Chemistry of North Slope, Alaska, Lakes and Reservoirs: September 2005 to May 2007

Chad Cormack making a transect at lake L9817 to classify methane bubbles in the ice, photo by Michael Lilly.

by

Amanda Blackburn, Hannah Clilverd, Rinu Samuel, Kristie Holland, and Dan White

November 2007

North Slope Lakes Hydrologic Project
Report No. INE/WERC 07.13

Water and Environmental Research Center

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

Water and Environmental
Research Center

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By: Amanda Blackburn[2], Hannah Clilverd[1], Rinu Samuel[1], Kristie Holland[2], and Dan White[1]

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- U.S. Department of Energy
- National Energy Technology Laboratory
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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the accuracy of the data presented herein. This research was funded by the U.S. Department of Energy (DOE) and the National Energy Technology Laboratory (NETL). Funding and support was also provided by the Bureau of Land Management (BLM), BP Exploration (Alaska) Inc. (BPX), ConocoPhillips Alaska, Inc. (CPA), and Geo-Watersheds Scientific (GWS). The contents of the report do not necessarily reflect the views of policies of the DOE, NETL, BLM, BPX, CPA, GWS, or any local sponsor. This work does not constitute a standard, specification, or regulation.

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CONVERSION FACTORS, UNITS, WATER QUALITY UNITS, VERTICAL AND HORIZONTAL DATUM, ABBREVIATIONS AND SYMBOLS

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter (mm)
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
Acre	43560.0	square feet (ft^2)
Acre	0.405	hectare (ha)
square foot (ft^2)	3.587e-8	square mile (mi^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	3785.412	milliliter (mL)
cubic foot (ft^3)	28.317	liter (L)
Acre-ft	1233.482	cubic meter (m^3)
Acre-ft	325851.43	gallon(gal)
gallon(gal)	0.1337	cubic feet (ft^3)
	Velocity and Discharge	
foot per day (ft/d)	0.3048	meter per day (m/d)
Square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/sec)
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per day (ft/d)	0.00035	centimeter per second (cm/sec)
meter per day (m/d)	0.00116	centimeter per second (cm/sec)
	Hydraulic Gradient	
foot per foot (ft/ft)	5280	foot per mile (ft/mi)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Pressure	
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)

Units

For the purposes of this report, both English and Metric (SI) units were employed. The choice of "primary" units employed depended on common reporting standards for a particular property or parameter measured. Whenever possible, the approximate value in the "secondary" units was also provided in parentheses. Thus, for instance, stream flow was reported in cubic feet per second (cfs) followed by the value in cubic meters per second (m^3/s) in parentheses.

Physical and Chemical Water-Quality Units:

Temperature:

Water and air temperature is given in degrees Celsius (°C) and in degrees Fahrenheit (°F). Degrees Celsius can be converted to degrees Fahrenheit by use of the following equation:

$$°F = 1.8(°C) + 32$$

Electrical Conductance (Actual Conductivity and Specific Conductance):

In this report conductivity of water is expressed as Actual Conductivity [AC] in microSiemens per centimeter (µS/cm). This unit is equivalent to micromhos per centimeter. Elsewhere, conductivity is commonly expressed as Specific Conductance at 25°C [SC25] in µS/cm which is temperature corrected. To convert AC to SC25 the following equation can be used:

$$SC25 = \frac{AC}{1 + r(T - 25)}$$

where:

SC25 = Specific Conductance at $25^{o}C$, in µS/cm
AC = Actual Conductivity, in µS/cm
R = temperature correction coefficient for the sample, in ^{o}C
T = temperature of the sample, in ^{o}C

Milligrams per liter (mg/L) or micrograms per liter (μg/L):

Milligrams per liter is a unit of measurement indicating the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentrations in parts per million (ppm).

Millivolt (mV):

A unit of electromotive force equal to one thousandth of a volt.

Vertical Datum:

"Sea level" in the following report refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929), a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called *Sea Level Datum of 1929*.

Horizontal Datum:

The horizontal datum for all locations in this report is the North American Datum of 1983 or North American Datum of 1927.

Abbreviations, Acronyms, and Symbols

AC	actual conductivity
ADOT&PF	Alaska Department of Transportation and Public Facilities
ASTM	American Society for Testing and Materials
atm	atmospheres
BOD	biological oxygen demand
C	celsius
COD	chemical oxygen demand
DOC	dissolved organic carbon
DO	dissolved oxygen
DVM	digital voltage multi-meter
e-tape	electric tape
F	fahrenheit (^{o}F).
ft	feet
GWS	Geo-Watersheds Scientific
GWSI	USGS Ground-Water Site Inventory
km^2	square kilometers
kPa	kilopascal
lb/in^2	pounds per square inch
m	meters
mg/L	milligrams per liter, equivalent to ppm
µg/L	micrograms per liter
mi^2	square miles
mm	millimeters
µS/cm	microSiemens per centimeter
mV	millivolt
NGVD	National Geodetic Vertical Datum
NTU	Nephelometric Turbidity Units
NWIS	National Water Information System
ORP	oxygen-reduction potential
ppm	parts per million, equivalent to mg/L
QA	quality assurance
QC	quality control
SC25	specific conductance at 25^{o}C
SWE	snow water equivalent
TOC	total organic carbon
UAF	University of Alaska Fairbanks
USACE	U.S. Army Corps of Engineers, Alaska District
USGS	U.S. Geological Survey
WERC	Water and Environmental Research Center
WWW	World Wide Web
YSI	Yellow Springs Instruments

<u>Lake Nomenclature</u>

KDA	Kuparuk Dead Arm (Prudhoe Bay field, serves Prudhoe Bay field operations)
MSB	Mine Site B (Prudhoe Bay field, serves Milne Point and Kuparuk field operations)
L9312	Lake L9312 (Alpine field, serves Alpine field operations)
L9817	Lake L9817 (Alpine field, serves Alpine field operations)
K113	Lake K113 (Prudhoe Bay field, not currently used for field operations)

PROJECT COOPERATORS

The North Slope Lakes project covers a large area of the North Slope and benefits from a number of positive partnerships, all contributing to the overall project objectives.

- BP Exploration (Alaska) Inc.
- ConocoPhillips (Alaska)
- Bureau of Land Management
- Alaska Department of Natural Resources
- The Nature Conservancy
- Northern Alaska Environmental Center

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Chemistry of North Slope, Alaska, Lakes and Reservoirs: September 2005 to May 2007

INTRODUCTION

The University of Alaska Fairbanks (UAF) Water and Environmental Research Center (WERC) and Geo-Watersheds Scientific (GWS), together with project cooperators, initiated a study in the Fall of 2002 (Phase One) to obtain baseline information about the physical and chemical characteristics of North Slope tundra lakes. The project was extended in 2005 (Phase Two). The location of study lakes changed and was expanded to include reservoirs so as to further develop the understanding and simulation tools necessary for water-source management. K113 is an un-pumped lake in the Kuparuk oilfield and is sampled on selected field trips during the year. L9312 is a natural lake studied in the Alpine operations area. L9817 is a natural lake in eastern NPRA, west of Nuiqsut. This lake was used in previous years for ice-road construction, but was not used during winters 2005-06 or 2006-07. Two reservoir systems (mine sites) were added to the study in 2005. Mine Site B, also known as Six-Mile Lake, is located near the Milne Point facility at the intersection of the Spine Road with the Milne Point access road and has two cells connected to East Milne Creek. The Kuparuk Reservoir System (Kuparuk Dead Arm Reservoirs) has 8 reservoirs. The three southernmost reservoir cells (1-3) were included in the study to observe ground-water and surface-water interactions between each cell and the adjacent Kuparuk River.

Water-quality and hydrologic data was collected in the field during monthly visits to the lakes and water samples were collected from priority locations for further analysis at the UAF-WERC chemistry laboratories. The purpose of this publication is to report the laboratory chemistry data collected during the 2005 – 2006 and 2006 – 2007 winter seasons.

OBJECTIVES

The goal of each sampling trip was to collect physical and chemical data from each study lake. At each lake, a gasoline powered ice auger was used to drill holes for *in situ* analysis of DO, electrical conductance and pH, and collection of water samples. Not all lakes were sampled each month as logistical limitations prevented access to certain lakes on different months. L9817 and L9312 were accessed by helicopter or tracked vehicle, and the KDA reservoirs, Lake K113, and the MSB reservoirs were accessed by road. Project workplans were distributed before each trip outlining the sampling schedule. This report covers the following objectives:

1. Explanation of methods involved in collecting the samples:
   - Lake Location
   - Water sampling procedures
   - Sample storage/handling methods
2. Explanation of the analytical methods and instrumentation utilized:
   - Flame atomic absorption Spectrometry (Fe^{3+}, Ca^{2+}, Mg^{2+}, Fe^{2+}, Na^{+}, K^{+})
   - Spectrophotometry (chemical oxygen demand)
   - Ion chromatography (PO_4^{3-}, SO_4^{2-} , NO_3^{-}, Br^{-}, NO_2^{-}, Cl^{-}, F^{-}).
   - Total organic carbon analyzer (TOC, DOC)
   - Biological Oxygen Demand (BOD) (analyzed by Analytica International Inc, and Fairbanks laboratories)
3. Report laboratory data from the 2005 – 2006 and 2006 – 2007 winter seasons.
4. Examine the effects of lake type (i.e., natural thaw lake *vs* gravel-bottomed reservoir), and water extraction on the chemistry of lakes and reservoirs on the North Slope of Alaska.

PROCEDURES

Study site

We measured dissolved oxygen (DO) and solute concentrations in seven cold monomictic lakes on the North Slope of Alaska. The lake locations span from approximately 25 km west of the lower Kuparuk River (70° 14'N, 151° 20'W) to 25 km west of the Colville River (70° 19' N, 148° 56'W; Figure 1). Temperature extremes on the North Slope of Alaska range from approximately -48 ºC to +24 ºC. Average daily temperature at Prudhoe Bay ranges from -25 ºC in January to +5 ºC in July, with an average annual temperature of -12 ºC (National Weather Service, 2007). Continuous permafrost is present north of the Brooks Mountain Range (Miller and Whitehead, 1999), and as a consequence permafrost underlies all of the study locations.

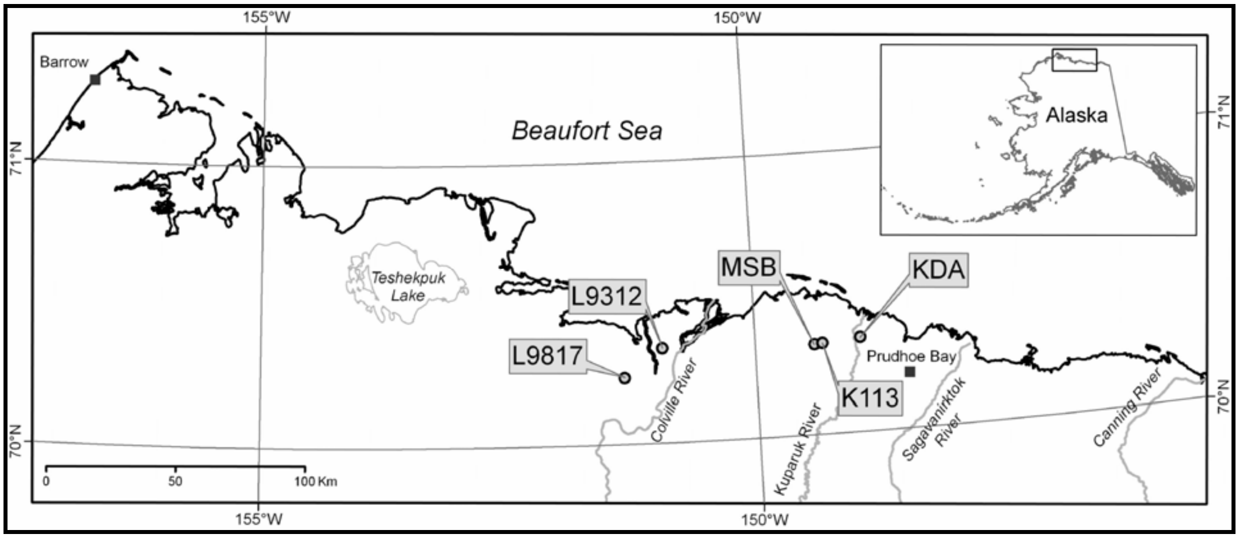

Figure 1. Location of study lakes (K113, L9817, L9312) and reservoirs (KDA, and MSB) in the oil-field operating areas on the North Slope, Alaska.

We studied three natural lakes (L9817, K113, and L9312) that were created by thaw or thermokarst processes, and four reservoirs (Kuparuk Deadarm Reservoirs, Cell 1 (KDA1), Cell 2 (KDA2), Cell 3(KDA3); Mine Site B, North Cell (MSBN), and South Cell (MSBS)) that are flooded gravel mine sites. This report will not discuss KDA3. Lakes L9817 and K113 are shallow (9.8 ft (3 m) and 7.5 ft (2.3 m), respectively; Table 1) thaw lakes, with an organic sediment layer. L9312 is a relatively large, medium-depth (11.5 ft (3.5 m); Table 1) natural lake that has a sandy substrate. KDA1 and KDA2 are medium depth reservoirs (21 ft (6.4 m) and 17 ft (5.2 m), respectively; Table 1), with gravel substrate that is typical of flooded gravel mines. MSBS and MSBN are deeper (25 ft (7.6 m) and 35.1 ft (10.7 m) respectively; Table 1) reservoirs, with a gravel substrate that have begun to fill-in with organic matter supplied from East Milne Creek. The Mine Site B (MSBN and MSBS) reservoirs are inter-connected by two channels that flow between the two cells during the summer and under the ice during most of the winter.

Table 1. Morphological information for the seven study lakes.

Lake	Lake description			
	Type	**Depth (m)**	**Area (m^2)**	**Water use**
K113	Thaw lake	2.3	165,900	Not pumped
L9817	Thaw lake	3.0	258,999	Not pumped[1]
L9312	Thaw lake	3.5	448,796	Pumped
KDA1	Flooded gravel mine	6.4	14,973	Not pumped
KDA2	Flooded gravel mine	5.2	27,519	Pumped
MSBS	Flooded gravel mine	7.6	22,912	Pumped
MSBN	Flooded gravel mine	10.7	13,355	Pumped

[1] – L9817 was pumped in 2004/05 and 2007/08 winters.

All of the study lakes and reservoirs are recharged in the spring by snowmelt; at lakes K113 and L9817 this is the primary source of recharge. Lake L9312 is also commonly recharged by overflow from the Colville River during spring snowmelt. The MSB reservoirs receive recharge from surrounding snowmelt runoff and from East Milne Creek, which flows during spring snowmelt and throughout the summer. The KDA reservoirs receive spring back-water flooding from the Kuparuk River, as well as recharge from surrounding watershed runoff. Since all of the lakes and reservoirs are in an area of continuous permafrost, they are not considered to have connections to ground-water systems outside their natural thaw bulbs.

Of the study lakes and reservoirs, one medium-depth reservoir (KDA1) and two shallow thaw lakes (L9817 and K113) were not pumped during the winters of 2005/06 and 2006/07, consequently they were used as controls for non-pumped conditions. Lake L9312 was pumped heavily throughout 2005 – 2007 for facility use at the Alpine Facility (Table 1). KDA2 and the

MSB reservoirs were also pumped during this period, for facility use, drilling operations and ice-road construction (Table 1).

Water chemistry sampling

All field work followed the specified health, safety, and environmental guidelines outlined by BPX and CPA (White and Lilly, 2007 *a*, *b*, *c*). Data in this report is from lake sampling each month over the winter from freeze-up (November) to break-up (May) for two years (2005 – 2007). Prior chemistry data for the project is reported in Hinzman and others, 2006. At each lake, we used a gasoline powered ice auger to drill holes approximately 16 cm in diameter. One hole at the center of each lake was drilled for *in situ* analysis of DO, electrical conductance, pH, oxygen reduction potential (ORP), turbidity and temperature, and collection of water samples. To address within lake variation of DO concentration within lakes, we drilled multiple holes at L9312 and L9817. We used an In Situ Troll model 9000 (submersible meter) to take measurements at 0.3 m intervals from the ice-water interface throughout the water column to the sediment-water interface. Before and after field sampling, the In Situ Troll 9000 multi-parameter meter was calibrated according to the criteria in Table 2.

Table 2. In-Situ Troll 9000 calibration quality control criteria.

Parameter	Standards used	Acceptable deviation from calibration standard value
Turbidity	Factory calibrated	± 2 (NTU)
pH	4.01, 7.0, 10.0	± 0.2
Conductivity	447 (µs/cm)	within 10%
100% DO	100 % saturated	within 10%
0% DO	0 % saturated solution	within 0.3 mg/L
ORP	InSitu QuickCal 224 mV	within 10%

Ice thickness, snow depth, freeboard (distance from ice-surface to water-surface in the drilled hole), and water depth at each hole were also measured at the time of sampling. Water samples were collected using a hand pump and Tygon tubing (6.4 mm ID). Before taking water samples, sample bottles were rinsed with lake water and tubing was purged to introduce fresh lake water. Water samples collected for analysis of dissolved organic carbon (DOC) and ferrous iron were passed through a 0.45 μm filter connected to the hand-pump. Samples were stored in a cooler until returned to the laboratory, preserved with acid, refrigerated, and then analyzed within 28 days.

Analytical techniques

We measured iron (Fe^{2+}, Fe^{3+}) concentrations in the field laboratory using FerroVer iron reagent and a HACH-DR/2010 portable data logging spectrophotometer. We analyzed cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) on an AAnalyst-300 flame atomic absorption spectrometer, and anions (Cl^{-}, NO_3^{-}, SO_4^{2-}), on a Dionex DX-500 ion chromatograph. Total organic carbon (TOC) and DOC were determined using an Apollo 9000 TOC analyzer. Biological oxygen demand (BOD) was measured by Analytica International Inc, Fairbanks laboratories using a 5-day BOD test.

Data analysis

The winter oxygen depletion rate (WODR) for the lakes and reservoirs were calculated by subtracting the total oxygen (sum of the average DO concentration at each 0.3 m sampling interval) in the lake in April from the total concentration in January. This period was chosen because most of the lakes were sampled in January and April.

The percent of under-ice water volume removed due to pumping was determined with measurements of ice thickness in April 2006 and 2007, assuming a pan bathymetry for the lakes and reservoirs (Chambers *et al.*, *2008*), and pumping data from B.P. Exploration and ConocoPhillips, Alaska.

Change in mean water-column chemistry over the winter was tested using one-way Analysis of Variance (ANOVA). If a significant difference was found ($p < 0.05$), we used a Tukey's test to determine which months were significantly different ($p < 0.05$).
Two-way ANOVA was used to determine temporal variations in lake chemistry for each lake.

SELECTED RESULTS

Spatial patterns in lake chemistry

Dissolved oxygen concentration was greatest at the ice-water interface in all lakes and declined with depth, with DO approaching zero in some lakes and reservoirs at the end-of-winter

(Figure 2a). All of the reservoirs and L9312 (located in delta deposits) had high DO levels throughout most of the water column at end of winter. Similar to oxygen, pH was highest at the top of the water column, and decreased substantially near the lake-bottom (Figure 2b). Electrical conductance was fairly stable throughout the water column, except at the lake-bottom where electrical conductance tended to increase abruptly (Figure 2c).

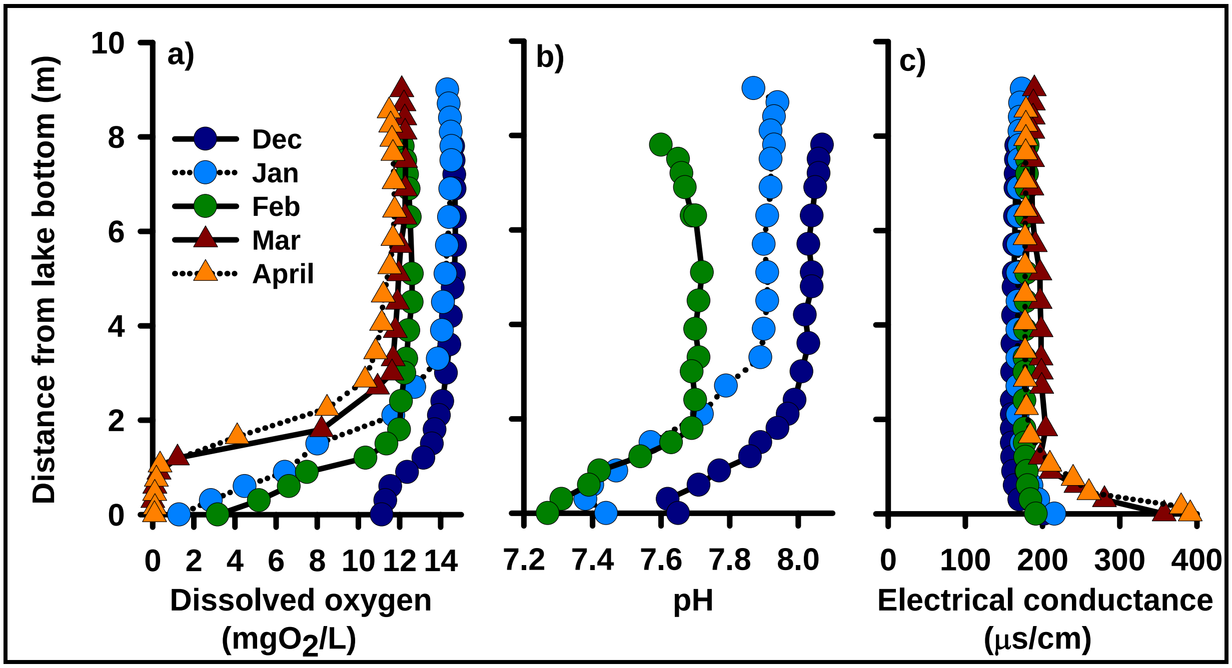

Figure 2. Examples of the decline in DO concentration (panel a) and pH (panel b), and the increase in electrical conductance (panel c) over time in an ice-covered lake (MSBN). In each chemistry profile, the highest data point from the lake bottom was taken directly beneath the ice.

Ferrous ion concentration was low throughout most of the water column, ranging from an average of 0.01 – 0.4 mg Fe^{2+}/L, but increased substantially at the bottom of the lakes with concentration on average between 5 – 17 mg Fe^{2+}/L (Figures 3a and 3b). Total organic carbon concentration in the lakes was largely composed of the dissolved fraction (< 0.1µm; Table 3). Dissolved organic carbon concentration ranged, on average, from 6 – 21 mg C/L among the lakes and reservoirs, and tended to be slightly higher near the bottom sediments ($p > 0.05$; Figures 3c and 3d).

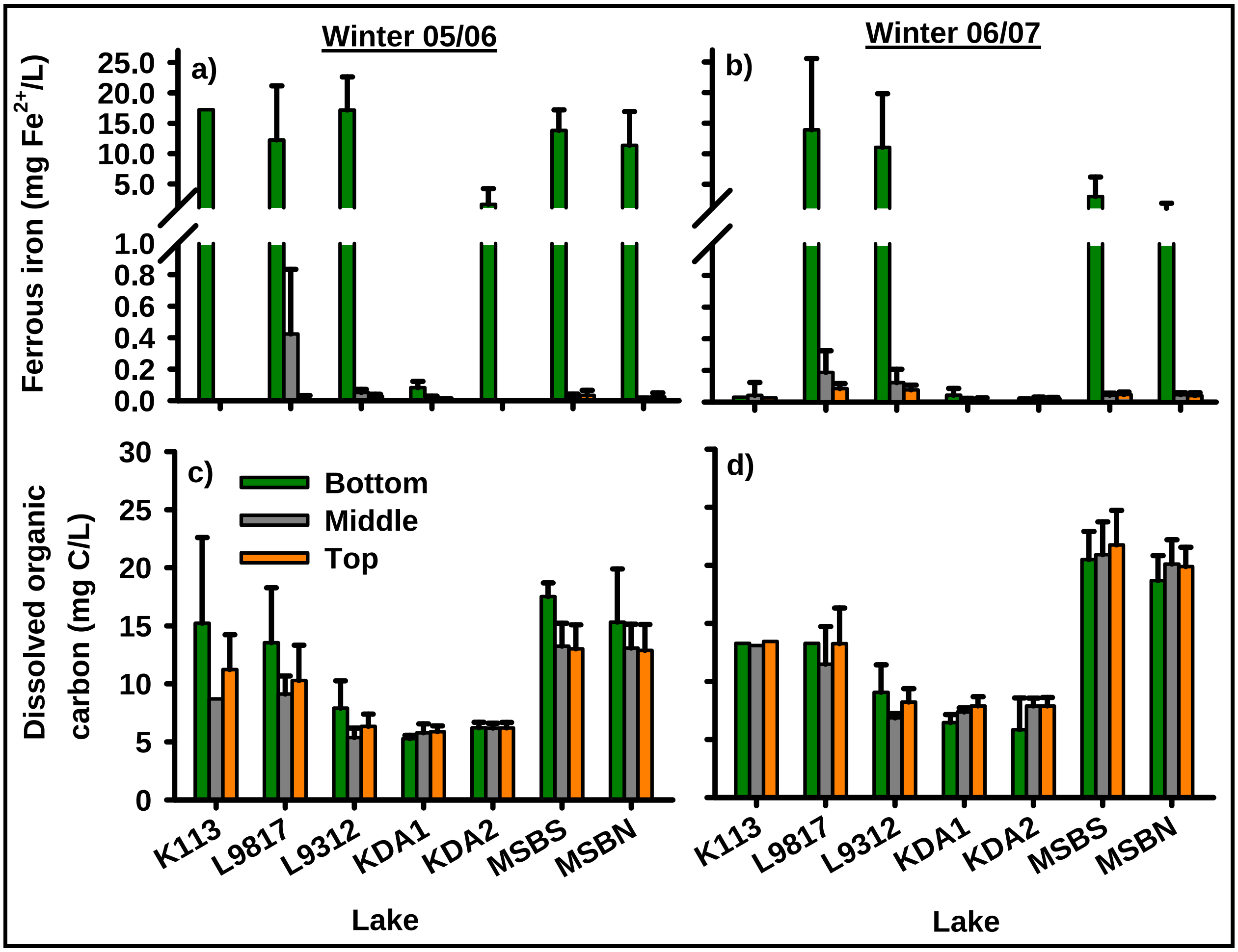

Figure 3. Mean (± 95% confidence interval) ferrous iron concentration for 2005/2006 (panel a) and 2006/2007 (panel b), and DOC concentration for 2005/2006 (panel c) and 2006/2007 (panel d), for each lake at three depths: bottom, middle and top.

Table 3. Chemistry of lakes on the North Slope of Alaska. Data were pooled from the top and middle of the water column over the 2005/2006 winter (mean ± 95% confidence interval).

	Lake						
	K113	**L9817**	**L9312**	**KDA1**	**KDA2**	**MSBS**	**MSBN**
TOC (mg/L)	11 ± 3	9.8 ± 1.2	6.0 ± 1.0	5.8 ± 0.4	6.4 ± 0.2	14 ± 1	13 ± 1
DOC (mg/L)	11 ± 3	9.6 ± 1.5	5.8 ± 0.7	5.8 ± 0.4	6.2 ± 0.3	13 ± 1	13 ± 2
COD (mg/L)	15 ± 1	9.8 ± 2.3	2.5 ± 2.5	6.3 ± 6.0	8.3 ± 4.7	31 ± 4	26 ± 7
Cl (mg/L)	31 ± 13	103 ± 21	9.4 ± 1.1	11 ± 1	11 ± 1	24 ± 1	23 ± 1
Ca (mg/L)	40 ± 9	49 ± 6	12 ± 2	37 ± 4	33 ± 2	36 ± 6	39 ± 2
Mg (mg/L)	4.4 ± 1.9	30 ± 17	9.7 ± 5.5	9.2 ± 7.4	8.5 ± 4.8	10 ± 6	11 ± 6
Na (mg/L)	8.1 ± 6.3	19 ± 7	5.3 ± 1.3	4.3 ± 1.8	5.1 ± 1.3	6.2 ± 1.4	6.4 ± 1.1
K (mg/L)	≤ 1	1.8 ± 0.4	≤ 1	≤ 1	≤ 1	≤ 1	≤ 1
Fe^{2+} (mg/L)	0.05 ± 0.04	≤ 0.02	0.07 ± 0.03	≤ 0.02	≤ 0.02	0.03 ± 0.01	0.03 ± 0.01
Fe^{3+} (mg/L)	0.22 ± 0.33	0.3 ± 0.16	0.06 ± 0.03	≤ 0.02	≤ 0.02	0.04 ± 0.02	0.04 ± 0.02

Changes in lake chemistry over the winter

Lakes and reservoirs were saturated with DO (12 – 14 mg O$_2$/L) in the autumn, but following ice-formation oxygen declined over the winter (Figure 2a). In contrast to oxygen, pH changed very little, on average 0.4 pH units over the winter (Figure 2b). Ferrous iron concentration at the lake-bottom tended to increase over the winter ($p < 0.05$). Electrical conductance increased significantly ($p < 0.05$) as ice thickness increased over the winter (Figure 2c). Despite a substantial increase in dissolved ions over the winter, however, DOC and TOC concentrations did not change temporally ($p < 0.05$; Figure 4).

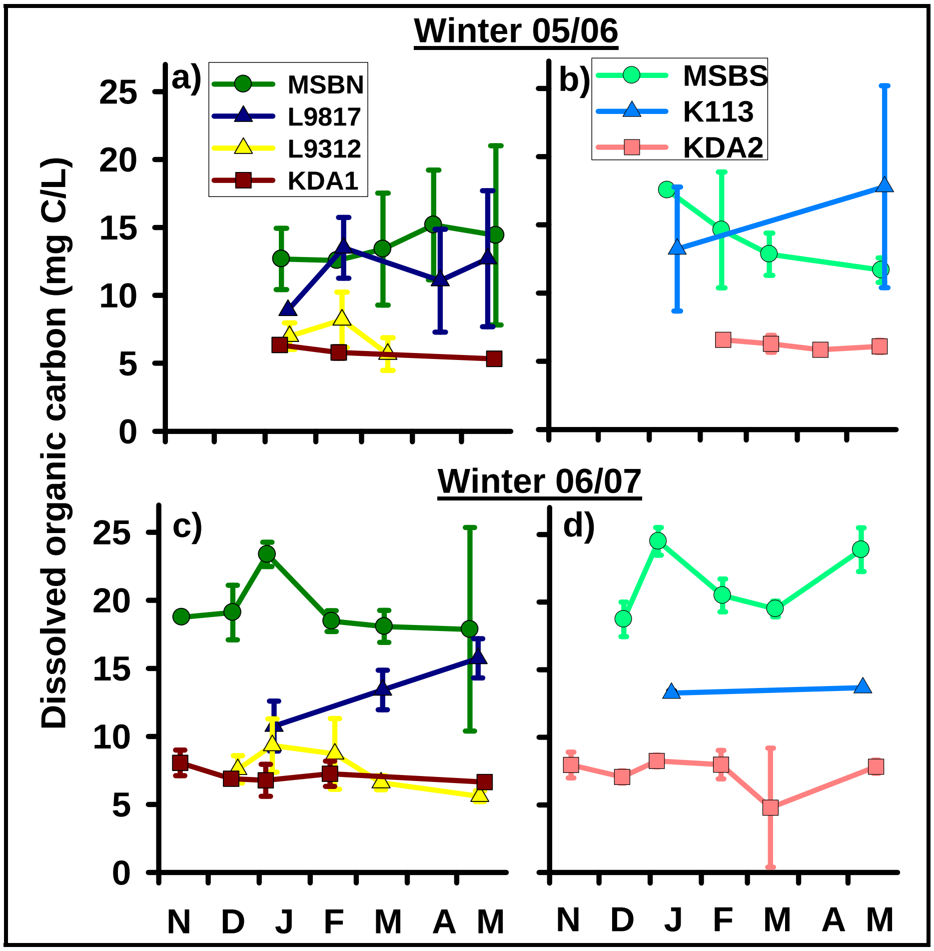

Figure 4. Temporal variation (November to May) in DOC concentration (mean ± 95% confidence interval) for winters 2005/2006 (panels a and b) and 2006/2007 (panels c and d) for each study lake.

Differences in chemistry among lakes

The concentration of DO at the end of the winter (April) was lowest in the shallowest lakes: K113 (depth ca. 0.9 m in April) and L9817 (depth ca.1.2 m in April), with < 4 mg O_2/L on average remaining in the water column (Table 4). Interestingly, DO concentration in L9312 was approximately three-fold greater than lakes K113 and L9812, averaging 10.9 mg O_2/L despite L9312 being only 0.5 – 0.8 m deeper (Table 1). KDA reservoirs (Cells 1 and 2) maintained very high DO levels throughout the winter, with DO concentration in April averaging 14.8 and 13.8 mg O_2/L, respectively (Table 4). MSBN and MSBS are the deepest of the study lakes (in April depths were ca. 7 and 9 m, respectively), and at the end of winter DO averaged 8.4 and 9.5 mg O_2/L, respectively (Table 4). Biological oxygen demand in the water column was below detection (< 3 mg O_2/L) in all lakes, indicating that sediment oxygen demand (SOD) accounts for the majority of oxygen consumption in the lakes.

Table 4. Mean (± 95% confidence interval) oxygen concentration, pH, and conductivity for the middle third of the water column. Measurements were taken at the end of winter (April unless noted otherwise; * data from May, ** Data from February) from study lakes on the North Slope of Alaska. Data were pooled from two winters (2005-2007).

Lake	Oxygen (mg/L)	pH	Conductivity (µs/cm)
K113	2.2 ± 1.4*	7.1 ± 0.3*	510 ± 84*
L9817	1.8 ± 1.8	6.6 ± 0.1	429 ± 282
L9312	10.9 ± 2.0	6.5 ± 0.1	90 ± 7
KDA1	14.8 ± 1.8	7.7 ± 0.1	149 ± 64
KDA2	13.8 ± 3.0	7.5 ± 0.1	140 ± 3
MSBS	8.4 ± 1.4	7.8 ± 0.2	215 ± 50
MSBN	9.5 ± 0.9	7.6 ± 0.1**	216 ± 23

Despite the large difference in DO among lakes and reservoirs, ferrous iron concentration was fairly similar among the study sites ($p > 0.05$; Table 4; Figure 3a and 3b), except for the KDA reservoirs where ferrous iron concentration was on average 0.5 mg Fe^{2+}/L, approximately 22-fold lower than the other lakes and reservoirs (Figure 3a and 3b). Differences in DOC concentration among lakes and reservoirs followed an opposite pattern to DO. Lakes K113 and L9817 had low oxygen but high DOC concentration (11 ± 3 and 9.6 ± 1.5 mg C/L, respectively; Table 3; Figure 4). Lakes L9312, and KDA (Cells 1 and 2) maintained high oxygen levels through the winter, but had low DOC concentration (5.8 ± 0.7, 5.8 ± 0.4, and 6.2 ± 0.3 mg C/L, respectively) (Table 3; Figure 3c and 3d). Dissolved organic carbon concentration was greatest at the MSB reservoirs, averaging 13 mg C/L (Table 3; Figure 3c and 3d). The MSB reservoirs, however, maintained relatively high DO concentration, suggesting an interaction between lake depth, oxygen and DOC.

In the study lakes, cation concentrations predominately followed the pattern of Ca>Mg>Na>K (Table 3). Electrical conductance varied significantly among the lakes and reservoirs, and was highest in the shallowest lakes (L9817 and K113) averaging 429 and 510 µs/cm, respectively ($p < 0.05$; Table 4). In general, the reservoirs (KDA and MSB) had lower dissolved ion concentrations and electrical conductance than the shallower, thaw lakes (Tables 3 and 4). An exception to this was Lake L9312, which had substantially lower electrical conductance (90 ± 7 µs/cm; Table 4), and at least two-fold lower calcium concentration (12 ± 2 mg Ca/L; Table 3) compared with the gravel-bottomed reservoirs.

Change in lake chemistry between winters

Dissolved oxygen concentration was markedly different between years in all of the lakes and reservoirs sampled, with approximately 1 – 4 mg O_2/L less DO measured in 2006 – 2007 winter than the previous winter ($p < 0.05$; Figure 5).

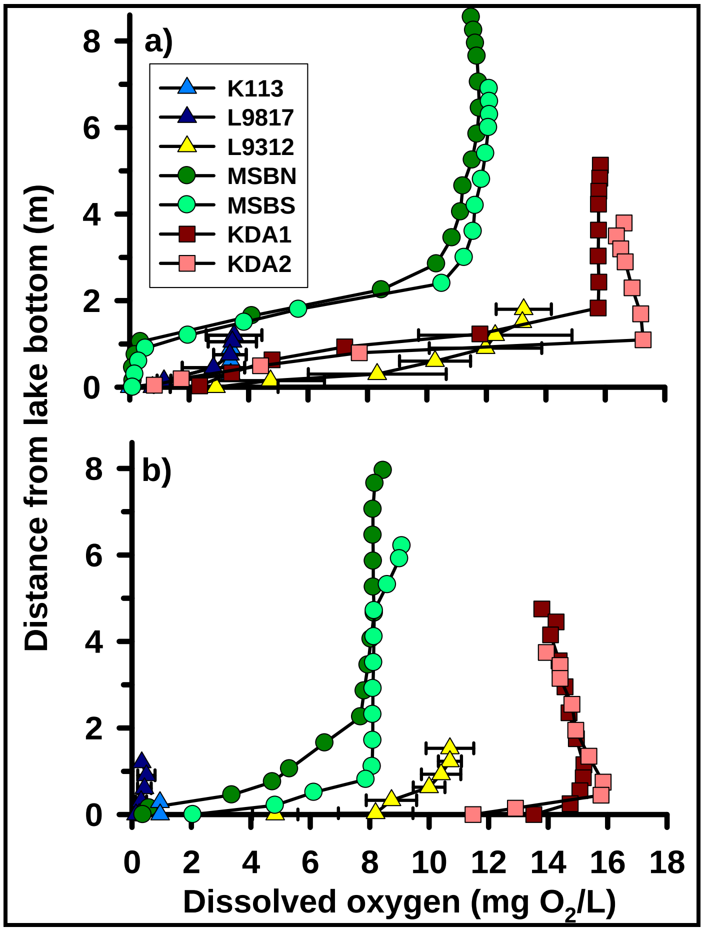

Figure 5. Dissolved oxygen concentration at the end of winter (April) for 2006 (panel a) and 2007 (panel b). In each lake the highest data point from the lake bottom was taken directly beneath the ice. For lakes L9312 and L9817, where multiple locations within each lake were sampled, DO concentration = mean ± 95% confidence interval.

Lower DO concentration in 2006/2007 was not, however, due to differences in winter water-column depletion rate throughout the winter or between years (Table 5). Instead, lower DO concentration in 2006/2007 occurred early in the winter (December or earlier) and persisted throughout (Figures 5 and 6). The shallow lakes, K113 and L9817, had particularly low oxygen in 2007 with < 1 mg O_2/L remaining in the water column from March onwards. In addition to the differences in mean DO concentration, oxygen profiles within the lakes and reservoirs also differed between years. An anoxic hypolimnion developed in the deeper reservoirs (KDA and MSB (up to 1.5 m)) at the end of the winter in 2006, whereas in 2007 DO concentration was comparatively uniform throughout the water column, only stratifying at the lake-bottom (Figure 6).

Table 5. Winter oxygen depletion rate (WODR) for two winters (2005/2006 and 2006/2007). As all of the lakes could not be sampled every month, WODR was calculated for the period January – April, when most lakes were sampled. *Data from December – April.

Lake	Winter oxygen depletion rate ($g O_2/m^2/d$)	
	2005/2006	2006/2007
K113	0.08	0.08
L9817	0.12	0.11
L9312	0.17	0.13
KDA1	0.14	0.04
KDA2	-0.03*	0.13
MSBN	0.38	0.32
MSBS	0.31	0.17

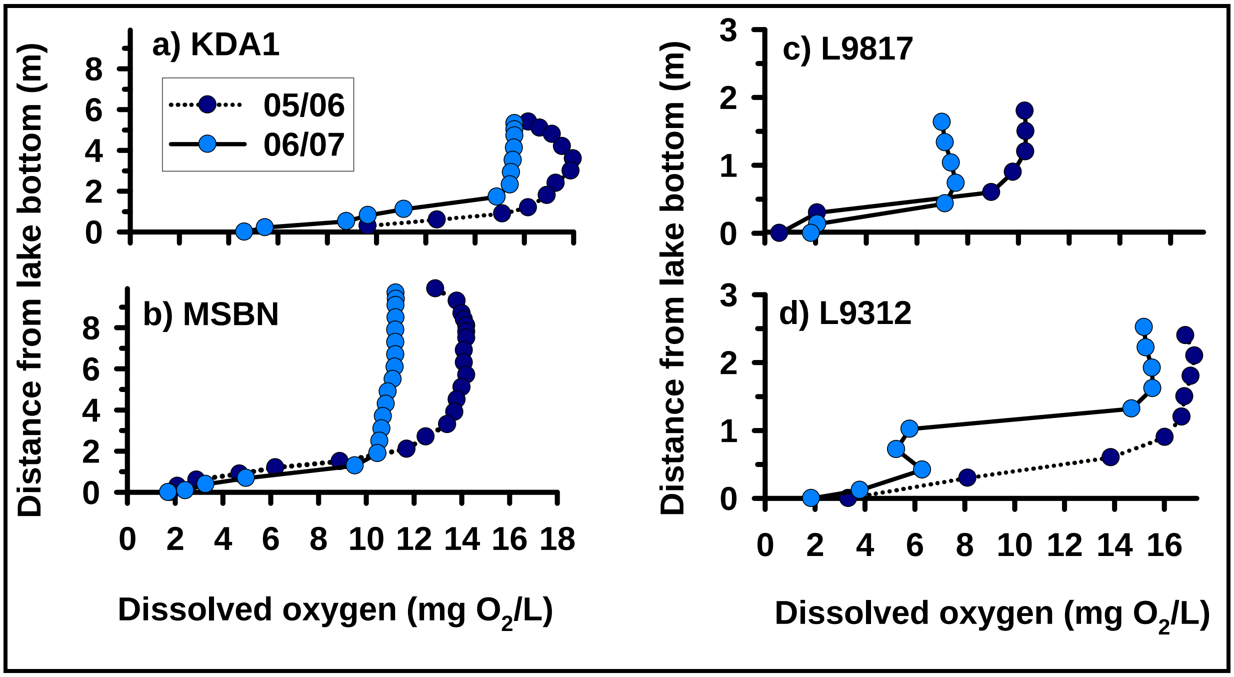

Figure 6. Examples of the difference in DO profiles in early winter for two years (2005/2006 and 2006/2007) for both pumped and non pumped lakes. KDA1 (non pumped lake; panal a) and MSBN (pumped lake; panel b) data are from December. L9317 (non pumped lake; panel c) and L9312 (pumped lake; panel d) data are from January. In each lake the highest data point from the lake-bottom was taken directly beneath the ice.

In contrast to DO, ferrous iron concentration (iron was below detection in the top and middle portion of the lakes) did not change significantly between years at L9817, L9312, and KDA1 ($p > 0.05$) (Figures 3a and 3b). Ferrous iron concentration was, however, substantially lower in 2006/2007 at K113, KDA2, and MSBN ($p < 0.05$; Figures 3a and 3b). In 2006/2007 winter, DOC concentration was slightly higher (ca. 1.5 mg C/L; $p < 0.05$) at the KDA reservoirs, and substantially higher (ca. 7 mg C/L; $p < 0.05$) at the MSB reservoirs (Figures 3c, 3d and 4). No significant difference was found in DOC between years at K113, L9817, or L9312 ($p > 0.05$; Figures 3c, 3d and 4).

Water extraction and ice thickness of North Slope Lakes

Lake L9312 was the most heavily pumped lake, with 13.6M gal (51,395 m^3) (5.6% under-ice volume) removed during 2005/2006 winter and 11.5M gal (43,545 m^3) (5% under-ice volume) removed during 2006/2007 winter (Table 6; Figure 7). At KDA2, 7.3M gal (27,367 m^3) was pumped in 2005/2006 and 6.8M gal (25,781 m^3) in 2006/2007, accounting for > 26% of the under-ice volume; a considerably larger proportion of lake-volume compared with the other pumped lakes (Table 6). MSBN was pumped at similar levels throughout both winters, with approximately 14% of under-ice volume removed (3.9M gal (14,820 m^3) in 2005/2006; 4.2M gal (15,968 m^3) in 2006 – 2007; Table 6; Figure 7).

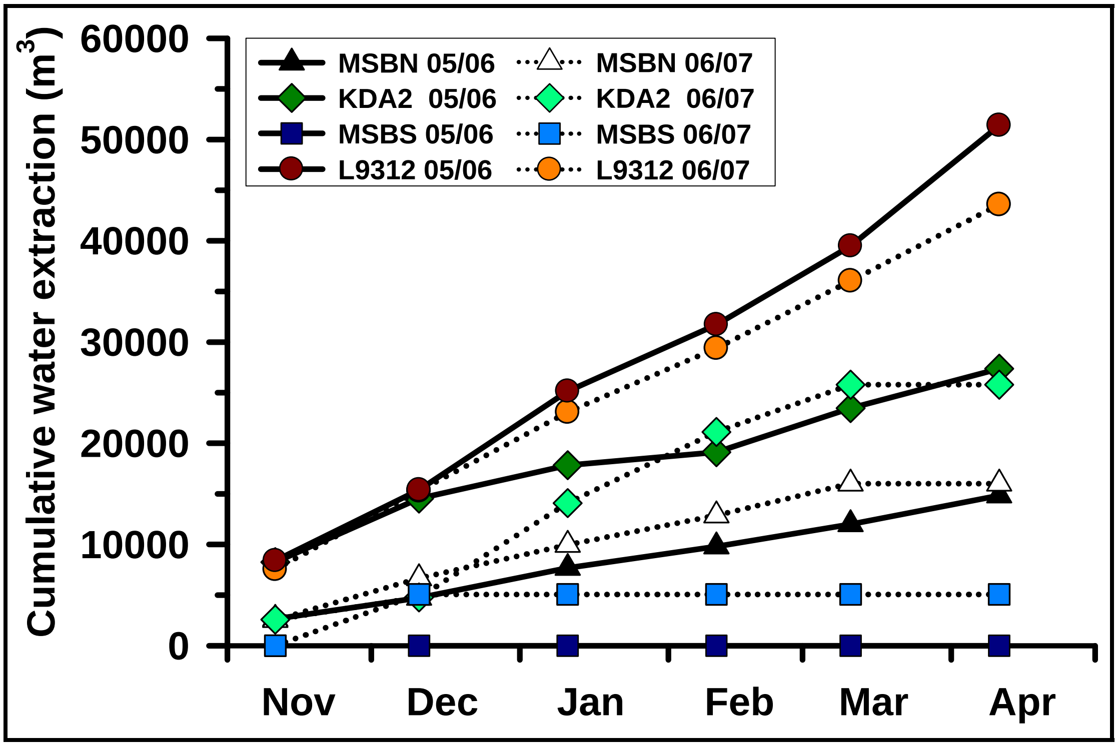

Figure 7. Comparisons of water-volume extracted from the study lakes during two winters (2005/2006 and 2006/2007).

Table 6. Cumulative water use from November 15th to April 15th for 2005/2006 and 2006/2007.

Lake	Cumulative water extraction volume (m^3), and percent under-ice volume removed. 2005/2006	2006/2007
L9312	51,395 (5.35%)	43,545 (5.1%)
KDA2	27,367 (25.6%)	25,781 (25.9%)
MSBN	14,820 (11.8%)	15,968 (12.9%)
MSBS	0	5,072 (3.7%)

Ice thickness, in all lakes and reservoirs, was noticeably greater at the end of winter (March – April) in 2007 (Figure 8), with 0.6 – 1.3 ft (0.2 – 0.4 m) difference between years. Although such differences in ice thickness are not likely to influence the chemistry of deeper lakes and reservoirs, a 1.4 ft (0.4 m) increase in ice thickness in shallower water bodies can substantially decrease the under-ice lake volume. For example, at L9817 greater ice-thickness in 2007 decreased the under-ice volume by 24% compared with the previous year.

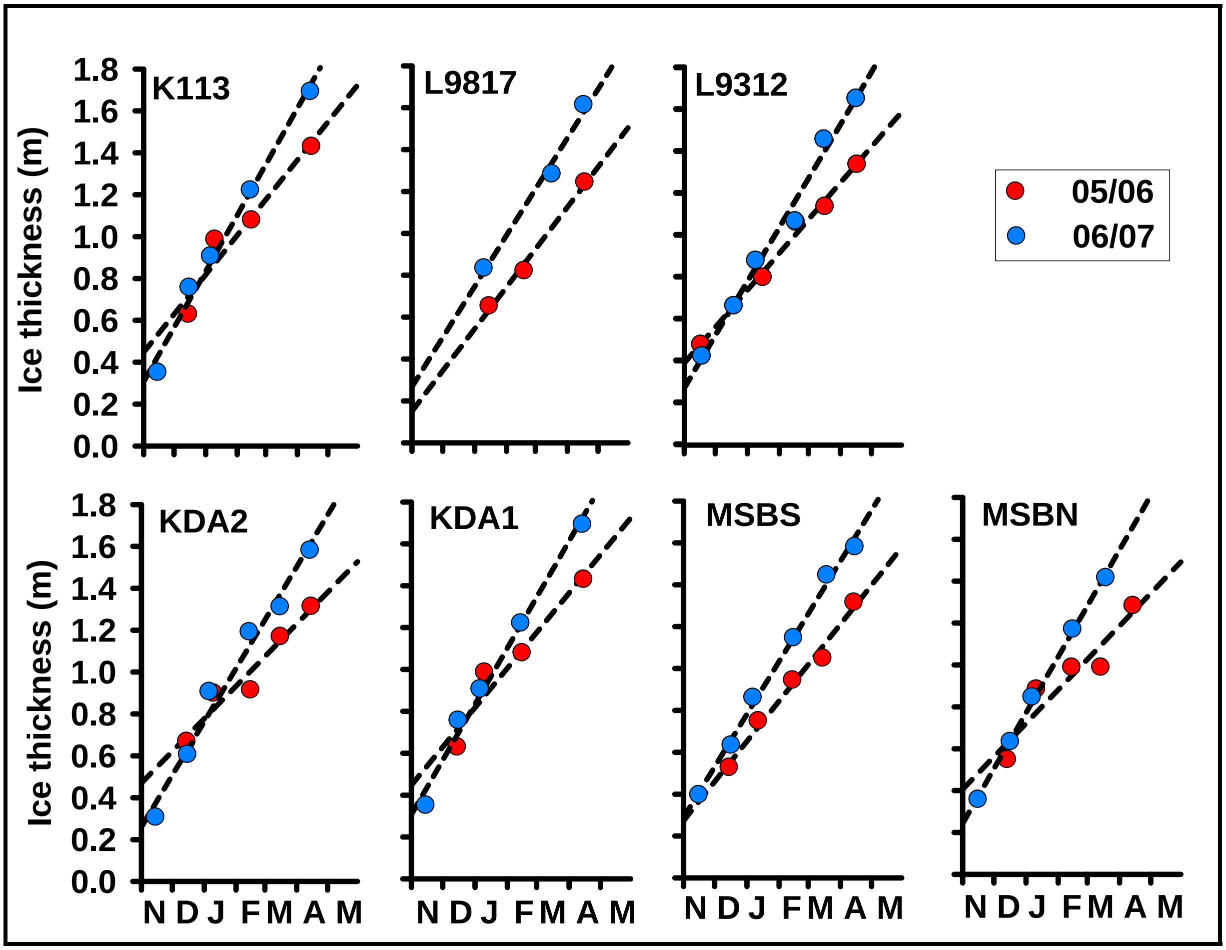

Figure 8. Comparisons of ice thickness over two winters (November – May 2005/2006 and 2006/2007) at Lake K113 (panel a), Lake L9817 (panel b), Lake L9312 (panel c), KDA2 (panel d), KDA1 (panel e), MSBS (panel f), and MSBN (panel g).

SUMMARY

Dissolved oxygen concentration decreased with depth, and temporally through the winter in all seven arctic lakes and reservoirs studied. However, the degree of oxygen depletion over the winter was influenced by differences in physical and chemical characteristics among the lakes and reservoirs. Differences in water-use practices among lakes and reservoirs caused little to no change in DO concentration over the winter. Both depth and DOC concentration appear to be key factors that control winter DO depletion rate, with lake and reservoir depth influencing the initial volume of oxygen that is available for lake-biota over the winter, and DOC concentration in the sediments fueling consumption-rates of oxygen. Our results suggest that shallow lakes with high DOC concentration (e.g., L9817 and K113) are particularly susceptible to low-oxygen conditions (< 5 mg O_2/L) developing over the winter, whereas lakes ≥ 3.5 m in depth with low DOC concentration (e.g., KDA) are best suited for water-use sources that also serve as over-wintering fish habitat for sensitive fish species. It is likely that there are further lake types that were not sampled during this study, for instance medium depth lakes with high DOC. Studying the effect of high DOC on oxygen consumption in these lakes is of high importance for water-extraction practices and fish survival. Capturing variability in DO concentration among years will also be important for the accurate prediction of lake-oxygen at the end of winter.

REFERENCES

Chambers, M.K., D.M. White, M.R. Lilly, L.D. Hinzman, K.M. Hilton, and R.C. Busey, 2008**.** Exploratory Analysis of the Winter Chemistry of Five Lakes on the North Slope of Alaska. *Journal of the American Water Resources Association.*

Hinzman, L.D., M.R. Lilly, D.L. Kane, D.D. Miller, B.K. Galloway, K.M. Hilton, and D.M. White. 2006. Physical and Chemical Implications of Mid-Winter Pumping of Tundra Lakes – North Slope, Alaska. December 2006, University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 06.15, Fairbanks, Alaska, 152 pp. plus appendices.

Miller, J.A., and Whitehead, R.L. 1999. Ground Water Atlas of the United States: Alaska, Hawaii, Puerto Rico and the U.S Virgin Islands. HA 730 N. U.S Geological Survey (USGS). http://capp.water.usgs.gov/gwa.html., *accessed* June 2007.

National Weather Service, 2007. Alaska Climate. National Oceanic and Atmospheric Administration (NOAA). http://pabr.arh.noaa.gov/climate.php, *accessed* June 2007.

White, D.M., and Lilly, M.R. 2007*a*. BPX: Health, Safety, and Environmental Interface Document. Water and Environmental Research Center, University of Alaska Fairbanks. 4 pages.

White, D.M., and Lilly, M.R. 2007*b*. BPX: Health, Safety, and Environmental Plan. Water and Environmental Research Center, University of Alaska Fairbanks. 6 pages.

White, D.M., and Lilly, M.R. 2007*c*. ConocoPhillips Alaska, Inc.: Health, Safety, and Environmental Plan. Water and Environmental Research Center, University of Alaska Fairbanks. 5 pages

APPENDIX A. CHEMISTRY RESULTS

The following forms report the data from the UAF/WERC Laboratory from samples collected in the field.

North Slope Lakes Project: 2006/2007 Laboratory Chemistry Analysis

ND, No detection; SNV, Site not visited; HT, Holding Time Expired for sample
NIC, No IC testing; NR, Test Not Run; UR, under range

Location/Depth	Sample Depth (ft.)	Date	Nitrate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	TOC (mg/L)	DOC (mg/L)	COD (mg/L)	Fe (Mg/L)	Na (Mg/L)
K113										
Top	3	1/14/2007	ND	45.56	0.060	13.32	13.44	33	0.260	5.65
Mid	5	1/14/2007	ND	44.41	UR	13.13	13.09	24.30	0.470	5.83
Bottom	6	1/14/2007	ND	44.03	0.030	13.17	13.28	23.70	1.13	2.80
Alpine										
	n/a	11/15/2006	3.71	7.43	1.58	6.97	8.23	NR	NR	NR
Big Lake										
Top	2	1/14/2007	3.71	92.40	1.53	10.92	NR	30.30	0.530	40.80
Mid	7	1/14/2007	3.70	173.08	3.02	15.79	NR	33	0.650	18.88
Kuparuk Deadarm Cell 1 January TOC and DOC data has been adjusted for lab calibration error										
Top	2	11/14/2006	ND	11.14	1.17	8.15	8.96	NR	NR	NR
Mid	10.5	11/14/2006	ND	10.80	1.08	7.76	7.89	NR	NR	NR
Bottom	20	11/14/2006	3.71	10.49	1.25	8	7.33	NR	NR	NR
Top	3	12/19/2006	ND	12.12	1.26	7.24	7.35	NR	NR	NR
Mid	10	12/19/2006	ND	11.71	1.13	7.35	7.23	NR	NR	NR
Bottom	20	12/19/2006	3.71	10.84	1.04	6.85	6.62	NR	NR	NR
Top	2	1/14/2007	ND	12.85	ND	8.08		15	0.400	8.93
Mid	10	1/14/2007	ND	ND	ND	8.12		16.3	0.460	7.63
Bottom	20	1/14/2007	3.72	11.54	1.13	6.69		15	0.230	7.63
Kuparuk Deadarm Cell 2 January TOC and DOC data has been adjusted for lab calibration error										
Top	2	11/14/2006	ND	11.78	0.865	8.30	8.92	NR	NR	NR
Mid	10	11/14/2006	ND	11.37	0.802	7.92	7.50	NR	NR	NR
Bottom	19.5	11/14/2006	3.71	13.37	1.31	8.25	7.43	NR	NR	NR
Top	2.5	12/19/2006	NR	NR	NR	6.80	7.09	NR	NR	NR
Mid	9	12/19/2006	NR	NR	NR	7.99	7.08	NR	NR	NR
Bottom	19	12/19/2006	NR	NR	NR	6.87	6.50	NR	NR	NR
Top	3	1/14/2007	ND	13.55	1.01	10.79	8.64	77.3	0.400	9.15
Mid	9	1/14/2007	ND	13.28	0.933	8.07	9.21	30.70	0.450	8.78
Bottom	19	1/14/2007	3.71	16.23		8.33	8.54	14.70	0.290	7.85
L9312										
Top	2	11/14/2006	NR	NR	NR	7.22	10.09	NR	NR	NR
Mid	7.5	11/14/2006	NR	NR	NR	NR	NR	NR	NR	NR
Bottom	11	11/14/2006	NR	NR	NR	8.53	8.23	NR	NR	NR
Top	3	12/19/2006	3.69	9.48	2.15	NR	NR	NR	NR	NR
Mid	6	12/19/2006	NR	NR	NR	NR	NR	NR	NR	NR
Bottom	11	12/19/2006	3.70	7.88	0.84	NR	NR	NR	NR	NR
Top	3	1/14/2007	3.70	10.22	2.23	7.16	9.82	12.00	0.330	1.22

North Slope Lakes Project: 2006/2007 Laboratory Chemistry Analysis
ND, No detection; SNV, Site not visited; HT, Holding Time Expired for sample
NIC, No IC testing; NR, Test Not Run; UR, under range

Location/Depth	Sample Depth (ft.)	Date	Nitrate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	TOC (mg/L)	DOC (mg/L)	COD (mg/L)	Fe (Mg/L)	Na (Mg/L)
Mine Site B South Cell January TOC and DOC data has been adjusted for lab calibration error										
Top	2	11/14/2006	ND	33.31	ND	NR	22.15	NR	NR	NR
Mid	18.5	11/14/2006	ND	33.17	UR	NR	NR	NR	NR	NR
Bottom	28	11/14/2006	3.71	40.26	UR	NR	NR	NR	NR	NR
Top	3	12/19/2006	ND	35.98	0.104	17.99	8.05	NR	NR	NR
Mid	18	12/19/2006	ND	36.04	UR	19.22	19.38	NR	NR	NR
Bottom	27.5	12/19/2006	ND	44.58	UR	19.54	18.08	NR	NR	NR
Top	3	1/14/2007	ND	38.05	UR	22.31	[redacted]	49.70	0.390	14.18
Mid	17	1/14/2007	ND	36.73	UR	24.13	[redacted]	49.30	0.570	14.18
Bottom	27	1/14/2007	ND	43.68	ND	[redacted]	[redacted]	48.70	2.95	15.55
Mine Site B North Cell January TOC and DOC data has been adjusted for lab calibration error										
Top	2	11/14/2006	ND	31.73	ND	18.47	18.78	NR	NR	NR
Mid	25	11/14/2006	ND	31.84	ND	NR	18.69	NR	NR	NR
Bottom	34.5	11/14/2006	3.72	39.84	UR	18.35	18.81	NR	NR	NR
Top	2	12/19/2006	ND	34.52	UR	8.17	20.34	NR	NR	NR
Mid	24	12/19/2006	ND	33.51	UR	6.34	19.89	NR	NR	NR
Bottom	34	12/19/2006	3.75	50.33	ND	8.16	17.08	NR	NR	NR
Top	3	1/14/2007	UR	35.51	UR	23.35	[redacted]	44.30	0.460	13.63
Mid	24	1/14/2007	3.69	34.35	UR	22.56	[redacted]	46.00	0.560	13.63
Bottom	33.5	1/14/2007	UR	58.20	0.065	22.31	[redacted]	44.70	2.95	15.68
L9817										
Top	3	1/14/2007	3.73	151.42	0.040	11.50	9.82	11.30	0.410	4.46
Mid	5	1/14/2007	3.73	149.58	0.040	12.32	7.41	9.82	0.320	25.03
Bottom	8	1/14/2007	ND	148.02	UR	12.06	10.77	20.30	5.30	11.70

All highlighted areas are over +/- 10% for accuracy

North Slope Lakes Project: 2007 Laboratory Chemistry Analysis
ND, No detection; SNV, Site not visited; HT, Holding Time Expired for sample
NIC, No IC testing; NR, Test Not Run; UR, under range

Location/Depth	Sample Depth (ft.)	Date	Nitrate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	TOC (mg/L)	DOC (mg/L)	COD (mg/L)	Fe (Mg/L)	Na (Mg/L)
K113 May TOC and DOC data has been adjusted for lab calibration error										
Top	6.5	5/10/2007	0.120	9.49	0.860	[redacted]	[redacted]	63	NR	NR
Alpine										
	n/a	2/13/2007	0.096	9.84	2.10	7.40	NR	15	0.385	5.60
Kuparuk Deadarm Cell 1 April and May TOC and DOC data has been adjusted for lab calibration error										
Top	4	2/13/2007	UR	13.52	1.12	6.70	8.02	1.00	0.390	5.4
Mid	10	2/13/2007	UR	13.31	1.38	6.33	7.35	7.67	0.252	1.3
Bottom	20	2/13/2007	UR	11.95	1.13	6.46	6.98	44	1.08	5.88
Top	5	4/13/2007	0.180	14.09	2.14	[redacted]	[redacted]	37.33	0.042	0.750
Mid	10	4/13/2007	0.190	14.21	2.26	[redacted]	[redacted]	41.67	0.050	0.360
Bottom	20	4/13/2007	0.190	15.05	2.54	[redacted]	[redacted]	31.33	0.010	0.880
Top	6	5/8/2007	0.110	14.51	2.01	[redacted]	[redacted]	6.70	NR	NR
Mid	12	5/8/2007	0.110	14.45	2.00	[redacted]	[redacted]	4.00	NR	NR
Bottom	20	5/8/2007	0.110	14.76	1.98	[redacted]	[redacted]	7.70	NR	NR
Kuparuk Deadarm Cell 2 April and May TOC and DOC data has been adjusted for lab calibration error										
Top	4	2/13/2007	1.36	14.34	ND	8.9	8.11	9.00	0.200	6.15
Mid	8	2/13/2007	1.44	14.10	UR	7.32	8.83	4.30	0.530	5.55
Bottom	18	2/13/2007	1.4	13.17	UR	6.33	6.98	1.30	0.190	5.33
Top	5	3/15/2007	0.180	13.55	2.04	7.26	6.81	16.67	0.200	1.40
Mid	11	3/15/2007	0.180	13.28	1.96	8.01	7.26	24.33	0.260	1.33
Bottom	16	3/15/2007	0.240	16.23	1.84	6.25	0.32	21.33	0.040	1.07
Top	5	4/13/2007	0.210	16.54	2.09	[redacted]	[redacted]	38.30	0.220	0.74
Mid	9	4/13/2007	0.190	15.80	2.07	[redacted]	[redacted]	38.70	0.120	0.900
Bottom	16.5	4/13/2007	0.190	15.21	1.89	[redacted]	[redacted]	40.00	0.100	0.64
Top	6	5/8/2007	0.110	16.35	1.86	[redacted]	[redacted]	5.70	NR	NR
Mid	10	5/8/2007	0.120	16.08	1.76	[redacted]	[redacted]	9.30	NR	NR
Bottom	16.5	5/8/2007	0.110	15.36	1.83	[redacted]	[redacted]	9.50	NR	NR
L9312 April TOC and DOC data has been adjusted for lab calibration error										
Top	4	2/16/2007	2.43	11.38	0.030	7.04	8.07	14.30	0.270	5.73
Middle	6	2/16/2007	2.21	10.63	0.010	7.12	6.81	12.30	0.430	5.48
Bottom	11	2/16/2007	ND	7.75	ND	10.78	11.26	31.7	ND	3.88
Top	5	3/16/2007	0.240	10.22	3.48	7.06	7.00	15.67	0.380	1.60
Middle	7	3/16/2007	0.280	7.71	3.23	6.79	6.70	20.67	0.330	1.49
Bottom	11	3/16/2007	0.210	10.22	1.84	6.91	6.10	16.33	2.25	1.13
Top	6	4/16/2007	0.280	13.16	3.51	[redacted]	[redacted]	42.30	0.300	0.78
Mid	9	4/16/2007	0.290	14.68	3.76	[redacted]	[redacted]	41.30	0.650	1.09
Bottom	11	4/16/2007	0.190	13.8	2.53	[redacted]	[redacted]	29.50	1.43	0.380
Top	6	5/13/2007	0.200	13.20	3.60	6.10	6.00	16.30	2.47	0.96
Mid	9	5/13/2007	0.200	14.10	3.40	6.00	5.40	16.70	0.280	1.04
Bottom	10.5	5/13/2007	0.200	13.20	2.80	5.60	5.40	16.70	0.010	0.390

All highlighted areas are over +/- 10% for accuracy

North Slope Lakes Project: 2007 Laboratory Chemistry Analysis
ND, No detection; SNV, Site not visited; HT, Holding Time Expired for sample
NIC, No IC testing; NR, Test Not Run; UR, under range

Mine Site B South Cell April and May TOC and DOC data has been adjusted for lab calibration error

Location/Depth	Sample Depth (ft.)	Date	Nitrate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	TOC (mg/L)	DOC (mg/L)	COD (mg/L)	Fe (Mg/L)	Na (Mg/L)
Top	4	2/14/2007	UR	39.06	UR	19.59	20.61	41.30	0.350	10.18
Mid	17	2/14/2007	UR	38.30	UR	18.57	19.36	41.00	0.220	10.15
Bottom	27	2/14/2007	ND	64.32	ND	21.85	21.49	54.30	5.54	15.10
Top	5	3/18/2007	0.200	38.05	0.800	19.18	19.92	60.33	0.270	2.33
Mid	16	3/18/2007	0.210	36.73	0.780	19.52	19.64	56.33	0.400	2.24
Bottom	26	3/18/2007	0.210	43.68	0.780	18.14	18.92	55.00	0.460	2.21
Top	6	4/14/2007	0.180	44.11	0.820	[illegible]	[illegible]	82.70	0.010	0.580
Mid	16	4/14/2007	0.190	43.36	0.770	[illegible]	[illegible]	84.70	0.020	0.530
Bottom	26	4/14/2007	0.180	47.71	0.690	[illegible]	[illegible]	85.00	0.990	0.640
Top	6	5/9/2007	ND	3.63	0.570	[illegible]	[illegible]	61.00	NR	NR
Mid	16	5/9/2007	ND	3.52	0.520	[illegible]	[illegible]	50.00	NR	NR
Bottom	26	5/9/2007	0.150	4.54	0.430	[illegible]	[illegible]	53.30	NR	NR

Mine Site B North Cell April and May TOC and DOC data has been adjusted for lab calibration error

Location/Depth	Sample Depth (ft.)	Date	Nitrate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	TOC (mg/L)	DOC (mg/L)	COD (mg/L)	Fe (Mg/L)	Na (Mg/L)
Top	4	2/14/2007	0.340	36.15	UR	19.71	19.08	37.70	0.450	10.08
Mid	23	2/14/2007	UR	35.11	UR	18.66	18.57	45.70	0.450	9.83
Bottom	33	2/14/2007	ND	64.79	ND	17.69	17.75	51.70	4.06	5.85
Top	5	3/18/2007	0.190	35.51	0.760	19.11	18.22	69.67	0.390	2.18
Mid	18	3/18/2007	0.200	34.35	0.780	18.49	19.04	56.00	0.020	2.29
Bottom	32	3/18/2007	0.170	58.19	0.790	17.45	16.98	47.00	4.77	2.49
Top	6	4/14/2007	0.210	39.47	0.850	[illegible]	[illegible]	38.00	0.150	0.520
Mid	22	4/14/2007	0.210	39.33	0.850	[illegible]	[illegible]	73.30	0.190	0.620
Bottom	32	4/14/2007	ND	65.73	4.13	[illegible]	[illegible]	70.30	3.53	0.790
Top	6	5/9/2007	0.110	3.16	0.770	[illegible]	[illegible]	47.00	NR	NR
Mid	21	5/9/2007	0.150	3.14	0.810	[illegible]	[illegible]	47.00	NR	NR
Bottom	31	5/9/2007	0.110	5.99	8.67	[illegible]	[illegible]	37.70	NR	NR

L9817 April TOC and DOC data has been adjusted for lab calibration error

Location/Depth	Sample Depth (ft.)	Date	Nitrate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	TOC (mg/L)	DOC (mg/L)	COD (mg/L)	Fe (Mg/L)	Na (Mg/L)
Top	5	3/17/2007	0.270	172.16	1.21	12.91	14.82	38.67	1.52	7.69
Mid	7	3/17/2007	0.250	145.54	1.17	12.70	13.13	43.67	3.15	7.51
Bottom	8	3/17/2007	0.200	146.84	1.02	13.21	12.3	49.67	15.73	7.45
Top	5	4/17/2007	0.200	373.74	1.49	[illegible]	[illegible]	64.70	1.84	1.08
Mid	6.5	4/17/2007	0.200	373.67	1.41	[illegible]	[illegible]	68.30	1.33	3.00
Bottom	8	4/17/2007	ND	378.49	1.24	[illegible]	[illegible]	75.00	1.45	0.890
Top	6	5/15/2007	5.10	1.61	19.80	18.20	15.10	47.30	0.500	1.30
Mid	7	5/15/2007	ND	1.54	1.40	15.40	14.90	42.70	1.14	2.48
Bottom	8	5/15/2007	ND	1.34	0.800	NR	17.20	59.30	1.37	0.99

All highlighted areas are over +/- 10% for accuracy