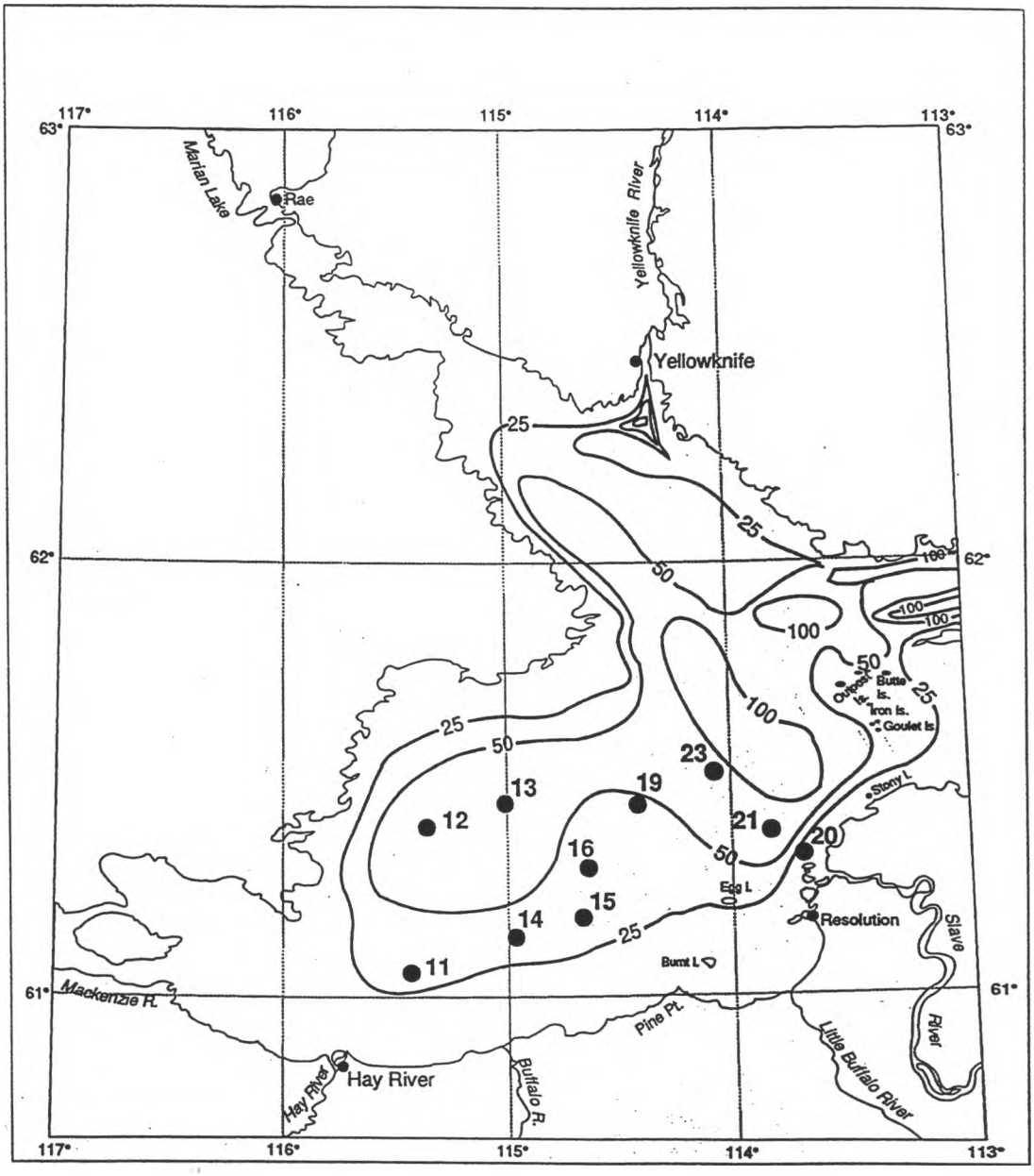

Figure 2. Map showing the location of the ten sites sampled for limnological parameters in the West Basin in March 1994.

Water samples were collected for chemical and biological analyses using a 4-L Niskin bottle. In general, samples were collected at 1-m and 10-m and 1-m above the sediments. Because we had a 100-m line, we were able to sample water just above the sediments at all sites. Immediately upon retrieval, water was placed in two 1-L (or one 2-L) brown Nalgene bottles for transport back to the base laboratory (Fisheries and Oceans, Hay River). Bottles were kept in a cooler to prevent freezing.

3.2 LABORATORY METHODS

Water samples were processed the same day. Samples for turbidity were placed in brown 250-mL Nalgene bottles. Samples (100 mL) for particulate organic carbon/nitrogen (POC, PN) were filtered through a precombusted 0.4 μm glass fiber filter, rinsed with 5 mL of 0.3% H_2SO_4, then the filter was placed in a petri dish and kept cool until shipment. Samples for ammonia and total phosphorus (TP) were placed in precleaned sample bottles: ammonia samples were preserved with a few drops of hydrochloric acid. Samples for dissolved phosphorus (DP), soluble reactive phosphorus (SRP), and dissolved organic carbon (DOC) were filtered through a precombusted 0.4-μm glass fiber filter and placed in appropriate sample bottles: SRP samples were preserved with a few drops of chloroform. Samples for chlorophyll analysis were filtered (750 mL) through a 0.4-μm glass fiber filter and then placed in an amber-colored vial containing 10 mL of 90% ethanol. Samples for phytoplankton analyses were prepared by combining 125 mL of sample with a 5 mL of Lugol's solution and then adding an equal volume of Dafano's solution. Only water from the upper 10 m (11 m for Site 16) was preserved for phytoplankton. Phytoplankton samples were not collected at Sites 11 and 15. All samples were kept cool until shipment to NHRI.

Nutrient and turbidity analyses were performed according to methods outlined in Environment Canada (1992). Chlorophyll and phaeophytin concentrations were determined by the boiling-ethanol extraction method (Nusch, 1980; Robarts et al., 1992). Phytoplankton composition, mean cell size, biomass, and numerical abundance were determined by the methods outlined in Earle et al. (1987).

4.0 RESULTS

4.1 GENERAL SAMPLING

Eleven stations were sampled over the nine-day sampling period (Figure 2). Snow cover was approximately 30 cm thick although it varied with the sampling site. The ice was exceedingly thick (1.5 m): it was primarily clear ice which appeared black because of its thickness. The general sampling is described below: physical - chemical data for the ten sites are given in Appendix B, Table 1.

Site 11 (March 21) was in 30 m of water. Significant freezing problems were encountered with the use of the Hydrolab probe, the water bottle, line, and the messengers. Only one water sample (at 29 - m) was collected at this station.

Site 12 (March 22) was in 70 m of water. The Hydrolab was used to measure the physical-chemical characteristics of the water column down to 50-m. Water for chemical analysis was collected at 1-m and 69-m. Low air temperatures and equipment freeze-up precluded additional water column sampling.

Site 13 (March 23) was in 62 m of water. The Hydrolab was used to measure the physical-chemical characteristics of the water column down to 49-m. Water was collected at 1-m, 10-m, and 61-m.

Site 14 (March 23) was in 23 m of water. The Hydrolab was used to measure the physical-chemical characteristics of the water column down to 22.4-m. No water samples could be collected because the water bottles and line remained frozen from the earlier Site 13 sampling.

Site 15 (March 25) was in 32 m of water. The Hydrolab was used to measure the physical-chemical characteristics of the water column down to 31.6-m. No water samples were collected at this site because of time constraints and equipment freezing following the earlier Site 16 sampling.

Site 16 (March 25) was in 37 m of water. The Hydrolab was used to measure the physical-chemical characteristics of the water column down to 36.4-m. Water was collected at 1-m, 11-m, and 36-m.

Site 19 was in 43 m of water. It was visited twice (March 25 and 26) and a Hydrolab profile was taken on both occasions to 42-m. By comparing the temperature, oxygen, conductivity, and pH profiles taken within a relatively short (less than one day) period, we were able to investigate the precision of the Hydrolab. Water was collected at 1-m, 5-m, and 42-m on the first sampling day.

Site 20 (March 29) was offshore of the Slave River mouth in 7 m of water. A Hydrolab profile was taken to 6.7-m. Water was collected at 1-m and 6-m.

Site 21 (March 29) was offshore of the Slave River mouth in 70 m of water. A Hydrolab profile was taken to 50-m. Water was collected at 1-m, 10-m and 69-m.

Site 23 (March 29) was on a shoal offshore of the Slave River mouth and located in 36 m of water. A Hydrolab profile was taken to 35-m. Water was collected at 1-m, 10-m and 35-m.

4.2 PHYSICAL - CHEMICAL DATA

With the exception of turbidity, all physical-chemical data (Appendix B) were recorded with the Hydrolab. Due to the fact that the cable length was ca. 53 m, an incomplete profile was obtained at deep water sites, i.e., Site 12 located in 70 m of water, Site 13 in 62 m of water and Site 21 in 70 m.

4.2.1 Specific Conductance

There were only small variations in specific conductance over the study area. Conductivity ranged from 0.19 - 0.25 mS/cm (Figure 3). Conductivity was relatively uniform with depth at Sites 16 and 20. Conductivity was more variable with depth at other sites, especially at Sites 12, 13, 19 and 21.

The lowest site-mean conductivity (0.21 mS/cm) was observed at Sites 20 and 21, offshore of the Slave River mouth, and Site 19B (March 26 sampling), to the west of the river mouth. The highest site-mean conductivity (0.23 mS/cm) was observed at Site 23, ca. 35 km offshore of the Slave River mouth, and Sites 12 and 13, which were also the farthest offshore study sites. There was poor agreement between the profiles taken at Site 19 on two respective days. Overall, conductivity was not a useful tracer of Slave River inflow during the March sampling.

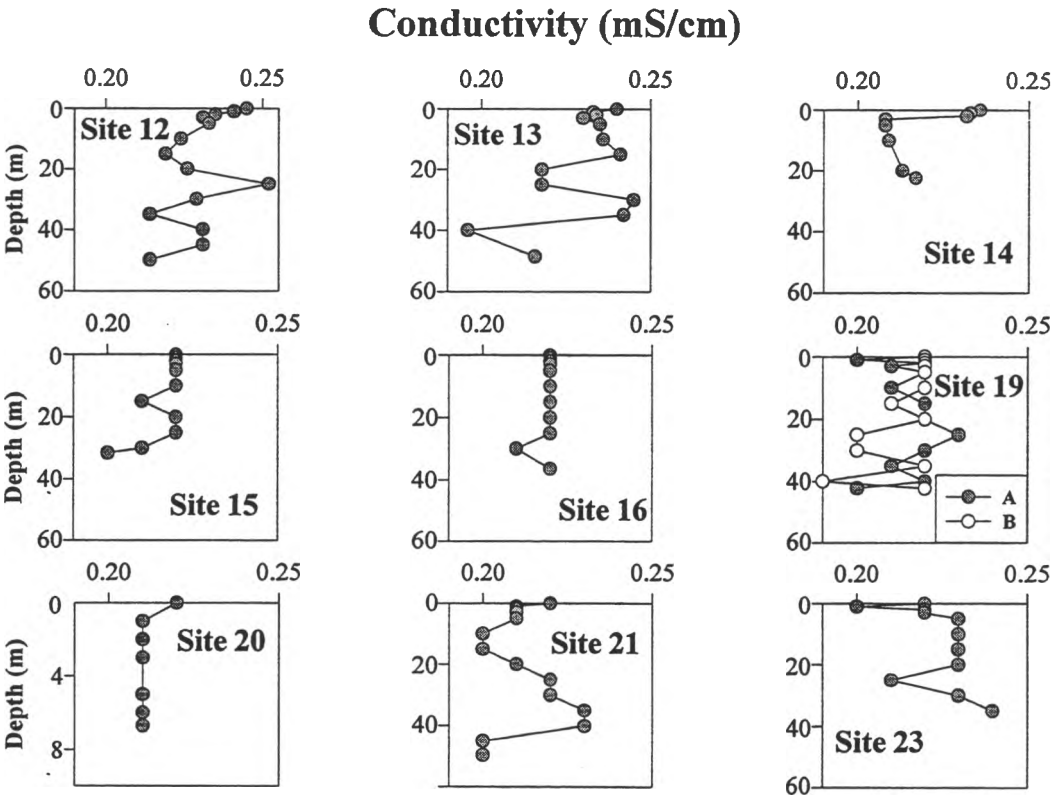

Figure 3. Conductivity profiles for nine sites investigated in the West Basin, March 21 - 29, 1994.

4.2.2 Turbidity

Turbidity was measured only at 1 to 3 depths at each station (Appendix C. Table 1). Mean turbidity for the upper 10m (11 m for Site 16) of the water column ranged from 4.4 NTU (Site 16) to 7.4 NTU (Site 21) (Figure 4). Turbidity at the Slave River mouth (Site 20) was similar to the turbidity observed at similar depths in other regions of the West Basin indicating that the suspended sediment load of the Slave River was very small in late March 1994.

Turbidity measurements made 1-m above the lake floor at the deeper stations provide information on sediment resuspension and downslope movement of particulates in the nepheloid layer (Figure 4).

Turbidity values ranged from 2.7 NTU (Site 11) to 11.7 NTU (Site 12). With the exception of Site 12, these values were not appreciably different from those observed in surface waters. This suggests that there was little resuspension of bottom sediments during this period of extended ice cover.

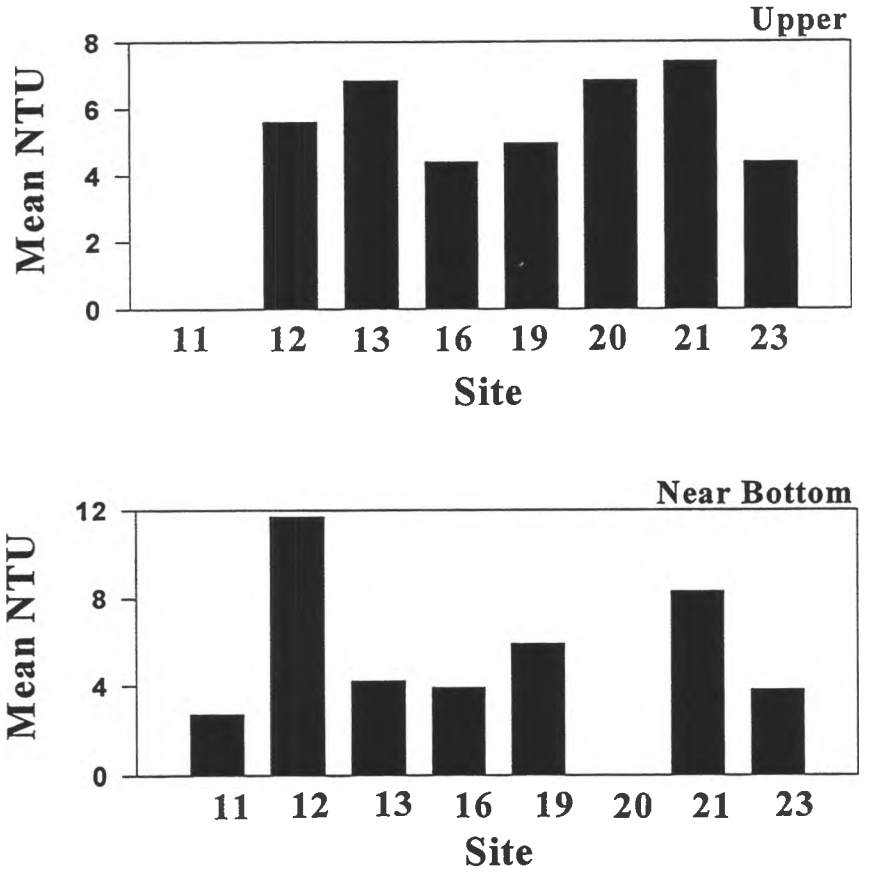

Figure 4. Mean water column turbidity at eight study sites.

4.2.3 Temperature

Water temperatures were low, ranging from 0.15 - 2.1 ^{o}C (Figure 5). In general, the water column was relatively isothermal down to 30m (Sites 16, 19 and 21) or 35 m (Sites 12, 13, 16 and 23) indicating strong wind-mixing of the water column prior to the lake freezing Water temperatures then increased with greater depth. The increase in water temperature with depth was gradual for the three deep-water stations (Sites 12, 13 and 21) but sharper for Sites 14, 15, 16 and 23.

This increase in temperature near the lake floor could be due to three factors. The relatively warm water near the lake floor could be due to stored (from summer) heat from the sediments.

This appears unlikely because seasonal variations in sediment surface temperature are relatively small in the deeper waters (> 5m) of lakes (Wetzel, 1975). The relatively warm bottom water at Sites 15 and 16 may have been due to a thin intrusion of warmer water from the offshore (e.g., Site 19) onto the shelf region of Great Slave Lake: this hypothesis is difficult to verify: moreover, the mechanism driving this possible water exchange is uncertain because there are few mechanisms for generating strong currents during winter ice cover. Finally, the warm bottom water at Sites 15 and 16 may represent thin remnants of warm, late-autumn water which was not mixed with the overlying water column by wind-driven vertical mixing.

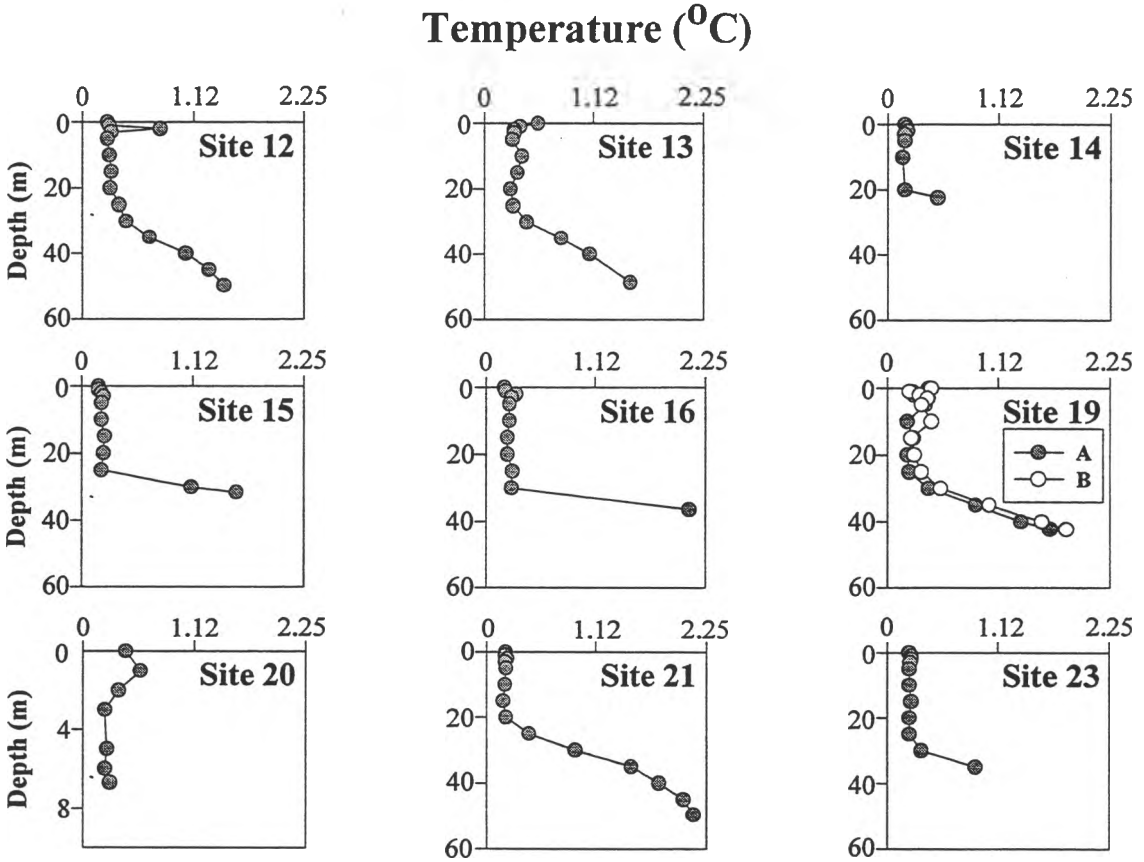

Figure 5. Temperature profiles for nine sites investigated in the West Basin, March 21 - 29, 1994.

At some sites, there was a very small increase in water temperature just below the ice. Slightly warmer temperatures at Sites 13, 15, 16 and 19 may have been associated with some heating which occurred with light penetration through the ice. At Site 12, water temperature increased 0.5 C° between 1-m and 2-m. This increase in temperature at 2-m at Site 12 has no ready explanation.

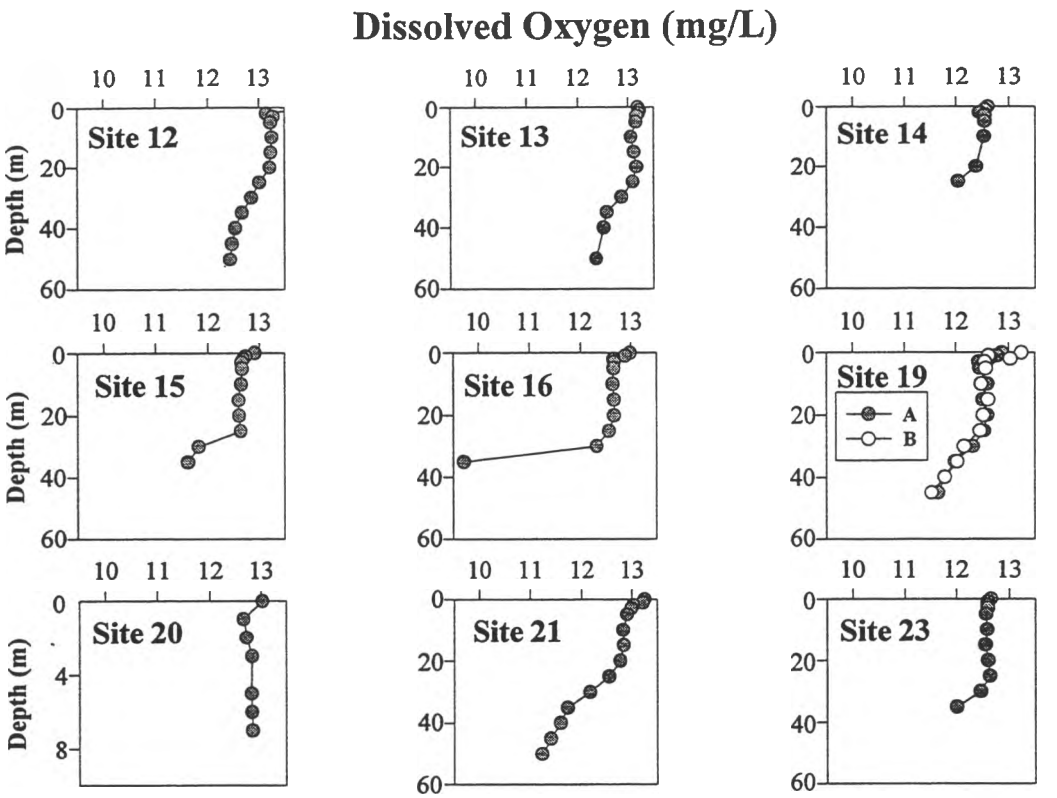

Figure 6. Dissolved oxygen profiles for nine sites investigated in the West Basin, March 21 - 29, 1994.

Site 20, at the Slave River mouth, had a 4-m thick layer of warm water overlying cooler water (Figure 5). This suggests that river water was slightly warmer than lake water. This Slave River water would have rapidly mixed into Great Slave Lake water. There was no thermal trace of this warmer river water in the surface layer at Site 21.

4.2.4 Dissolved Oxygen

Dissolved oxygen concentrations were relatively high ranging from 9.71 - 13.2 mg/L. In general, concentrations were relatively uniform in the top 25 - 30 m of water and then decreased markedly thereafter (Figure 6). Dissolved oxygen concentrations decreased sharply above the lake floor at Site 15 (11.6 mg/L) and Site 16 (9.71 mg/L), suggesting significant oxygen consumption by the sediments. Dissolved oxygen concentrations also were somewhat low above the sediments at Site 19 (11.7 mg/L and 11.5 mg/L for the two profiles). Dissolved oxygen concentrations were lower at 50 m at Site 21 (11.2 mg/L) near the Slave River outflow than at Site 12 (12.4 mg/L) and Site 13 (12.4 mg/L) which were substantially further away from the river outflow.

Percent oxygen saturation was relatively high, ranging from 83.2 - 99.1% at most sites (Figure 7). Saturation decreased with depth indicating a loss of dissolved oxygen by decomposition processes occurring in the water column and at the sediment-water interface. The steepest gradients occurred at Sites 14, 15, 16 and 21 where the percent oxygen concentration immediately above the sediments was 85.3%, 84.8%, 72.0%, and 83.2%, respectively. The highest percent saturation in deep-water (50 m) occurred at Site 12 (91.3%) and Site 13 (90.2%), which were furthest from the Slave River. Percent oxygen at 50-m at Site 23 was 83.2%, suggesting a greater deep-water consumption of oxygen by decomposing organic matter near the Slave River mouth than at stations further away.

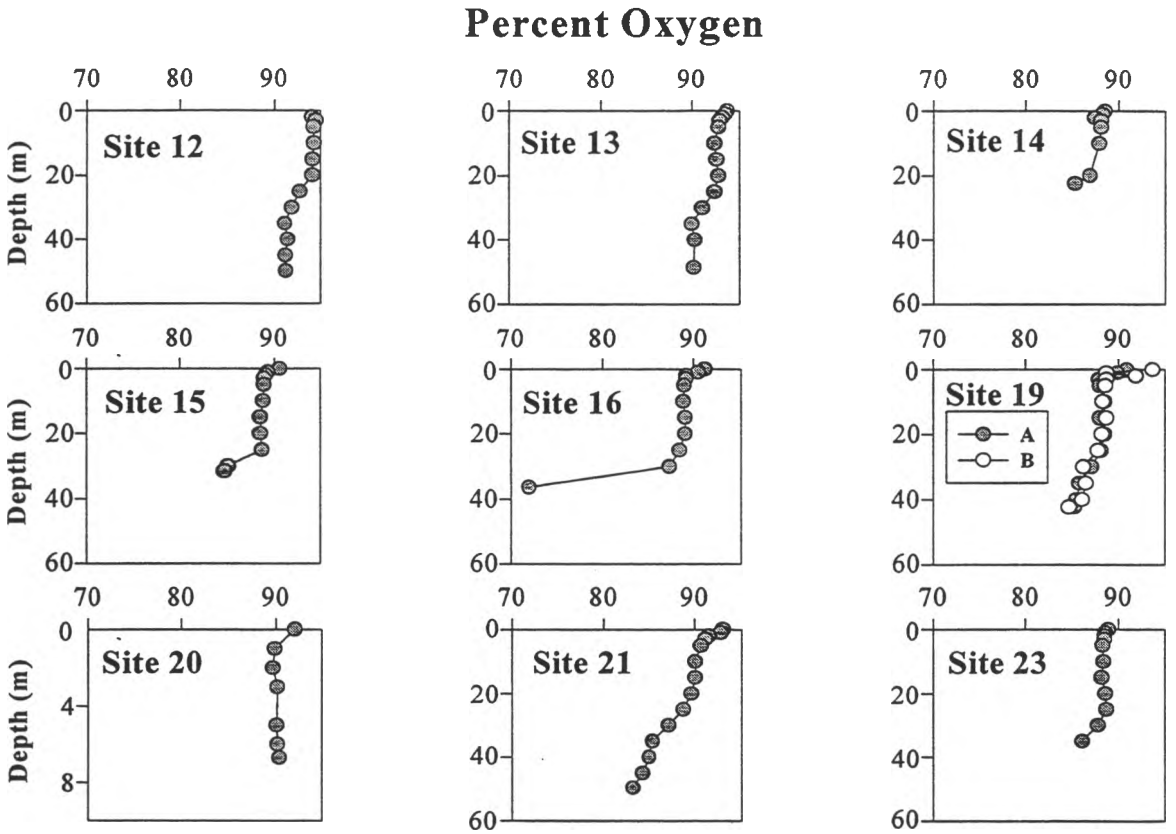

Figure 7. Percent oxygen profiles for nine sites investigated in the West Basin, March 21 - 29, 1994.

Percent oxygen saturation immediately below the ice was high (99.1%) at Site 12, possibly due to algal photosynthesis: chlorophyll concentrations were relatively high (2.3 µg/L) in the 1-m sample (see below). Similarly, high percent saturation (93.0%) at 0-m at Site 21 may have been related to relatively high chlorophyll concentrations (1.7 µg/L). However, while percent oxygen saturation was high at 0-m at Site 13 (93.7%), chlorophyll concentrations were low (0.3 µg/L). Higher percent oxygen saturation in the upper 1-m of the water column also may have been due to oxygen diffusing into the lake from the overlying air: mechanical disturbances created by the auger would have facilitated this process. Some dissolved oxygen also may be released into the water with ice-formation and thickening.

4.2.5 pH

pH ranged from 7.45 - 7.74 (Figure 8). The lowest pH values (7.45 - 7.47) were associated with Site 20 at the Slave River outflow and the upper 25 m at Site 21, also offshore of the Slave River. pH increased to 7.57 - 7.71 at greater depths at Site 21. Thus, there were two water masses at Site 21: a surface layer of cold, relatively low-pH water and a deep layer of warm, relatively-high pH water. The upper water mass probably contained Slave River water which recently entered the West Basin. The deep water mass consisted of hypolimnetic water and thus contained older (and hence different) Slave River water.

pH in the upper 10 m of the water column was higher at Sites 15, 16 and 19 than at Sites 20 and 21; pH at sites 15, 16 and 19 were similar to the pH of the deeper water at Site 21. The highest pH was observed at the most offshore sites, i.e., Sites 12, 13 and 23.

pH tended to increase with depth at most sites in contrast to dissolved oxygen which tended to decrease in concentration (and percent saturation) with depth. The increase in pH with depth may be related to seasonal variations in Slave River input, i.e., the upper depths may contain a greater fraction of the low-pH river water which apparently enters the lake during winter. At some sites (Sites 15, 16, 19 and 21) pH decreased near the lake floor as a probable consequence of decomposition processes which released carbon dioxide into the water.

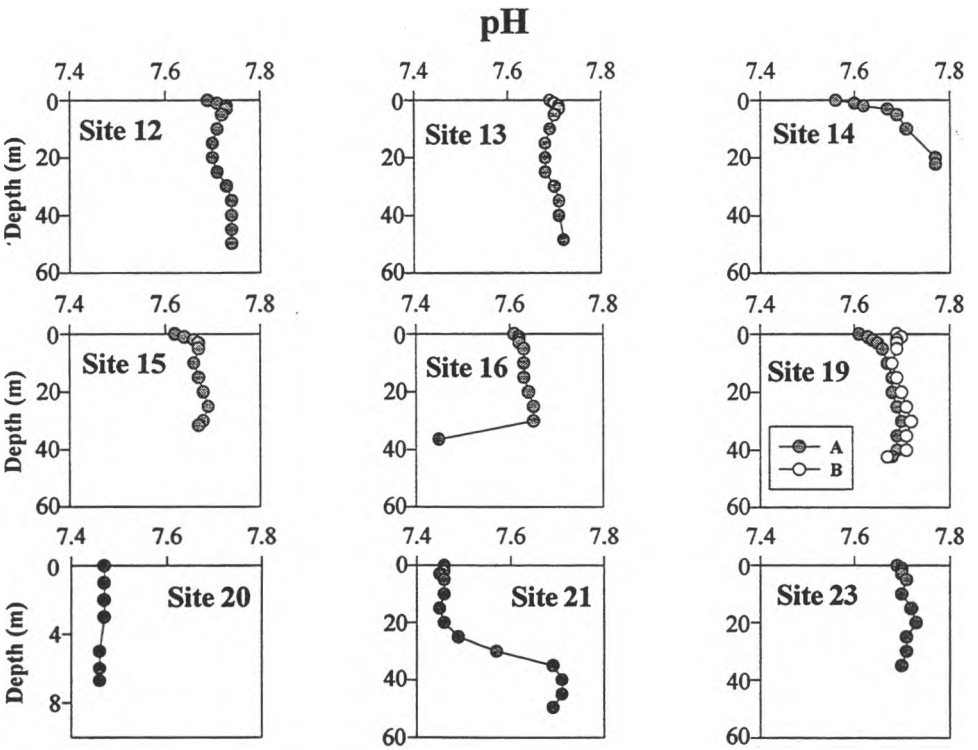

Figure 8. pH profiles for nine sites investigated in the West Basin, March 21 - 29, 1994.

4.3 NUTRIENT AND PARTICULATE DATA

4.3.1 Phosphorus

TP concentrations ranged from 9 - 26 µg/L in the upper 10 m (11 m for Site 16) of the water column and from 9 - 22 µg/L 1-m above the lake floor at deeper stations. Highest mean concentrations in the upper layer were observed at Site 12 (26 µg/L), Site 13 (17.5 µg/L) Site 20 (19.5 µg/L) and Site 21 (21 µg/L) (Figure 9; Appendix C. Table 2).

Dissolved phosphorus (DP) accounted for more than half of the TP at most sites. Highest concentrations were at Site 12, followed by Site 20. Soluble reactive phosphorus (SRP) concentrations were very low ranging from 2 - 4 µg/L for all sites except Site 12 (8 g/L). SRP concentrations increased near the lake floor at the deep study sites (Sites 12, 13, 19A and 21) suggesting significant nutrient regeneration.

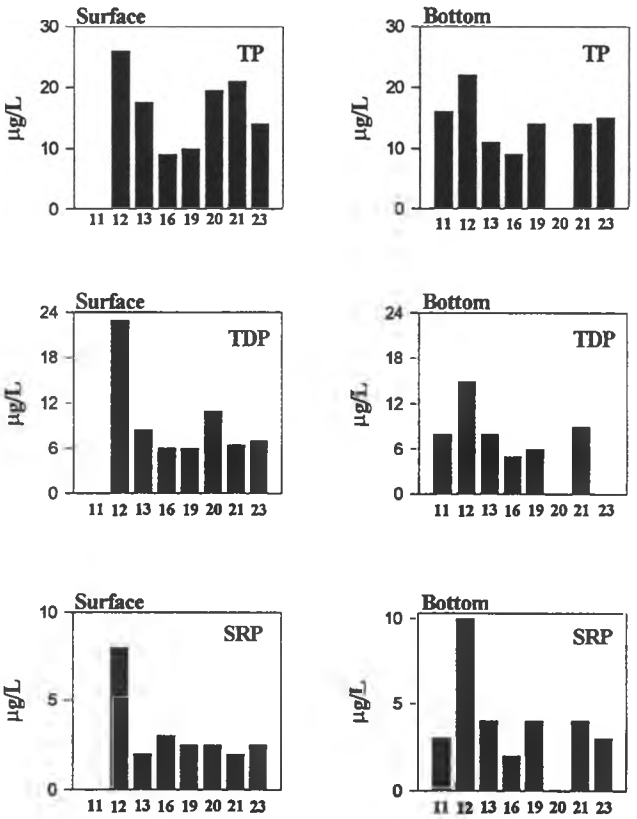

Figure 9. Total phosphorus, dissolved phosphorus, and soluble reactive phosphorus concentrations at eight study sites, March 1994.

4.3.2 Nitrogen

Surface ammonia concentrations were low ranging from 5 - 8 µg/L with highest concentrations occurring at Sites 12 and 13 (Figure 10; Appendix C. Table 2). There was no evidence of an increase in ammonia concentrations near the lake floor, nor at the Slave River outflow (Site 20).

Surface nitrite - nitrate concentrations ranged from 93 - 101 µg/L. Nitrite - nitrate concentrations increased near the lake floor for the deep study sites (Sites 12, 13 and 21). No such trend was evident for shallower (< 60 m) sites.

Particulate nitrogen concentrations ranged from <10 - 39 µg/L with the highest concentrations being observed at Sites 12, 13 and 21. Concentrations tended to be slightly higher in surface waters.

Overall, there was no evidence that the Slave River was a significant source of nitrogen to the West Basin in March 1994. However, this interpretation may be confounded by the fact that algal biomass was high at Sites 20 and 21 (see below). Similarly, there was little evidence of significant nitrogen regeneration from the sediments, except for sites deeper than 60 m.

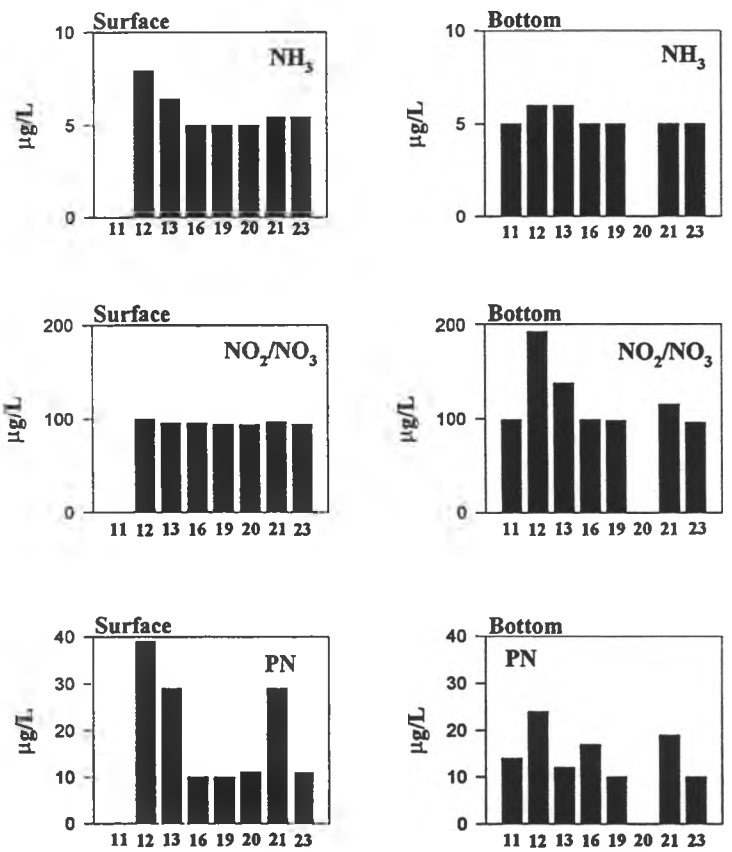

Figure 10. Ammonia, nitrite/nitrate, and particulate nitrogen concentrations at eight study sites, March 1994.

4.3.3 Organic Carbon

Particulate organic carbon concentrations were highly variable ranging from 10 - 369 µg/L. The highest concentrations were observed at Site 12 (1 and 69 m), Site 13 (1 m) and Site 21 (1 m) (Figure 11; Appendix C. Table 2).

Dissolved organic carbon (DOC) concentrations were considerably less variable than particulate organic carbon with concentrations ranging from 3,430 - 5,820 µg/L (Appendix C. Table 2). The lowest concentrations were observed at Site 20 (mean = 3,620 µg/L) and in the upper 10 m of water at Site 21 (mean = 3,605 µg/L). This suggests that Slave River inflow was relatively low in DOC in March. With the exception of a low value (4,510 µg/L) for the 69-m sample at Site 12, DOC concentrations ranged from 5,100 - 5,820 µg/L over the rest of the study area. There was a general tendency for DOC to decrease in concentration with depth at most of the deep sites away from an immediate Slave River influence, i.e., Sites 12, 13, 16, 19A and 23. This decrease could be associated with greater DOC metabolism with depth possibly because of warmer water temperatures. Alternately, the deep water at these sites was older (or had a different source) than the more shallow waters.

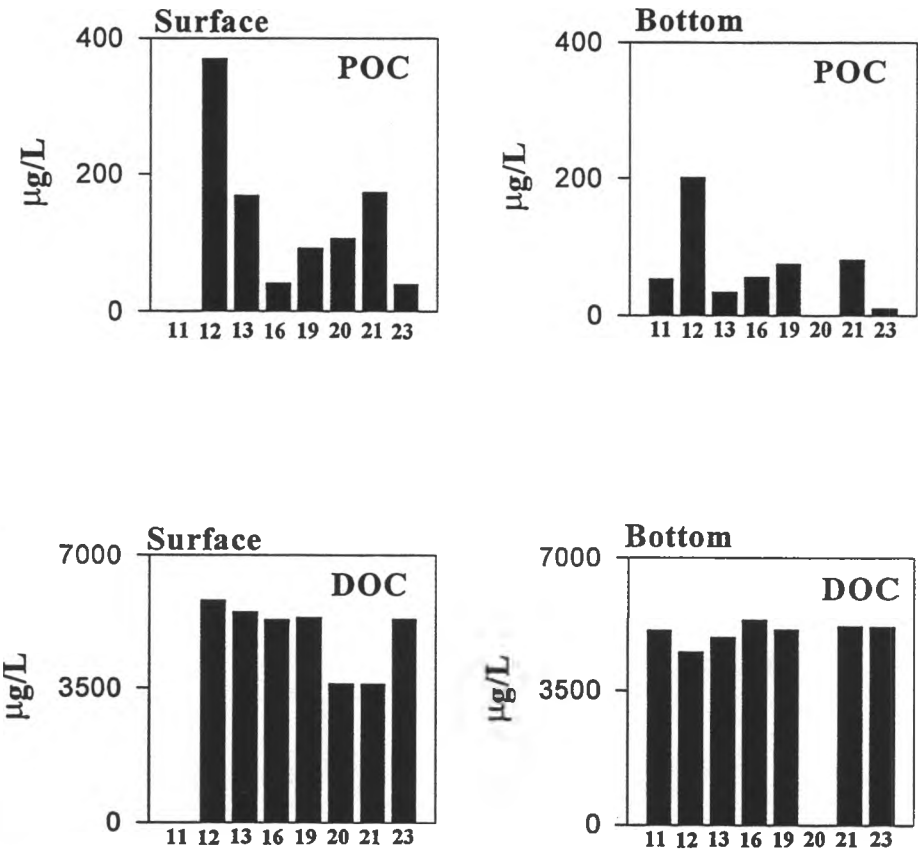

Figure 11. Particulate organic carbon and dissolved organic carbon concentrations at eight study sites, March 1994.

4.4 PHYTOPLANKTON

4.4.1 Chlorophyll and Phaeophytin

Phytoplankton concentrations were very low with chlorophyll concentrations ranging from 0.1 - 2.3 µg/L over most of the study area (Figure 12). The notable exception was Site 11 where a chlorophyll concentration of 6.4 µg/L was observed for the 29-m sample. This sample contained a small amount of fine sedimentary material either from the nephloid layer or from some disturbance of the bottom sediments when the sample was collected. It is noteworthy that turbidity, nutrient and particulate organic carbon and nitrogen concentrations were not relatively high in this sample (Appendix C. Table 2). The highest surface chlorophyll values were observed at Sites 12 and 21. With the exception of Site 19A, chlorophyll concentrations were lower in bottom than surface waters.

Phaeophytin concentrations were low, ranging from 0.1 - 1.1 µg/L over most of the study area (Figure 12): the notable exception was the 69-m sample at Site 11 where the phaeophytin concentration was 13.7 µg/L. Highest surface concentrations were at Sites 12, 20 and 21. The chlorophyll:phaeophytin ratio ranged from 0.6 - 4.0, in the upper 10 - 11 m of the water column: the mean ratio was 1.9. The ratio was substantially lower in near-bottom waters, ranging from below detection limits (for chlorophyll) to 1.0 and averaging 0.5. This suggests that there was an increasing proportion of degraded phytoplankton with increasing depth in the water column. Phytoplankton degradation occurs through a variety of mechanisms: zooplankton grazing and algal senescence are the two most important mechanisms. Both result in the eventual settling of detrital particulates to the lake floor.

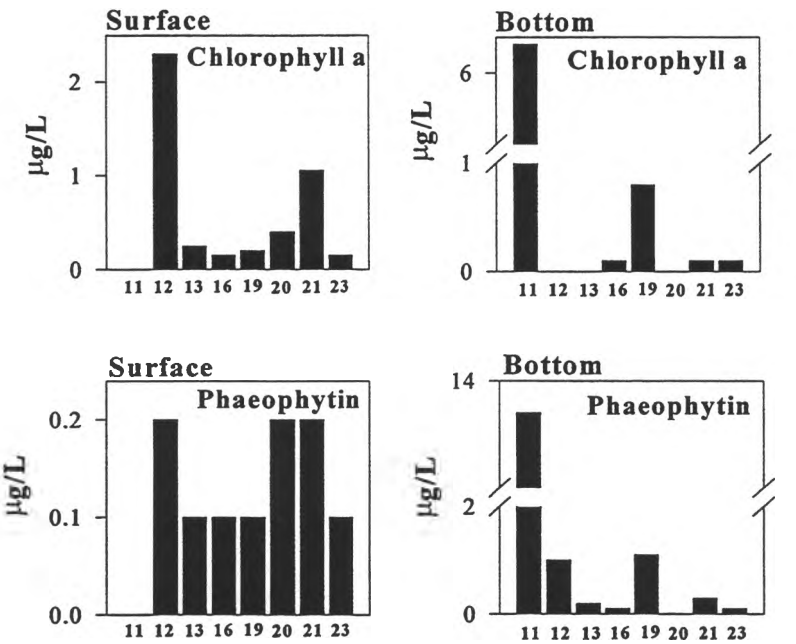

Figure 12. Mean chlorophyll and phaeophytin concentrations at eight study sites.

4.4.2 Algal Biomass and Composition

Phytoplankton were collected for species identifications and biomass determinations only in the top 10 m of the water column. Total algal biomass was highly variable ranging from 5.7 mg/m^3 at Site 19 (10-m) to 270 mg/m^3 at Site 21 (1-m) (Appendix D).

Only a 1-m sample was collected at Site 12. Algal biomass (92.8 mg/m^3) was dominated by Cryptophyta (39.4 mg/m^3) and Pyrrophyta (31.4 mg/m^3) (Figure 13). *Rhodomonas minuta* was the dominant cryptophyte while *Peridinium inconspicum* Lemm. was the dominant pyrrophyte. Chrysophyta (*Chromulina* sp. and *Chrysidalis peritaphrena*) were of secondary abundance (Figure 14). Cryptophyta, Pyrrophyta and Chrysophyta are motile: they may use their flagella to maintain their position in the water column just below the ice surface. Most (95.7%) of the algal biomass was in the 2 - 40 µm size range (Appendix D), the commonly preferred feeding size range for the majority of crustacean zooplankton.

Algal biomass was similar in the 1-m (18.0 mg/m^3) and the 10-m (25.7 mg/m^3) samples collected from Site 13. Pyrrophyta and diatoms dominated at both depths (Figures 13 and 14). *P. inconspicum*, *Gymnodinium helveticum* and *G. ordinatum* were the dominant Pyrrophyta while *Melosira islandica* and *M. distans* were the dominant diatoms. Most (72.4% at 1-m and 96.8% at 10-m) of the algal biomass was in the 2 - 40 µm size range. The notable exception was a somewhat large biomass (5.0 mg/m^3) of large, chaining forming *M. islandica* at 1-m.

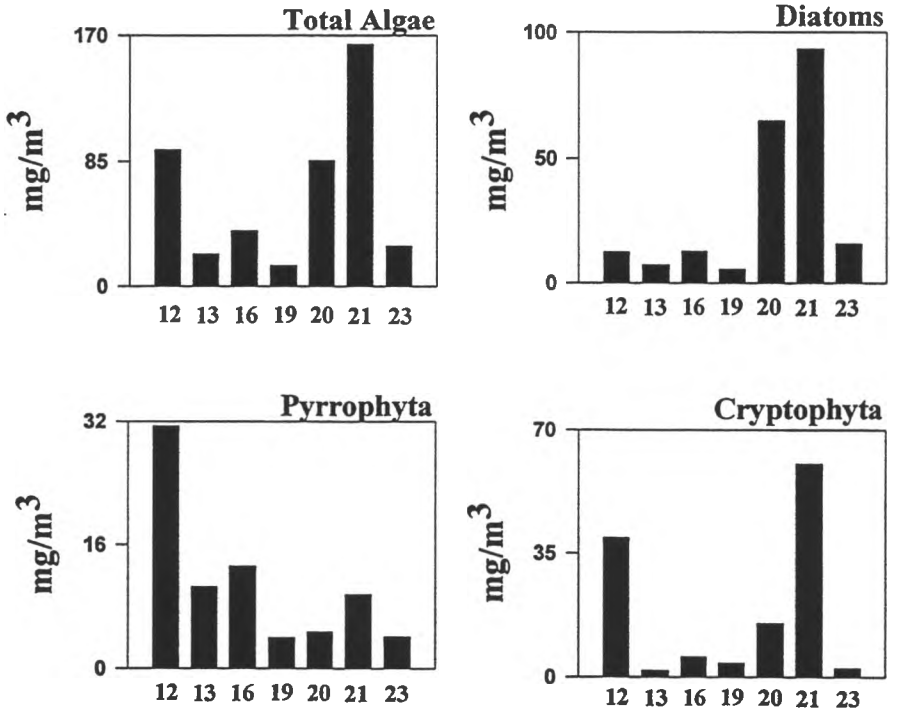

Figure 13. Mean (1 and 10 m) total algal biomass (wet weight) and the biomass of diatoms, Pyrrophyta, and Cryptophyta at seven study sites.

Algal biomass at Site 16 was 27.8 mg/m^3 at 1-m and 48.3 mg/m^3 at 10-m. The 1-m sample was dominated by an unidentified Cyanobacteria, Cryptophytes (primarily *Cryptomonas erosa* and *R. minuta*), and Pyrrophyta (primarily *G. helveticum*) (Figures 13 and 14; Appendix D). The 10-m sample was dominated by the large-celled, chaining-forming diatom *M. islandica* and by Pyrrophyta (primarily *G. helveticum*). Cryptophyta (primarily *C. erosa*) also were abundant. Most of the algal biomass was in the 2 - 40 μm size range, i.e., 96.6% at 1-m and 68.4% at 10-m.

Algal biomass at Site 19 was 22.1 mg/m^3 at 1-m and 5.7 mg/m^3 at 10-m. Cryptophyta (primarily *C. erosa*) and diatoms (primarily *M. islandica*) dominated at 1-m while Pyrrophyta (primarily *G. ordinatum*) and diatoms (primarily *Rhizosolenia eriensis*) dominated at 10-m (Figures 13 and 14). Most of the algal biomass was in the 2 - 40 μm size range, i.e., 73.0% at 1-m and 76.1% at 10-m.

Algal biomass at Site 20, the Slave River mouth, was relatively great: 138.4 mg/m^3 at 1-m and 33.0 mg/m^3 at 6-m. Large-celled diatoms *(M. islandica)* followed by Cryptophyta (*C. erosa*) dominated at 1-m. Pyrrophyta (*G. helveticum*) also were abundant at 1-m. Species diversity was greater at 6-m with *M. islandica* and *R. eriensis* the dominant diatoms and *C. eros* and *R. minuta* the dominant Cryptophyta (Figures 13 and 14; Appendix D). A major fraction (66.2% at 1-m and 47.7% at 6-m) of algal biomass was greater than 40-μm in length. The predominance of large, heavy cells at Site 20 is strongly suggestive of a Slave River source, i. e., the turbulent waters of the Slave River may have enabled these cells to remain in suspension in the water column until they entered Great Slave Lake.

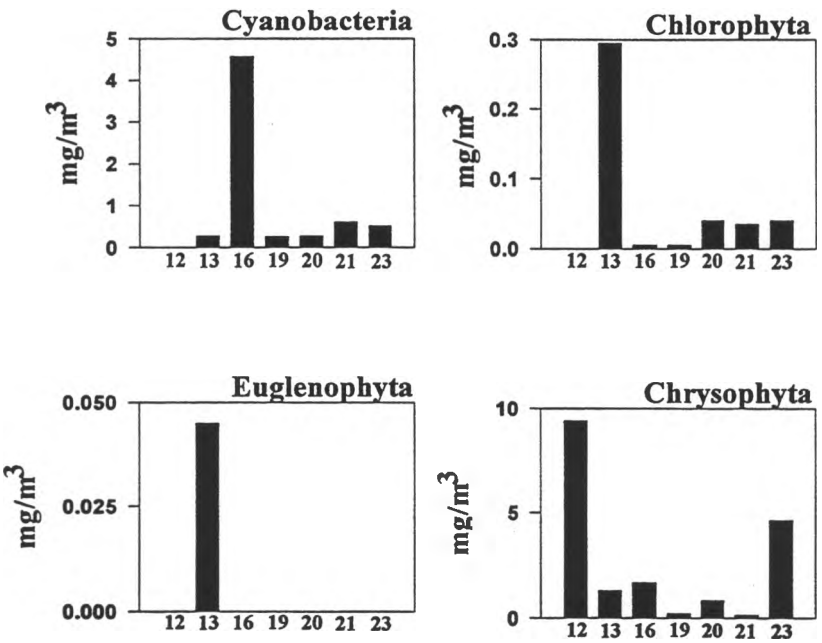

Figure 14. Mean (1 and 10 m) algal biomass (wet weight) of Cyanobacteria, Chlorophyta, Euglenophyta and Chrysophyta at seven study sites.

Algal biomass was relatively great at Site 21, also offshore of the Slave River mouth. Biomass was 270.0 mg/m^{3}at 1-m with large-celled diatoms (*M. islandica*) and Cryptophyta (*C. erosa*) dominating. Biomass was 57.6 mg/m^3 at 10-m with diatoms (*M. islandica*), Crypotophyta (*R. minuta*), and Pyrrophyta (*G. ordinatum*) dominating (Figures 13 and 14). A major fraction (60.8%) of the algal biomass at 1-m was greater than 40-µm in length: this strong dominance by large, heavy cells is suggestive of a Slave River influence. Large cells and/or colonies, greater than 40-µm in length accounted for a smaller fraction (10.4%) of the 10-m phytoplankton.

Algal biomass at Site 23 was 17.4 mg/m^3 at 1-m with diatoms (*M. islandica*), Cryptophyta (*R. minuta*), and Pyrrophyta (*G. helveticum*) dominating (Figures 13 and 14; Appendix D). Algal biomass was higher at 10-m (37.3mg/m^3) with diatoms (*M. distans* and *Cocconeis placentula*) and the Pyrrophyte *G. ordinatum* dominating. Large cells and colonies accounted for 35.6% of the biomass at 1-m but only 4.3% of the biomass at 10-m.

Overall, the greatest algal biomass was at Sites 12, 20 and 21 (Figure 13). Diatoms, Pyrrophyta, and Cryptophyta were the dominant taxonomic groups over the study area. Diatoms attained their largest standing stocks offshore of the Slave River mouth (Sites 20 and 21) while Pyrrophyta were most abundant at Site 12 and tended to decrease in abundance with increasing proximity to the Slave River mouth. Chrysophyta were abundant only at Sites 12 and 23, Cyanobacteria was abundant only in the 1-m sample at Site 16 (Appendix D). Chlorophyta and Euglenophyta were rare (Figure 14) and relatively abundant only at Site 13.

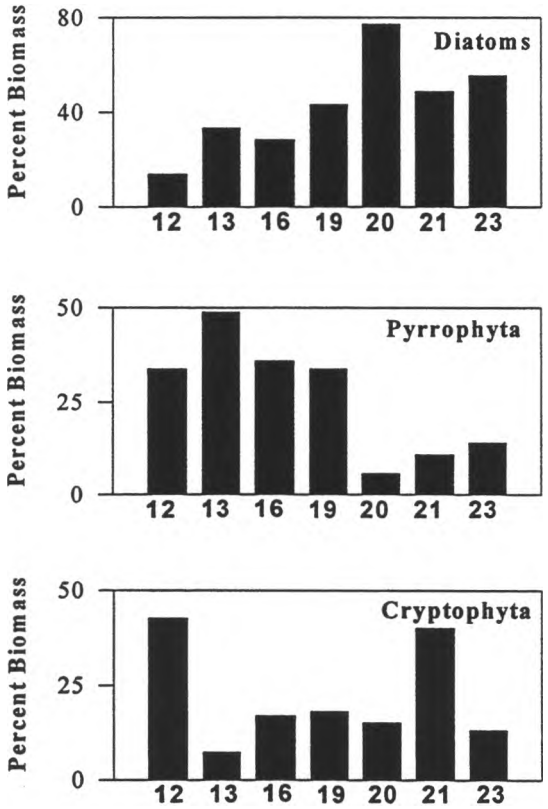

Figure 15. Mean (1 and 10 m) percent composition (biomass basis) of diatoms, Pyrrophyta, and Cryptophyta at seven study sites.

Diatoms accounted for an average of 41.9% of algal biomass at the seven sites investigated. In addition, they dominated algal biomass at Site 20 (77.1%) and decreased in dominance with increasing distance from the Slave River outflow (Figure 15). At Site 12, diatoms accounted for only 13.6% of algal biomass.

Pyrrophyta accounted for an average of 27.2% of the algal biomass at the seven sites investigated. Pyrrophytes accounted for the lowest fraction of biomass (Figure 15) at Site 20 (5.7%), Site 21 (10.8%) and Site 23 (14.0%): elsewhere, Pyrrophyta accounted for 33.8 - 48.0% of algal biomass (Figure 15). Cryptophyta accounted for an average of 22.1% of the algal biomass at the seven sites investigated. However, with the exception of Site 12 (42.5%) and Site 21 (39.9%), Cryptophyta accounted for only 7.2 - 18.0% of algal biomass. Chlorophyta and Euglenophyta accounted for slightly over 1% of algal biomass at Site 13 and a substantially lower proportion elsewhere (Figure 16). Cyanobacteria accounted for 15.4% of the biomass at Site 16 and substantially less elsewhere. Chrysophyta accounted for 15% of biomass at Site 23, declined to close to half of this value at Site 12 and were substantially less dominant at the remaining sites.

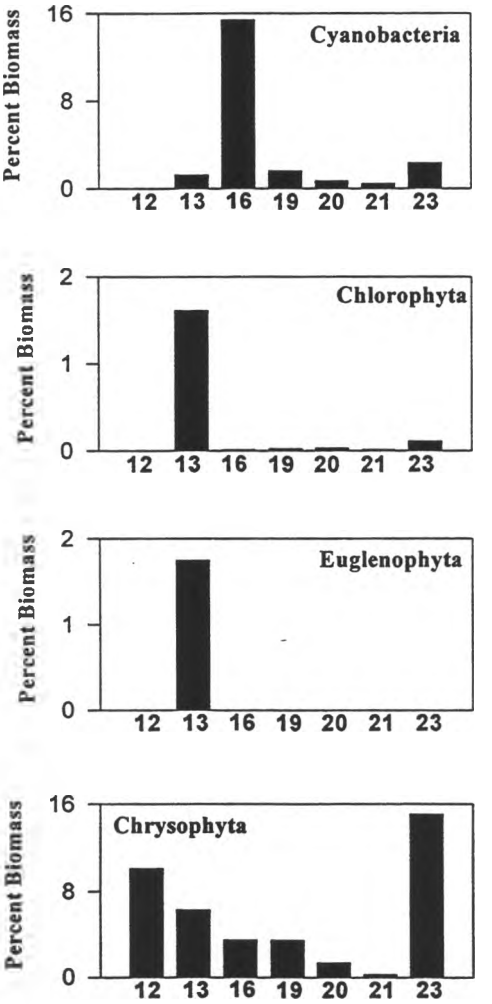

Figure 16. Mean (1 and 10 m) percent composition (biomass basis) of Cyanobacteria, Chlorophyta, Euglenophyta, and Chrysophyta at seven study sites.

4.4.3 Ciliates

Ciliates were enumerated and identified as part of the phytoplankton studies. Biomass ranged from 0.08 mg/m^3 (Site 12, 1-m) to 20.53 mg/m^3 (Site 21, 1-m) (Appendix D). Overall, ciliates appeared to become relatively more abundant with respect to algal biomass with increasing proximity to the Slave River. Ciliate biomass was less than algal biomass: 0.09% at Site 12, 33.2% at Site 13, 28.2% at Site 16, 43.1% at Site 19, 77.1% at Site 20, 43.0% at Site 21, and 55.3% at Site 23. The most common taxon was *Strombidium* sp.: however, most species were not identified (Figure 17).

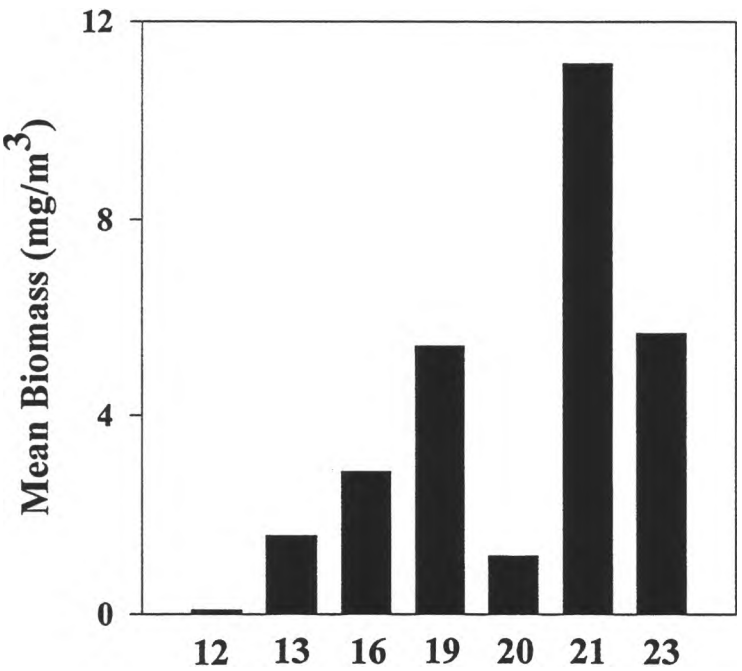

Figure 17. Mean total ciliate biomass at 1-m and 10-m at seven study sites, March 1994.

5.0 DISCUSSION

Ice begins to form in the small bays of Great Slave Lake by mid-October with the larger bays freezing by early December (Rawson, 1947): the main body of the lake is usually frozen by early January. Thus, the March 1994 limnological sampling was conducted in a region of the West Basin which had been ice-covered for slightly less than two months. Ice begins to melt in the small bays of Great Slave Lake in late May: the harbor areas of Hay River and Resolution Bay are open by June 1. The main body of the West Basin is free of ice by about June 10, Lutsel K'e in Christie Bay is free of ice by about June 20 and McLeod Bay is ice-free by early July. Thus, ice probably would not have left our study area for another six to eight weeks.

Slave River inflow rates vary seasonally with peak discharges (mean annual maximum = 7,200 m^3/sec) occurring over July and August and minimum discharge (mean annual minimum = 1,200 m^3/sec) occurring in March and April (Mackenzie River Basin Committee 1981). Thus, the March 1994 limnological sampling was conducted during a period in which the direct Slave River influence on the West Basin was at its weakest.

5.1 TEMPERATURE AND DISSOLVED OXYGEN

The physical limnology of the West Basin during the March sampling reflected the calm, thermally-stratified conditions associated with a period of extended ice cover. The upper 30-m of the water column generally was isothermal (<1°C) indicating strong wind mixing before freeze-up. Below this upper layer, was a layer of warm water which appeared to be physically stagnant. This was evident from the following three observations: First, turbidity was relatively low and comparable to surface values, indicating little resuspension of bottom sediments and down-slope movement of sediments. Second, dissolved oxygen concentrations (and percent saturation) were lower in the deep layer than in the upper regions of the water column. Thus, there was little replenishment of lower oxygen deep waters with the more oxygen-rich surface waters. Lower oxygen concentrations near the lake floor indicate that significant amounts of organic matter were decomposing at the sediment-water interface, and possibly in the deep water itself, consuming the dissolved oxygen. Finally, nutrient concentrations tended to be higher in deep waters (>60 m) than in surface waters. This again indicates that there was little exchange of water between the surface and deeper layers of the water column.

Dissolved oxygen concentrations in the upper 10-m of the water column at Sites 12 and 13 (Table 1) were similar to dissolved oxygen concentrations at two sites investigated in the West Basin in March 1992 (Evans and Headley, 1993). In addition, dissolved oxygen concentrations were similar at Site 20 (offshore of the Slave River mouth) to concentrations at the two sites investigated at Lutsel K'e (East Arm) in March 1992. Thus, the upper regions of the water column of Great Slave Lake appear to remain well-oxygenated in March.

There was evidence of moderately-low dissolved oxygen concentrations and percent saturation in some deep waters both in March 1992 and March 1994. In March 1992, low dissolved oxygen concentrations and percent saturation were observed at 50-m depth at Station 1: values were 7.8 mg/L and 55.9%. respectively (Evans and Headley, 1993). Site 1 was in ca. 70 m of water: thus, oxygen concentrations would have declined even more with greater depth. In March 1994, moderately-low dissolved oxygen concentrations (9.7 mg/L) and percent saturation (72.0%) were observed just above the sediments at the 37 m deep Site 16. More detailed sampling, especially in waters deeper than 50 m, is required to determine whether or not there is a broad scale pattern for dissolved oxygen concentrations to decline to moderately-low values (<75%) just above the sediments in the deeper waters of the West Basin during winter.

5.2 SPECIFIC CONDUCTIVITY

Conductivity was measured as a possible tracer of Slave River water movement in the West Basin. There was some evidence of small east-west differences in conductivity i.e., slightly higher values at Sites 12 and 13 (0.235 mS/cm) than at Site 20 (0.212 mS/cm) near the Slave River mouth (Table 1).

The mean conductivity for the upper 10-m of the water column at Sites 12 and 13 was similar to determinations made at two stations to the west of Site 12 which were sampled in March 1992 (Evans and Headley 1993).

Conductivity offshore of the Slave River mouth was substantially higher in August 1993 (0.236 mS/cm) than in March 1994 (0.212 mS/cm) indicating that the conductivity of the Slave River varies seasonally (Table 2). The Mackenzie River Basin Commission (1981) reported that the mean conductivity of Slave River water is 0.203 mS/cm and ranges from 0.115 - 0.261 mS/cm. Moreover, there was no consistent seasonal trend for conductivity to be higher in one month than another. The Commission hypothesized that variations in the conductivity of Slave River waters may be in part related to differences in the relative contribution of the Peace and Athabasca Rivers to Slave River flow. Similarly, horizontal and vertical variations in conductivity of West Basin waters in March 1994 may be related to seasonal variations in Slave River inflow and the subsequent mixing of river waters within the lake. More detailed sampling is required to determine whether the conductivity of Great Slave Lake waters varies in a systematic manner with increasing distance from the Slave River.

Table 1. Comparison of mean physical, chemical, and biological properties of the upper 10-m of the water column for March 1992 and selected March 1994 collections. See Evans and Headley (1993) for details on the March 1992 sampling.

	March 1992 West Basin		**March 1994 West Basin**			**March 1992 Lutsel K'e**	
	Site 1	**Site 2**	**Site 12**	**Site 13**	**Site 20**	**Site 3**	**Site 4**
Conductivity (mS/cm)	0.234	0.233	0.235	0.235	0.212	0.097	0.143
Temperature (°C)	-	-	0.27	0.38	0.37	-	-
Oxygen (mg/L)	12.4	12.3	13.4	13.2	12.8	12.6	13.9
% Oxygen	88.8	88.1	95.5	93.1	90.4	89.8	99.2
pH	-	-	7.72	7.70	7.47	-	-
Total phosphorus (µg/L)	9	10	26	17.5	19.5	5.0	6.4
Dissolved P (µg/L)	6	5	23	8.5	11.0	3.2	4.8
Soluble reactive P (µg/L)	5	<2	8	2	2.5	1.6	4.1
Nitrite-nitrate (µg/L)	104	104	101	95.5	94	85.3	120
Ammonia (µg/L)	-	12	8	6.5	5	<5.7	<5
Part. organic N (µg/L)	<10	<10	39	29	11.0	<10	<5
Part. organic C (µg/L)	79	63	369	169	106	80	<30
Diss. organic C (µg/L)	-	6,210	5,810	5,510	3,620	4,775	4,720
Chlorophyll (µg/L)	0.4	0.3	2.3	0.3	0.4	0.8	1.0
Phaeophytin (µg/L)	0.0	0.0	0.2	0.1	0.2	0.1	0.2

Conductivity of West Basin waters (March 1992 and 1994 sampling) was substantially higher than at Lutsel K'e in the East Arm (Table 1). This suggests that while conductivity does not appear to be a sensitive tracer of Slave River movement in the West Basin, it should be sensitive tracer of West Basin water movement into the East Arm.

Table 2. Comparison of mean physical, chemical, and biological properties of the upper 10-m of the water column for three stations sampled in August 1993 (Evans unpublished data) **with three stations sampled in a similar area in March 1994 offshore of the Slave River mouth.** See Evans et al. (1996) for locations of the August 1993 sites.

	August 1993			March 1994		
	Delta-1	**Delta-2**	**Delta-4**	**Site 20**	**Site 21**	**Site 23**
Specific Conductivity (mS/cm)	0.236	0.233	0.234	0.212	0.210	0.223
Turbidity (NTU)	166	114	19	6.9	7.4	4.4
Temperature (°C)	14.2	14.1	14.5	0.4	0.2	0.4
Oxygen (mg/L)	10.0	9.9	10.1	12.8	13.0	12.6
% Oxygen	100.8	98.4	101.9	90.4	91.6	88.5
pH	7.47	7.40	7.67	7.47	7.46	7.70
Total phosphorus (µg/L)	176	140	37	20	21	14
Dissolved P (µg/L)	47	56	16	11	7	7
Soluble reactive P (µg/L)	27	15	9	2.5	2	3
Nitrite-nitrate (µg/L)	53	50	46	94	97	96
Ammonia (µg/L)	11	9	<7	5	6	6
Part. organic N (µg/L)	229	259	79	11	29	11
Part. organic C (µg/L)	2,420	1,972	343	106	174	40
Diss. organic C (µg/L)	9,405	9,140	6,750	3,620	3,605	5,215
Chlorophyll (µg/L)	1.2	0.8	3.0	0.4	1.1	0.2
Phaeophytin (µg/L)	0.7	0.8	0.5	0.2	0.2	0.1

5.3 TURBIDITY

Turbidity also was measured as a possible tracer of Slave River water movement in the West Basin in March 1994. Turbidity values at the Slave River mouth (6.6 - 7.1 NTU) were similar to values observed in other regions of the West Basin (2.7 - 11.7 NTU). Thus, turbidity was a poor tracer of Slave River water movement during March. In contrast, in August 1994, turbidity offshore of the Slave River mouth (Delta -1) ranged from 148 - 183 NTU and averaged 166 NTU (Table 2). Turbidity decreased rapidly with distance offshore declining to a mean value of 19 NTU at Delta-4.

August 1994 values at Delta - 4 compare to a mean value of 4.4 at Site 23 in March 1994. The Mackenzie River Basin Commission (1981) reported that the mean turbidity of Slave River water was 140 NTU and that values ranged from an April low of 9 NTU to a June high of 845 NTU.

5.4 pH

While not measured as a possible tracer of Slave River water movement, pH did appear to be significantly lower at the Slave River mouth (Site 20 mean = 7.47) than at Sites 12 and 13 (mean = 7.72 and 7.70 respectively), farther to the west (Table 1). pH also appeared to increase with distance offshore of the Slave River mouth, both in August 1993 and March 1994 (Table 2): pH values were similar to one another in August and in March at each of the three sites. The Mackenzie River Basin Commission (1981) reported that the Slave River has a mean pH of 7.8 and that pH ranges from 7.3 - 8.4.

Although dissolved oxygen concentrations and percent saturation decreased with depth at the nine study sites, pH generally increased. The reason for this increase is uncertain. The decrease in pH immediately above the sediments at some sites (Sites 15, 16, 19, 21 and 23) can be related to the decomposition of organic matter.

5.5. NUTRIENTS

Nutrient concentrations were low in March 1994 and, with the exception of total and dissolved phosphorus, not appreciably higher at the Slave River mouth than other regions of the West Basin. Algal biomass tended to be higher at sites nearer the Slave River. Therefore the phytoplankton community may have depleted nutrients from the inflowing Slave River waters; nutrient (SRP, nitrite-nitrate) concentrations tended to be higher in bottom than surface waters at deep-water (>60 m) sites and were a probable consequence of nutrient regeneration.

5.5.1 Phosphorus

Highest concentrations were observed at Sites 20 and 21, offshore of the Slave River mouth, and at Sites 12 and 13. Total and dissolved phosphorus concentrations were higher in March 1994 at Sites 12 and 13 than at the two comparable stations sampled in the West Basin in March 1992 (Table 1). Lowest phosphorus concentrations were at Lutsel K'e in the East Arm.

Phosphorus concentrations (Table 2) were substantially higher in the Slave River outflow in August 1993 (Delta-1) than March 1994 (Site 20). TP concentrations were ca. 8.8 times higher and soluble reactive phosphorus ca. 10.8 times higher at Delta-1 than Site 20. Seasonal differences in phosphorus concentrations were less pronounced further offshore with TP concentrations in the upper 10 m of the water column averaging 37 µg/L at Delta-4 in August and 14 µg/L at Site 23, its March equivalent.

The Slave River is clearly a significant source of phosphorus to the West Basin of Great Slave Lake. Total dissolved phosphorus (TDP) concentrations in the Slave Delta channels ranged from 30 - 350 µg/L over June to October 1979 and averaged 140 µg/L (Mackenzie River Basin Committee, 1981).

The Slave River discharge rate has been estimated as 135 km^3/y (Rawson, 1950), with most of the inflow occurring between June and October. Thus, the Slave River may be contributing some 18,900 metric tons of TDP to Great Slave Lake. If we assume a TDP to particulate phosphorus (PP) ratio of 0.23 (Brunskill et al., 1975), the Slave River may be contributing an additional 82,174 metric tons of particulate phosphorus to the lake each year. Thus, total phosphorus loading to Great Slave Lake by the Slave River may be as high as 101,074 metric tons per year.

The West Basin has a surface area of 19,400 km^2, a mean depth of 41 m, and an estimated volume of 795 km^3 (Rawson, 1950). Thus, the areal TP loading rate to Great Slave Lake by the Slave River may be as high as 5.2 $g/m^2/y$. Assuming that the majority of Slave River water resides in the West Basin, the Slave River may be enriching the West Basin by ca. 23.8 µg/L TDP, 103.5 µg/L PP, and 127.9 µg/L TP each year.

Slave River TP loading rates to the West Basin of Great Slave Lake are similar to TP loading rates derived for Lake Erie during the early 1970s. Vollenweider et al., (1974) estimated that the western basin of Lake Erie had a TP loading rate of 6.0 $g/m^2/y$ while the eastern basin had a TP loading rate of 0.8 $g/m^2/y$.

Phosphorous concentrations in the West Basin are similar to those of Lake Erie. Dobson et al., (1974) reported that, in the eutrophic waters of the western basin of Lake Erie, SRP concentrations ranged from 2 - 21 µg/L (mean = 11.5 µg/L), DP concentrations from 7.7 - 26.9 µg/L (mean = 17.2 µg/L) and PP concentrations from 21.7 - 60.4 µg/L (mean = 32.2 µg/L). These values are not appreciably different from those observed immediately offshore of the Slave River mouth (Table 2). In the mesotrophic waters of the eastern basin of Lake Erie, Dobson et al., (1974) reported that SRP concentrations ranged from 1 - 6 µg/L (mean = 3.5 µg/L), DP concentrations from 3.8 - 11.0 µg/L (mean = 7.1 µg/L) and PP concentrations from 3.8 - 13.6 µg/L (mean = 8.4 µg/L). These values are not appreciably different from those observed in the West Basin (Fee et al., 1985: this report). In contrast, Dobson et al., (1974) reported that SRP concentrations in oligotrophic Lake Superior were less 1 µg/L, DP ranged from 1.6 - 2.4 µg/L (mean = 2.0 µg/L), and that PP ranged from 0.9 - 1.6 µg/L (mean = 1.3 µg/L).

Although the West Basin of Great Slave Lake has phosphorus concentrations which are similar to those of Lake Erie, primary production rates are believed to be low. Fee et al., (1985) estimated the annual primary production of the West Basin was 30 $gC/m^2/y$. This value is substantially lower than Vollenweider et al.'s (1974) estimate of 350 $gC/m^2/y$ for the western Lake Erie and 170 $gC/m^2/y$ for eastern Lake Erie. However, this value is similar to Vollenweider et al.'s (1974) primary production estimate of 50 $gC/m^2/y$ for Lake Superior.

The low primary production of the West Basin, despite its relatively high estimated loading TP, may be related to five factors. First, climate is important, limiting the length and intensity of the growing season. Second, turbidity from the Slave River may be important, limiting the amount of light which is able to penetrate the water column. Third, water column depth may be important. The West Basin is moderately deep and, in the absence of thermal stratification during the ice-free season, phytoplankton are readily mixed by wind action below the compensation depth. Fourth, much of the TP entering Great Slave Lake may be associated with particulates which rapidly settle to the lake

floor along with the massive load of suspended sediments entering the lake. Sedimented particulate phosphorus may rapidly enter the food web, first being scavenged by the benthic community and then consumed by benthic-feeding fish such as lake whitefish (*Coregonus clupeaformis*), making it unavailable for primary production. Finally, much of the dissolved phosphorus entering Great Slave Lake may be in a form that is not readily utilized by the algal community.

Phosphorus enters rivers such as the Peace, Athabasca, and Slave through four basic processes, i.e., precipitation, runoff, erosion, and anthropogenic inputs. Of these, erosion, particularly during ice break-up, appears to be the most important (Scrimgeour et al., 1994). Chambers and Dale (1996) estimated that non-point sources accounted for 93.6% of the total TP load (2,051 metric tons/y) to the Athabasca River. Some 68.7% of the phosphorus load originated from forested lands and another 11.4% from agricultural lands

Most of the TP (101,074 metric tons/y) entering Great Slave Lake apparently remains in the lake. Brunskill et al., (1975) estimated that that the Mackenzie River delta has a TP loading rate of 60,000 metric tons/y with 5% (3,000 metric tons/y) originating from Great Slave Lake. Thus, as little as 5% of the TP entering Great Slave Lake via the Slave River may exit the lake with the Mackenzie River outflow. Because Great Slave Lake waters remain well-oxygenated (>75% saturation) through the year, phosphorus which settles to the lake floor is not efficiently recycled back into the water column. Wetzel (1975) notes that when oxygen levels in the microzone are high, mobilization from the lake sediments of ferrous iron and adsorbed phosphorus (a known coprecipitate) is low. Thus, the sediments are the primary sink of TP in Great Slave Lake.

5.5.2. Nitrogen

Ammonia concentrations were low during the March 1992 and 1994 and the August 1993 sampling. Nitrite-nitrate concentrations were higher than ammonia. Similar concentrations were observed in the West Basin and at Lutsel K'e in March 1992 and at the eight stations investigated in March 1994 (Table 1). Nitrite-nitrate concentration (Table 2) was lower in Slave River outflow in August 1993 (Delta-1) than in March 1994 (Site 20). Ammonia concentrations tended to be slightly higher in March 1994 than August 1993 although concentrations were low in both months.

The Slave River appears to be a significant source of nitrogen to the West Basin of Great Slave Lake. The Mackenzie River Basin Committee (1981) reported that total dissolved nitrogen (TDN) concentrations in the Slave Delta ranged from 0.46 mg/L (early July) to 1.02 mg/L (late August) and averaged 0.60 mg/L. Wetzel (1975) reported that dissolved inorganic nitrogen (DIN) commonly accounts for one-half of TDN. Thus, DIN concentrations in the Slave River may average 0.30 mg/L. If we assume a TDN to particulate nitrogen (PN) ratio of 1:1 (Brunskill et al., 1975) for Slave River waters, PN concentrations in the delta channels may average 0.60 mg/L: thus, total nitrogen concentrations may average 1.2 mg/L.

Assuming an average TN concentration of 1.2 mg/L in the Slave delta channels and a Slave River inflow rate of 135 km^3/y, the river may be enriching Great Slave Lake by 162,000 metric tons of nitrogen per year versus 101,074 metric tons of total phosphorus. Furthermore, of the total nitrogen entering the lake, 50% may be dissolved (i.e., 81,000 metric tons/y) and 50% of the dissolved

nitrogen (40,500 metric tons/y) may consist of inorganic nitrogen. Thus, the Slave River may enrich West Basin DIN concentrations by ca. 51 µg/L/y and PN concentrations by 102 µg/L. Brunskill et al. (1995) estimated that the Mackenzie River delta receives 220,000 metric tons of nitrogen annually. Of that amount, 17% or 37,400 metric tons originated from Great Slave Lake. Thus, less than 23% of the TN entering Great Slave Lake via the Slave River may exit via the Mackenzie River.

5.5.3. Dissolved Organic Carbon

The Slave River, by virtue of its high flow rates, is a significant source of dissolved organic carbon to Great Slave Lake. DOC concentrations at the Slave River mouth varied over time. Concentrations were 9,405 µg/L in August 1993 and 3,620 µg/L in March 1993 (Table 2). In summer, DOC concentrations decreased with distance offshore suggesting that DOC concentrations were enriched in the Slave River. In March, concentrations decreased with distance offshore suggesting that DOC concentrations were low in the Slave River in winter.

5.6. PHYTOPLANKTON

Chlorophyll concentrations were low (generally < 1 µg/L) in March 1994. Algal biomass was also low ranging from 5.7 - 270 mg/m^3. Low standing stocks of phytoplankton were to be expected given the thick ice cover and the several centimeters of overlying snow which severely restricted light penetration (Bolsenga et al., 1991; Bolsenga and Vanderploeg, 1992). However, in areas where the snow cover was blown away, significant amounts of light may have penetrated the ice. The phytoplankton community was dominated by pyrrophytes and cryptophytes (motile forms) which were capable of migrating in response to changes in light regime. Similarly, Wright (1964) noted that flagellates were a major component of the phytoplankton community in an ice-covered lake in Massachusetts.

Diatoms were a significant component of the winter phytoplankton community in the West Basin in March 1994 and tended to be most abundant offshore of the Slave River. Diatoms, in general, attain their maximum abundance in turbulent waters, i.e., during spring and autumn. Turbulence enables these large, and frequently heavy-celled, algae to remain in the photic zone. The abundance and dominance of diatoms offshore of the Slave River mouth is highly suggestive of a riverine source of these populations.

Little recent research has been conducted on phytoplankton populations in Great Slave Lake. Fee et al. (1985) noted that chrysophytes and cryptophytes were the taxonomic dominants over most of Great Slave Lake in summer 1983. However, diatoms dominated in the offshore waters of the West Basin. Total biomass ranged from 120 - 440 mg/m^3 over most of the lake with a somewhat higher biomass in Yellowknife Bay (660 mg/m^3). Thus, the March 1994 phytoplankton community in the West Basin was generally similar in composition to the summer community as observed by Fee et al. (1985). However, standing stocks were lower in winter than summer.

6.0 CONCLUSIONS

Our March 1994 sampling determined that the Slave River exerted a weak, direct influence on the limnological properties of the West Basin. The water column was quiescent with a warm-water hypolimnion only in the deepest regions of the study area. Dissolved oxygen concentrations and percent saturation were high in most locations. Dissolved oxygen concentrations probably would have declined further through the additional 6 - 8 weeks of ice cover. The Slave River may have provided an enriched supply of phosphorus to the West Basin during winter. However, the Slave River supplied more nutrients in late spring and summer when its flow rate was higher and nutrient concentrations greater. The phytoplankton community was in large measure dominated by motile forms which were capable of maintaining themselves high up in the water column and near the limited light penetrating snow and ice cover. The strong presence of diatoms offshore of the Slave River is suggestive of a riverine source.

7.0 RECOMMENDATIONS

This study obtained information on the limnological features of the West Basin of Great Slave Lake during late March 1994. The sampling, while successful, was constrained in three ways. The limnological sampling was incidental to a field program designed to collect sediment cores for dating and contaminant studies. Logistic considerations (low air temperatures and the volume and weight of limnological equipment which could be carried by the helicopter) limited the amount of sampling which could be conducted in a day. Limitations imposed by the length of the Hydrolab cable restricted the depth which the water column could be sampled for temperature, dissolved oxygen, pH, and specific conductivity. Therefore, the following are recommended.

1. A special study should be designed to investigate the influence of the Slave River on the winter limnology of the West Basin of Great Slave Lake. Sampling sites should vary, being closest in the vicinity of the Slave River mouth. The entire water column should be sampled for turbidity, temperature, oxygen, pH, and conductivity: special effort should be made to sample the lower meter of the water column. Nutrients should be measured at a number of depths with special attention given to the sediment-water interface.

2. Research sampling in March is difficult: low air temperatures contribute to significant problems with equipment freeze-up and limit what can be accomplished during a day. It is highly recommended that limnological sampling be conducted in April or, if feasible, May. April or May sampling also would provide for a better assessment of reductions in dissolved oxygen concentrations in the deeper regions of the lake during a period of extended ice cover. Such sampling also would provide for a better assessment of nutrient regeneration from the lake floor. Sediments should be sampled for organic carbon, nitrogen, phosphorus and biogenic silica content. Sampling conducted in April or May also would provide information on algal community structure and growth under the ice with increasing day length and under-ice warming.

3. Given the fact that the West Basin has apparently increased in productivity, especially since the 1950s, it is highly desirable to establish a long-term water quality monitoring program on Great

Slave Lake. At least two sites should be investigated. High priority should be given to Resolution Bay, at the outflow of the Slave River. The community at Fort Resolution should participate in this study and should be able to make many of the necessary seasonal collections. The second site is the East Arm which would serve as a control distinguishing between changes in productivity related to Slave River influences (and its watershed) and changes associated with the atmosphere (nutrient deposition, climate change). The most practical site would be Lutsel K'e. Additional sites at Yellowknife and/or Hay River would provide for our assessment of the effects of localized anthropogenic activities on water quality and productivity. The monitoring program should begin with frequent and intensive sampling which would be scaled down as a better understanding is gained as to how climate, river inflow and anthropogenic activities affect the physical-chemical and biological properties of Great Slave Lake. Such properties include dissolved oxygen concentrations, nutrients, algal standing stocks, and production. While not conducted during this study, zooplankton and benthos investigations also should be conducted.

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NORTHERN RIVER BASINS STUDY

APPENDIX A TERMS OF REFERENCE

Project 2333-C1: SIave River Delta and Great Slave Lake Sediment Sampling

I. Introduction

Great Slave Lake is one of the most important aquatic ecosystems in northern Canada. It supports important commercial (West Basin) and sports fisheries (East Arm). Moreover, many indigenous people rely on Great Slave Lake fish as an essential component of their diet. The lake is also a major staging area for a number of waterfowl species. Some 18,000 people or more than 50% of the population of the Northwest Territories live along the shore of the lake. These people are, in various ways, highly dependent upon the quality of Great Slave Lake waters and its biota. Contaminants entering the lake therefore are and will continue to be of concern. Such contaminants include aerial-born compounds (e.g., PCBs, PCCs, organochlorine pesticides, PAHs, some metals) which are deposited (wet and dry deposition) on the watershed, washed into the Peace and Athabasca rivers, and transported downstream via the Slave River to Great Slave Lake. Other contaminants have localized anthropogenic sources, especially from the more developed regions to the south. These localized sources will be of increasing concern to Great Slave Lake (and the Arctic ecosystem) as economic development (pulp and paper mills, oil and gas developments, agriculture, urban centres) continues to intensify in Alberta, British Columbia and Saskatchewan.

The purpose of this study is to collect surficial sediments and sediment cores from the Slave River Delta and Great Slave Lake for dating and organic and heavy metal contaminant analyses to determine the extent to which the Great Slave Lake aquatic ecosystem has been impacted by air-born and water transported contaminants.

II. Requirements

The contractor is to collect a series of sediment cores and/or surficial sediment samples from at least two regions (Hay River and the Slave River Delta) of Great Slave Lake. If time, conditions and funding permit, additional samples are to be collected from the East Arm of the lake. The sampling program should be as follows:

1) The study is to begin with a series of exploratory core collections to determine the best location to collect a more detailed series of cores for contaminant studies. The first series of cores will be centred on the Hay River region with the transect extending as far west as Pointe de Roche and as far east as Sulphur Cap. Approximately six stations are to be sampled.

2) The second transect series will be centred on Resolution Bay. The actual location of the transect will be dependent upon further analysis of core samples collected in the area by Dr. Marlene Evans, National Hydrology Research Institute, Saskatoon in August 1993. However, it is anticipated that the transect will run from the Egg Island region west to Presqu'lle Cape. A second transect will be sampled running from the Middle Channel of the Slave River to approximately 25 km offshore. Of particular interest is whether the quiescent water column conditions allow for the accumulation of a light flocculent layer of organic material (and contaminants) immediately above the sediments as has been observed by Dr. Rick Bourbonniere, National Water Research Institute, Burlington in Lake Athabasca. At each of these sites, a core sample will be collected and visually inspected to determine gross sediment types. Cores which have a continuous sediment-profile of silts and clays with no obvious layerings with sand are to be retained for further study. Cores collected along the transects are to be returned to the base laboratory, sectioned, placed in plastic bags, frozen and retained for later dating and sediment grain analysis. In addition, a surficial sediment grab will is to be taken at each site, placed in a precleansed glass jar, frozen and retained for organic contaminant analysis. The water column at each sediment sampling site is to be characterized with respect to temperature, dissolved oxygen, turbidity (or suspended solids) and dissolved organic carbon. These data are to be used to characterize the physical-chemical regime of the water column (i. e., is it quiescent or is there a significant amount of resuspension in a nephloid layer?). These data are also to be used for mapping (horizontal and vertical) of the Slave River plume. Finally, if time allows, limited numbers of water column samples are to be collected to measure nutrient concentrations relative to the Slave River outflow.

3) Following the transect studies, one or two sites in each of the minor regions are to be selected for detailed collection of cores for organic contaminant analysis. Multiple cores are to be collected using a 10-cm internal diameter gravity corer. All samples are either to be transported via helicopter to the base laboratory or immediately processed in the field. Cores are to be sectioned at 1-cm intervals down to 24 cms and at 2-cm intervals down to the base of the core or to a maximum depth of 1 m. Samples are to be extruded vertically using a hydraulic extrusion system, placed in pre-cleaned glass containers, and immediately frozen. During the extrusion process, general characteristics of each section are to be noted (i.e., sediment colour, apparent grain size (clay, silt, etc.) and any other noteworthy observations). Core materials are also to be retained for dating and sediment grain-size analysis.

4) If time, conditions and funding permit, a third transect series is to be collected in the East Arm, extending from Grant Point to Peterson Point. This transect is to extend the spatial coverage of cores collected for the investigation of regional

variation in sedimentation rates and surficial - sediment organic contaminant concentrations relative to the Slave River plume.

5) The latitude and longitude are to be recorded for each sediment and water column sampling location using Geographic Positioning System technology.

III. Reporting Requirements

The contractor is to submit a brief summary report documenting the sampling locations for sediment and water column collections to the component coordinator by March 31, 1994.

IV. Contract Administration

This contract is being carried out under the Contaminants Component of the Northern River Basins Study. Dr. John Carey, National Water Research Institute, Burlington is the Contaminants Component leader.

The Scientific Authority on this project is:

Dr. Marlene Evans
National Hydrology Research Institute
11 Innovation Boulevard
Saskatoon, Saskatchewan S7N 3H5
phone: (306) 975-5310 fax: (306) 975-5143

Questions of a scientific nature should be directed towards her.

The component coordinator for this project is:

Greg Wagner
Northern River Basins Study
690 Standard Life Centre
10405 Jasper Avenue
Edmonton, Alberta T5J 3N4
phone: (403) 427- 1742 fax: (403) 422-3055

Questions of an administrative nature should be directed towards him.

Appendix B

Hydrolab data for the nine study sites, March 1994. Site 19 was sampled on March 25 (19A) and March 27(19B).

SITE 12

DEPTH meters	SPCOND mS/cm	TEMP °C	DO %sat	DO mg/L	pH
0	0.25	0.25	99.06	13.90	7.69
1	0.24	0.27	96.96	13.62	7.71
2	0.24	0.79	94.10	13.15	7.73
3	0.23	0.29	94.54	13.28	7.73
5	0.23	0.25	94.30	13.23	7.72
10	0.22	0.27	94.33	13.25	7.71
15	0.22	0.29	94.18	13.23	7.70
20	0.23	0.28	94.16	13.21	7.70
25	0.25	0.37	92.80	13.01	7.71
30	0.23	0.44	91.90	12.85	7.73
35	0.21	0.68	91.14	12.66	7.74
40	0.23	1.05	91.46	12.53	7.74
45	0.23	1.28	91.21	12.47	7.74
49.8	0.21	1.43	91.26	12.43	7.74

SITE 13

DEPTH meters	SP/COND mS/cm	TEMP °C	DO %sat	DO mg/L	pH
0	0.24	0.56	93.70	13.20	7.69
1	0.23	0.37	93.50	13.23	7.70
2	0.23	0.31	93.20	13.21	7.71
3	0.23	0.31	92.90	13.17	7.71
5	0.24	0.29	92.80	13.16	7.70
10	0.24	0.39	92.40	13.06	7.69
15	0.24	0.34	92.60	13.12	7.68
20	0.22	0.27	92.80	13.17	7.68
25	0.22	0.30	92.40	13.10	7.68
30	0.25	0.44	91.10	12.87	7.70
35	0.24	0.80	90.00	12.58	7.71
40	0.20	1.09	90.30	12.52	7.71
48.6	0.22	1.50	90.20	12.37	7.72

Site 14

DEPTH meters	SP/COND mS/cm	TEMP °C	DO mg/L	DO %sat	pH
0	0.24	0.17	12.60	88.50	7.56
1	0.23	0.19	12.55	88.20	7.60
2	0.23	0.20	12.44	87.40	7.62
3	0.21	0.17	12.54	88.10	7.67
5	0.21	0.17	12.54	88.10	7.69
10	0.21	0.15	12.53	87.90	7.71
20	0.21	0.17	12.38	86.90	7.77
22.4	0.22	0.50	12.04	85.30	7.77

SITE 15

DEPTH meters	SPCOND mS/cm	TEMP °C	DO mg/L	DO %sat	pH
0	0.22	0.17	12.91	90.60	7.62
1	0.22	0.17	12.73	89.30	7.64
2	0.22	0.20	12.68	89.10	7.66
3	0.22	0.22	12.65	88.90	7.67
5	0.22	0.20	12.66	88.90	7.67
10	0.22	0.20	12.64	88.80	7.66
15	0.21	0.23	12.59	88.50	7.67
20	0.22	0.22	12.60	88.50	7.68
25	0.22	0.20	12.63	88.70	7.69
30	0.21	1.11	11.82	85.20	7.68
31.6	0.20	1.56	11.62	84.80	7.67

SITE 16

DEPTH meters	SPCOND mS/cm	TEMP °C	DO mg/L	DO %sat	pH
0	0.22	0.19	12.99	91.20	7.61
1	0.22	0.20	12.89	90.50	7.62
2	0.22	0.31	12.66	89.20	7.62
3	0.22	0.26	12.67	89.20	7.62
5	0.22	0.24	12.66	89.00	7.63
10	0.22	0.24	12.64	88.90	7.63
15	0.22	0.22	12.67	89.10	7.63
20	0.22	0.22	12.67	89.10	7.64
25	0.22	0.27	12.57	88.50	7.65
30	0.21	0.26	12.32	87.40	7.65
36.4	0.22	2.09	9.71	72.00	7.45

SITE 19A

DEPTH meters	SPCOND mS/cm	TEMP °C	DO mg/L	DO %sat	pH
0	0.22	0.41	12.87	90.90	7.61
1	0.20	0.25	12.78	89.90	7.63
2	0.22	0.27	12.64	88.90	7.64
3	0.21	0.41	12.43	87.90	7.65
5	0.22	0.38	12.46	88.00	7.66
10	0.21	0.20	12.59	88.50	7.67
15	0.22	0.26	12.51	88.00	7.68
20	0.22	0.20	12.59	88.50	7.68
25	0.23	0.22	12.53	88.10	7.69
30	0.22	0.41	12.32	87.10	7.70
35	0.21	0.89	11.98	85.80	7.69
40	0.22	1.36	11.78	85.50	7.69
42.2	0.20	1.65	11.66	85.30	7.68

SITE 19B

DEPTH meters	SPCOND mS/cm	TEMP °C	DO mg/L	DO % sat	pH
0	0.22	0.44	13.24	93.70	7.69
1	0.22	0.22	12.62	88.70	7.70
2	0.22	0.32	13.03	91.90	7.69
3	0.22	0.40	12.55	88.70	7.69
5	0.22	0.34	12.57	88.60	7.69
10	0.22	0.44	12.48	88.30	7.68
15	0.21	0.24	12.61	88.70	7.69
20	0.22	0.27	12.52	88.20	7.70
25	0.20	0.34	12.46	87.80	7.71
30	0.20	0.53	12.16	86.20	7.72
35	0.22	1.03	12.03	86.50	7.71
40	0.19	1.57	11.79	86.10	7.71
42.3	0.22	1.81	11.53	84.70	7.67

SITE 20

DEPTH meters	SPCOND mS/cm	TEMP °C	DO mg/L	DO %sat	pH
0	0.22	0.43	13.03	92.10	7.47
1	0.21	0.58	12.66	89.90	7.47
2	0.21	0.36	12.72	89.70	7.47
3	0.21	0.22	12.83	90.20	7.47
5	0.21	0.24	12.82	90.10	7.46
6	0.21	0.22	12.83	90.20	7.46
6.7	0.21	0.27	12.84	90.40	7.46

SITE 21

DEPTH meters	SPCOND mS/cm	TEMP °C	DO %sat	DO mg/L	pH
0	0.22	0.20	93.00	13.25	7.46
1	0.21	0.19	92.80	13.22	7.46
2	0.21	0.21	91.50	13.03	7.46
3	0.21	0.19	91.20	12.99	7.45
5	0.21	0.20	90.70	12.91	7.46
10	0.20	0.19	90.10	12.83	7.46
15	0.20	0.17	90.10	12.84	7.45
20	0.21	0.20	89.70	12.77	7.46
25	0.22	0.44	88.80	12.55	7.49
30	0.22	0.92	87.20	12.17	7.57
35	0.23	1.48	85.40	11.73	7.69
40	0.23	1.77	85.00	11.59	7.71
45	0.20	2.02	84.30	11.40	7.71
49.6	0.20	2.12	83.20	11.23	7.69

SITE 23

DEPTH meters	SPCOND mS/cm	TEMP °C	DO %sat	DO mg/L	pH
0	0.22	0.22	88.90	12.65	7.69
1	0.20	0.24	88.60	12.59	7.70
2	0.22	0.24	88.50	12.59	7.70
3	0.22	0.23	88.50	12.59	7.70
5	0.23	0.22	88.30	12.56	7.71
10	0.23	0.22	88.40	12.58	7.70
15	0.23	0.24	88.20	12.55	7.72
20	0.23	0.22	88.60	12.60	7.73
25	0.21	0.22	88.70	12.63	7.71
30	0.23	0.34	87.80	12.46	7.71
35	0.24	0.89	86.10	12.01	7.70

Appendix C

Table 1. Turbidity values by station and sample depth for the March 1994 study sites.

Site	Depth (m)	NTU
11	29	2.7
12	1	5.6
	69	11.7
13	1	10.9
	10	2.8
	61	4.2
16	1	4.4
	11	4.3
	36	3.9
19A	1	5.9
	10	4
	45	5.9
20	1	6.6
	6	7.1
21	1	8.2
	10	6.6
	69	8.3
23	1	3.8
	10	5
	35	3.8

Table 2. Nutrient, particulate, chlorophyll, and phaeophytin concentrations by station and sample depth for the March 1994 study sites.

Site	Depth (m)	TP (µg/L)	DP (µg/L)	SRP (µg/L)	NH3 (µg/L)	NO2/NO3 (µg/L)	PN (µg/L)	POC (µg/L)	DOC (µg/L)	Chl.a (µg/L)	Phaeo (µg/L)
11	**29**	16	8	3	5	99	14	53	5,090	6.4	13.7
12	**1**	26	23	8	8	101	39	369	5,810	2.3	0.2
	69	22	15	10	6	192	24	201	4,510	0	1
13	**1**	26	11	2	8	96	39	256	5,820	0.3	0.1
	10	9	6	2	5	95	19	81	5,200	0.2	0.1
	61	11	8	4	6	138	12	34	4,900	0	0.2
16	**1**	9	-	3	5	96	10	28	5,400	0.2	0.1
	11	9	6	3	5	95	10	54	5,200	0.1	0.1
	36	9	5	2	5	99	17	56	5,360	0.1	0.1
19A	**1**	9	6	2	5	97	10	59	5,410	0.3	0.1
	10	11	6	3	5	95	10	125	5,300	0.1	0.1
	45	14	6	4	5	98	10	75	5,100	0.8	1.1
20	**1**	19	16	3	5	95	11	119	3,670	0.6	0.2
	6	20	6	2	5	93	11	93	3,570	0.2	0.2
21	**1**	25	6	2	5	94	32	258	3,780	1.7	0.3
	10	17	7	2	6	99	26	89	3,430	0.4	0.1
	69	14	9	4	5	115	19	81	5,190	0.1	0.3
23	**1**	13	7	2	5	96	10	16	5,200	0.2	0.1
	10	14	7	4	7	95	12	63	5,230	0.1	0.1
	35	15	-	3	5	96	10	10	5,180	0.1	0.1

Appendix D

Phytoplankton abundance and biomass by taxonomic category and size category at the seven study sites, March 1994.

Site 12, 1 m.

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	0	0
Chlorophyta	0	0
Euglenophyta	0	0
Chrysophyta	43,488	9.41
Cryptophyta	184,247	39.41
Pyrrophyta	13,382	31.38
Diatoms	13,125	12.59
Total Algae	254,242	92.79
Total Ciliate	515	0.08

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	38,599	7.26
2 - 10	190,938	31.11
10 - 20	20,072	22.65
20 - 40	3,089	27.72
40 - 64	515	1.01
>64	1,029	3.03

Site 13, 1 m and 10 m.

1 m

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	2,959	0.21
Chlorophyta	129	0.55
Euglenophyta	0	0
Chrysophyta	6,948	1.37
Cryptophyta	257	0.41
Pyrrophyta	1,158	9.18
Diatoms	4,374	6.23
Total Algae	15,825	17.96
Total Ciliate	129	1.65

10 m

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	7,205	0.34
Chlorophyta	772	0.04
Euglenophyta	579	0.9
Chrysophyta	15,439	1.25
Cryptophyta	11,709	3.12
Pyrrophyta	4,246	11.9
Diatoms	22,580	8.11
Total Algae	62,530	25.66
Total Ciliate	1,737	1.46

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	6,305	1.91
2 - 10	6,819	0.9
10 - 20	1,029	4.03
20 - 40	643	6.16
40 - 64	0	0
>64	1,029	4.96

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	19,299	1.12
2 - 10	33,002	6.01
10 - 20	8,658	8.67
20 - 40	772	9.05
40 - 64	0	0
>64	772	0.81

Site 16, 1 m and 11 m.

1 m

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	27,276	7.76
Chlorophyta	0	0
Euglenophyta	0	0
Chrysophyta	515	0
Cryptophyta	40,143	6.44
Pyrrophyta	5,919	11.3
Diatoms	4,375	2.25
Total Algae	78,228	27.79
Total Ciliate	1,029	0.8

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	26,247	7.58
2 - 10	45,290	7.29
10 - 20	5,147	11.98
20 - 40	0	0
40 - 64	0	0
>64	1,544	0.95

11 m

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	15,954	1.39
Chlorophyta	343	0.01
Euglenophyta	0	0
Chrysophyta	6,347	3.37
Cryptophyta	14,753	5.09
Pyrrophyta	6,347	15.11
Diatoms	10,808	23.36
Total Algae	54,552	48.34
Total Ciliate	2,231	4.89

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	16,812	1.54
2 - 10	21,958	3.74
10 - 20	12,180	12.34
20 - 40	2,058	15.44
40 - 64	0	0
>64	1,544	15.27

Site 19, 1 m and 10 m.

1 m

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	3,860	0.47
Chlorophyta	386	0.01
Euglenophyta	0	0
Chrysophyta	1,544	0.05
Cryptophyta	35,897	7.88
Pyrrophyta	2,702	5.4
Diatoms	6,948	8.29
Total Algae	51,337	22.1
Total Ciliate	2,702	5.13

10 m

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	1,716	0.06
Chlorophyta	0	0
Euglenophyta	0	0
Chrysophyta	2,659	0.38
Cryptophyta	343	0.02
Pyrrophyta	3,217	2.46
Diatoms	5,018	2.76
Total Algae	12,953	5.68
Total Ciliate	2,187	5.71

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	5,018	0.41
2 - 10	44,196	10.7
10 - 20	1,158	2.71
20 - 40	193	2.33
40 - 64	0	0
>64	772	5.96

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	2,059	0.1
2 - 10	6,519	0.91
10 - 20	3,989	3.32
20 - 40	0	0
40 - 64	0	0
>64	386	1.36

Site 20, 1 m and 6 m.

1 m

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	4,117	0.14
Chlorophyta	1,029	0.08
Euglenophyta	0	0
Chrysophyta	1,930	1.05
Cryptophyta	42,074	26.51
Pyrrophyta	6,562	7.36
Diatoms	27,277	103.28
Total Algae	82,989	138.42
Total Ciliate	1,158	1.15

6 m

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	6,616	0.41
Chlorophyta	0	0
Euglenophyta	0	0
Chrysophyta	6,334	0.65
Cryptophyta	28,318	3.65
Pyrrophyta	2,470	2.02
Diatoms	17,418	26.31
Total Algae	61,156	33.04
Total Ciliate	1,081	1.15

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	6,819	0.2
2 - 10	27,534	5.69
10 - 20	28,564	36.19
20 - 40	772	4.66
40 - 64	0	0
>64	19,300	91.68

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	6,616	0.37
2 - 10	42,549	4.78
10 - 20	5,506	5.86
20 - 40	1,081	9.37
40 - 64	618	0.1
>64	4,786	12.55

Site 21, 1 m and 10 m.

1 m

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	23,160	0.94
Chlorophyta	3,088	0.07
Euglenophyta	0	0
Chrysophyta	0	0
Cryptophyta	281,773	94.88
Pyrrophyta	13,124	8.38
Diatoms	15,440	165.78
Total Algae	336,585	270.04
Total Ciliate	3,088	20.53

10 m

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	6,176	0.29
Chlorophyta	0	0
Euglenophyta	0	0
Chrysophyta	772	0.28
Cryptophyta	168,098	25.74
Pyrrophyta	21,615	10.68
Diatoms	15,697	20.62
Total Algae	212,358	57.62
Total Ciliate	1,158	1.76

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	16,984	0.53
2 - 10	248,578	31.46
10 - 20	60,215	73.75
20 - 40	1,544	0.05
40 - 64	1,544	32.87
>64	7,720	131.38

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	6,176	0.29
2 - 10	196,725	35.7
10 - 20	6,369	5.94
20 - 40	772	9.69
40 - 64	386	0.21
>64	1,930	5.79

Site 23, 1 m and 10 m.

1m

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	5,006	0.65
Chlorophyta	0	0
Euglenophyta	0	0
Chrysophyta	6,066	1.74
Cryptophyta	28,254	4.35
Pyrrophyta	3,242	2.06
Diatoms	4,369	8.59
Total Algae	46,937	17.4
Total Ciliate	926	1.61

10m

Algal Group	Cell Number (#/L)	Biomass (mg/m^3)
Cyanobacteria	8,440	0.38
Chlorophyta	1,304	0.08
Euglenophyta	0	0
Chrysophyta	14,512	7.52
Cryptophyta	3,363	0.44
Pyrrophyta	5,799	6.05
Diatoms	12,147	22.82
Total Algae	45,565	37.29
Total Ciliate	7,411	9.74

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	7,808	0.8
2 - 10	37,431	7.29
10 - 20	772	1.63
20 - 40	308	1.49
40 - 64	0	0
>64	618	6.19

Size Class	Cell Number (#/L)	Biomass (mg/m^3)
0 - 2	8,852	0.34
2 - 10	20,792	4.94
10 - 20	12,764	27.62
20 - 40	995	2.78
40 - 64	0	0
>64	2,162	1.61